As Good as Gold?

About the Financial Implications of Gold and Silver

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SAINT PATRICK'S DAY 2017

Declaration

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Summary

International currency or production asset? Safe haven or classical commodity? This thesis offers insights into the financial implications of gold and silver by focusing on three distinct investigations motivated by a brief history on the role of the two precious metals in fiscal and financial politics, and underpinned by a thorough literature review identifying research fields that are better explored than others.

A first investigation offers insights into the relationship between precious metals and a set of different inflation measures in the United States of America, the United Kingdom of Great Britain and Northern Ireland, and Japan. A clean and modern methodology uncovers time-variation in the relationship between precious metals and inflation for all countries; but also the superiority of silver as a hedging tool in the United Kingdom and Japan.

The second focus of this thesis is set around model specification and relies on a complex big data methodology allowing the computation of millions of possible realistic scenarios in order to discover possible variables associated with price movements of gold and silver. While results point towards the importance of classical variables such as the US Dollar and inflation, other less traditional variables appear to be more important than initially suggested - such as the UK economic uncertainty index or the S&P Case-Shiller national home price index.

The final research question considered offers unique insights into the drivers of physical gold and silver demand for a large set of countries. A combination of sophisticated linear and dynamic panel data models is applied and empirical insights are obtained. Results for gold point towards a positive relationship with short-term yields and economic uncertainty, while stronger country-specific effects are uncovered for silver.

Dedication

To whom it may concern.

ACKNOWLEDGMENTS

Tu quoque, fili mi. History has repeatedly proven the ungratefulness of protégés, raising concerns why mentors still exist in todays' world. When Professor Dr. Brian M. Lucey asked me if I was interested in becoming his PhD student in the early Summer of 2013, I didn't know that I would see Australia a year later, become an Assistant Professor with Queen's University Belfast two years later, and put my life at risk on an *improvised boat* in the Mekong Delta about three years later.

For all of this, I would like to thank him from the bottom of my heart; he has gone far beyond what any student can expect from his supervisor and it is thanks to him, and him alone, that I look forward to a life in academia - the most enjoyable career I could have ever wished for.

I once told Professor Lucey that I will never be able to repay him for all he has done for me; his answer was that I am not supposed to, but that I should carry on the favour and look after my own doctoral student one day. I hope that I will be as good as my mentor in this endeavour and will always remember how helpful and patient he was when I was completely lost. While I can only hope to one day master this task, I remain until then a loyal friend and follow the motto - *Potius mori quam foedari!*

I would also like to thank Dr. Fergal A. O'Connor who truly acted as a second supervisor in this endeavour and was both helpful and motivating!

Extended gratitude goes to Professor Joseph McDonagh and Samantha Peavoy for an excellently organised PhD Programme.

I would also like to mention my gratitude towards Dean Burke - it has been a privilege being part of the growth of the Trinity Business School and I am excited to see how the School will evolve in the years to come.

I would like to thank the University of Dublin for financing my PhD and Queen's University Belfast for all the help received in making this dissertation a reality.

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Chapter 1

Introduction

Gold is fascinating. Gold has held its value throughout the millennia; proving to be an extraordinarily reliable asset throughout war, tragedy and other crises. While some respectfully label it the *golden constant* (Erb and Harvey (2013)), others call it a *barbaric relic* (Keynes (1924)) even going so far as to say that gold *should be discarded by all civilised nations as a medium of exchange*[1]. Gold literally outshines other assets and it has also outshone silver in academic research which has focussed considerably more on gold rather than silver despite the latter having been more commonly used in currency systems than gold (O'Connor et al. (2015)). A growing interest in silver as an investment asset over the years points towards the shift in the nature of silver; it is becoming closer to the nature of gold. This thesis is the culmination of several years of academic research on both precious metals and focuses on three detailed questions in order to clarify some aspects of these two mysterious but truly fascinating commodities.

1.1 Background and Motivation

The second chapter of this thesis provides a brief history of the role of gold and silver in different currency systems. One observation is striking: there is a relationship between the quality of a nation's currency and the political stability of that same

[1] Indeed, Tennessee merchant John T. Goss allegedly pronounced these very words in front of the US Senate in 1894.

country. This thesis is by no means an attempt to persuade policy makers to shift away from *fiat currency* systems, it is merely asking what gold and silver *are* now that they are not the essential part of our currency systems any longer?

This question is, in my view, dividing the *gold and silver bugs* from the *precious metal pessimists*. Indeed, gold and silver are mere commodities needed for production. From a wedding ring to an iPhone, precious metals are production inputs, just like oil and copper. On the other hand, however, central banks don't store copper bars and it is said that *selling the family jewels* is the last option when facing turmoil. So, undeniably, precious metals aren't *just commodities*; there is more to them than just production demand.

The culmination of complex factors driving gold and silver, alongside the psychological factors influencing them is the true motivation behind this work. Furthermore, while gold is widely studied and researched, silver seems to have fallen back into the line of *usual commodities* since the *international gold standard* was truly ended in 1971 (Garber (1993)). Silver is, however, in many aspects comparable to gold: while, on one hand, it is a production input, its use in jewellery and silverware alongside official coins and medals suggests some sort of alleged investment benefits. The introduction of a silver ETF in April 2006 alongside rising investment demand for physical silver (The Silver Institute (2016)) are all indications that the white precious metal is becoming an ever closer substitute for gold. Unsurprisingly, therefore, return spillovers of the two metals on each other increased in recent times (Batten et al. (2015)).

1.2 Contribution

Three essential research questions are addressed in this thesis and presented in three separate chapters as described in the three subsections below.

1.2.1 An Investigation Into the Relationships Between Precious Metals and Inflation

The end of the Bretton Woods system in 1971 and the departure of the United States of America from a gold linked currency to a fiat currency led to an increased academic and professional interest in the nature and extent of the role of precious metals (gold in particular) in financial markets. However, both the academic and the professional world fail to derive if, and to what extent, an investment in precious metals offers financial protection to a typical investor.

Regarding gold, the question has been approached from a multitude of angles and some questions are better explored than others. Looking at protection offered against falling debt and equity prices in a multitude of countries, Baur and Lucey (2010) and Baur and McDermott (2010) provide the reader with a sound and efficient system to approach the question of both the hedging capacity of gold, and its possible virtue as a safe haven in times of heavy financial distress. Unfortunately, there is no commonly accepted answer or even model that would best describe the relationship between gold and inflation.

As of now, two distinct approaches to the relationship between gold and inflation can be observed in academic literature. The first approach focuses on how inflation affects gold prices. A recent example is an article by Batten et al. (2014) who find evidence for time-variation in the gold/inflation relationship and that changes in the interest rate are responsible for gold's sensitivity to inflation. One year later, Bampinas and Panagiotidis (2015) consider over two hundred years of data and find that gold was an inflation hedge in the long run in both the USA and the UK. Very recently, Hoang et al. (2016) propose a different methodology and offer evidence in support to the findings of Bampinas and Panagiotidis (2015). The second approach focuses more on how the price of gold affects inflation. Examples such as Moore (1990) state that gold prices are affected by the market's view of inflation or Mahdavi and Zhou (1997) who consider gold to be a leading indicator of the inflation rate.

Chapter 7 reconciles both strands by taking a pragmatic approach and by looking at the possible cointegration relationship between the two variables in order to understand their basic relationship; a formal test for time variation is also applied and detects breaks in the relationship amongst the variables.

Regarding silver, the relationship between the precious metal and inflation is again divided in two fields: one field arguing in favour of a positive relationship while the other field argues against it. Taylor (1998), for example, examines monthly US CPI data between 1914 and 1996 and finds that silver was indeed a hedge against inflation during the period considered. Results supported by Adrangi et al. (2003) who augment the findings by proving that the Fischer (1930) hypothesis holds for silver; in other words, silver returns are not adversely affected by inflation. McCown and Zimmerman (2007) propose to look at silver returns following the

Arbitrage Pricing Theory (APT) and show that expected inflation exercises an important role on the price of silver.

Only a few more recent papers, find evidence for a negative relationship between silver and inflation. Examples include Apergis et al. (2014) extending the time period considered, and Bampinas and Panagiotidis (2015) who argue that silver failed to be a hedge against inflation in the USA and the UK over the past 200 years, though results from a time-varying framework indicate spans of cointegration in the United Kingdom.

Theoretically, if precious metals are considered an international currency, an increase in expected inflation leads to a reduction of the anticipated purchasing power of a given currency, which would lead to investors driving down their proportion of cash and investing in gold or silver, hence pushing the price upwards. On the other hand, if precious metals are considered to be regular assets, their price should rise in inflationary scenarios since the definition of inflation is that the dollar price of a typical good rises (Jaffe (1989)).

Ghosh et al. (2004) offer a theoretical framework based on the long-run determinants of the gold price: in a competitive market where gold producers are profit maximisers, the price of gold is equal to the marginal extraction cost and to the marginal cost of leasing gold from central banks. If the costs associated with extracting gold rise at the general inflation rate, the price of gold will rise at the same rate and hence hedge inflation.

When looking at the relationship between precious metals and inflation, a major issue arises in the very definition of the term as there is an open debate about how to measure inflation effectively. This controversy arises because official inflation rates (as issued by the Bureau of Labor Statistics in the USA, the Office for National Statistics in the UK and the Ministry of Internal Affairs & Communication in Japan) might not truly reflect the changes in monetary value. Demand for precious metals can be divided into three different types: investment, industrial and consumption (jewellery and luxury goods). Different inflation indices are relevant to the different types of demand: the CPI reflects consumer price inflation, the PPI reflects producer price inflation, and money supply can be used as an inflation proxy relevant to the investment side. An investigation into the ability of precious metals to protect consumer, producers and investors of inflation is necessary to derive implied financial benefits.

The choice of the three major economies not only allows a study of three different

Figure 1.1: Silver demand in Mio. OZ in the United States of America

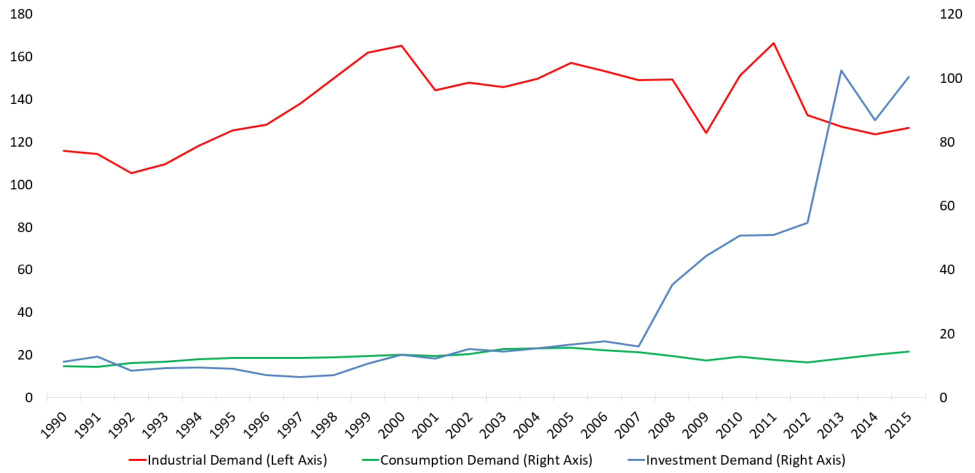
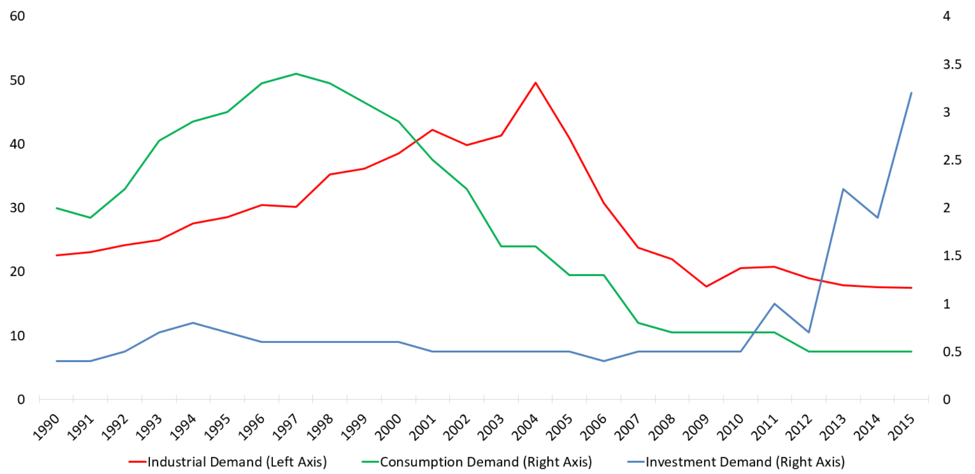


Figure 1.2: Silver demand in Mio. OZ in the United Kingdom of Great Britain and Northern Ireland



currencies and three major centre of trade, but also grows from the type of demand observed in the USA, UK and Japan.

Considering the United States of America, a major shift in silver demand can be observed (Figure 1.1).

While silver was purely an industrial asset during the 1990s and the early 2000s, it seems that the Global Financial Crisis led to an exponentially growing demand for silver coins and bars as investment assets.

A different picture is however observed for the United Kingdom (Figure 1.2) where silver never really had an important role as an investment asset. The demand for silver originates mainly from industry and keeps on falling over the years.

Figure 1.3: Silver demand in Mio. OZ in Japan

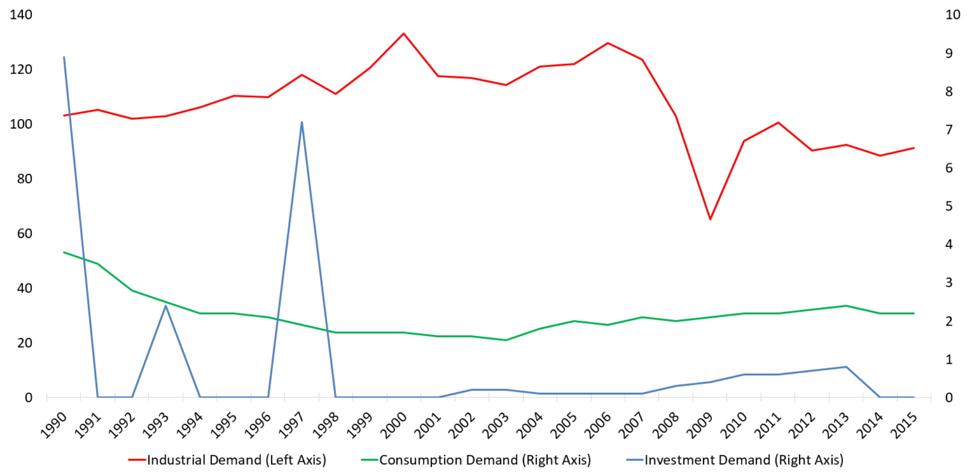
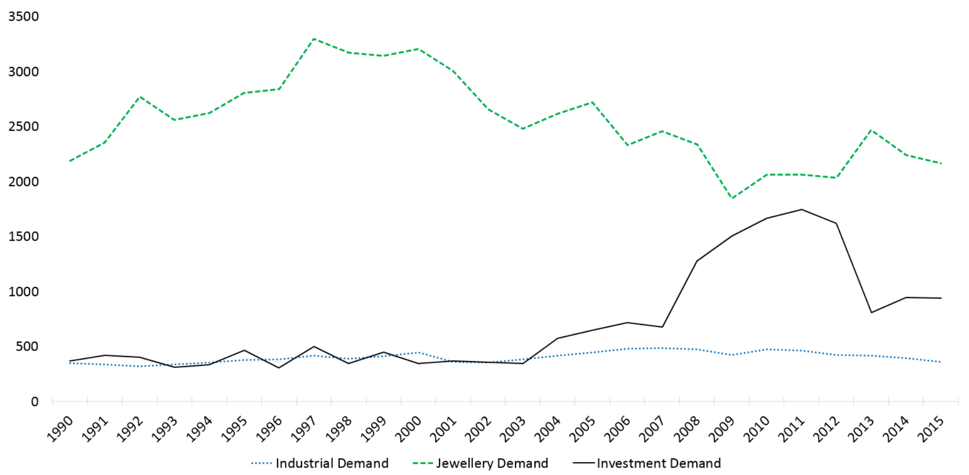


Figure 1.4: Global Demand for Gold by Type in Tonnes



Finally, in Japan the demand for silver originates mainly from industry and it seems that silver doesn't play a role as an investment asset at all. A noteworthy drop in industrial demand can be observed around the Global Financial Crisis and the production shocks linked to it.

Considering gold, an interesting drop in global investment demand can be observed over the recent years, accompanied by an increase in investment demand (Figure 1.4).

Even though other countries, such as India and China, are both considerable players in the precious metal market, the unavailability of data and the relative importance of physical demand rather than gold and silver demand regulated through a stock exchange is a major reason to focus on the countries mentioned above.

Building on previous academic works, namely Batten et al. (2014) and Bampinas and Panagiotidis (2015), a key issue is to look at the link between gold prices and inflation from a time-varying perspective. This allows for multiple methodological contributions: first by applying a lean but thorough methodology in order to understand time-varying relationships, secondly, contrary to previous academic work, in augmenting these findings with tests revealing the breaks in cointegration. Robustness of results is assured through subtests for cointegration on the time windows indicated by the formal procedures and also considers predicted inflation and inflation surprise derived through an ARIMA model.

This endeavour is placed in the growing field of interest of time-varying issues in the nature of cointegration between gold and inflation and is the first one that provides insights into the time dependency of the cointegration-relationship between gold and money supply.

1.2.2 Extreme Bounds Analyses of Gold and Silver

Academic and practitioner literature finds that many variables influence the price of gold and silver (O'Connor et al. (2015)). However, in the light of a large number of potential variables, research output is typically focused on a few of them, determined ex ante by reference to other papers or to a specific theoretical model so that the overall strength or weakness of the relationships remains unclear, as a relationship found may in fact not be robust to alternative model specifications Baur (2013a). Chapter 8 addresses the issue by running millions of possible regressions, extracting the distribution of coefficient and analysing them in order to derive which variables truly are explanatory and which fail to be.

There is hardly a macroeconomic variable over which fellow researchers agree that an empirical and clear-cut relationship with gold or silver exists. An interesting approach is, therefore, to approach the question in an objective manner and simply consider a wide set of variables in order to understand which one is indeed associated with changes in the prices of any of the two precious metals. A thorough literature review, as outlined in Chapter 3, ensures that the research undertaken is not falling in the trap of *data snooping*. *Data snooping* consists of adding random variables into an econometric system and find some sort of relationship that is not supported by economic theory (Brooks (2014)). The strength of the chapter is that the answer to what is researched is not given before the question is asked;

the model is built so that no particular outcome is expected. Furthermore, while a relationship between gold or silver and a particular variable is observed in certain previous publications, the true reason for that relationship could be rooted in another variable. A very obvious example is a possible relationship between gold and inflation during individual subperiods which might merely reflect the changes of the price of gold to the price of oil which in turn is driving inflation (O'Connor et al. (2015)).

Chapter 8 does the opposite of Chapter 7. Instead of building upon a known relationship, the approach taken is very objective and consists of running a computationally intensive procedure climaxing in several million regressions in order to define the statistical probability that a specific variable is associated with the price of gold and silver, and if so, what would be the typical relationship observed?

Furthermore, the investigation in Chapter 8 is also a response to the *computational fallacy* of certain econometric models. While a relationship between two variables might be suggesting some sort of association between them, the true underlying reason could be found in completely different variables. These *true* variables are uncovered by providing different comprehensive model specifications which are exposed by the initial model.

Chapter 8 is a direct response to the extensive literature review provided by O'Connor et al. (2015) on gold and by this very thesis on silver, and is the first attempt made to use *high performance computing tools* to model the prices of gold and silver considering a comprehensive but very large dataset.

1.2.3 A Panel Approach on the Physical Demand Drivers of Gold and Silver

Financial research about precious metals draws conclusions about empirical behaviour and aspects of the two metals by considering the *official* price originating on stock markets.

However, the very nature of precious metals attributes them an alleged safety character that one would think would only truly come to light through a physical investment into the asset. While indeed the regulated purchase of gold through an exchange is beneficial to an investor's portfolio for multiple reasons (see Baur and Lucey (2010) and Batten et al. (2014)), the real safety of gold lies in holding it physically as a last resort asset in extreme situations (Starr and Tran (2008)). A similar reasoning is valid for silver: that different forces influence physical demand.

While similar methodologies can be used in modelling the physical demand market, the task remains very complicated due to the limited availability of data for physical demand. Indeed, extracting these figures is a very cumbersome and labour-intensive task which can only be done by manually looking into the annual surveys of the past decades computed by the Gold Fields Mineral Services Ltd and available only in physical copies at their offices in London. Similar surveys exist for silver, such as those computed by the Silver Institute in Washington D.C.

Non-Government physical demand for precious metals can be broken down into three different categories:

1. *Industrial Demand* - reflecting the demand for precious metals as a production input in electronics, dentistry etc.

2. *Investment Demand* - being the demand for bars and coins, targeted only at the safety aspects of precious metals.

3. *Luxury Demand* - consisting of the amount of gold and silver needed for the production of jewellery and silverware.

Important country effects might affect the physical demand for precious metals by influencing some of the three categories more than others. In order to try and derive empirical results instead of running country-specific models, a panel approach is advisable.

The choice of country is made in regard to the country's relative importance on the offer and/or demand side of gold and silver. Regarding gold, the following countries are considered: Australia, Canada, China, Egypt, Germany, India, Italy, Japan, Mexico, Russia, Saudi Arabia, South Korea, Switzerland, Thailand, Turkey, the United Kingdom of Great Britain and Northern Ireland, and finally, the United States of America. In regards to silver, the following countries are considered: Australia, Canada, China, Germany, India, Italy, Japan, Mexico, Russia, South Korea, Thailand, the United Kingdom of Great Britain and Northern Ireland, and finally, the United States of America.

While results for gold demand point towards an influential importance of debt yields as a proxy for the stability of the underlying economy, panel regression results for silver indicate a negative relationship with money supply.

1.3 Aims and Objectives

This work is a comprehensive investigation into three distinct questions about the role and nature of gold and silver on financial markets.

The aim of all three different chapters is to guarantee a certain distance to the investigation itself and to minimise the research bias as much as possible. This is assured through a thorough and comprehensive methodology optimised for the different investigations.

Different and distinct objectives can be identified from the three results sections. A first objective is to get clearer, and easier to understand, results about the relationship between precious metals and inflation in order to provide investors and regulators with a time-varying framework on the inflation-hedging potential of both gold and silver. The second objective is to offer an econometric review of the macroeconomic variables associated with price movements of gold and silver; this is of great value to researchers as it produces a better-calibrated econometric model. A third objective is to get an initial understanding of the drivers of physical demand for gold and silver and to compare them to the drivers for aggregated demand - this will provide the reader with a better understanding of the physical precious metal market.

1.4 Structure

The next chapter provides the reader with a short history on the role of gold and silver in monetary systems, providing an introduction to the role of gold and silver in economics.

Chapter 3 provides a much more detailed overview of the role and function of precious metals in financial economics by presenting and reviewing relevant academic publications in the field.

In Chapter 4 some philosophical implications of this research thesis are briefly discussed.

Chapter 5 presents the dataset considered throughout the following chapters.

In Chapter 6 the entire econometrical methodology used throughout this thesis is presented in detail.

Chapters 7, 8 and 9 display and discuss the results obtained from the formal investigations into the different research questions outlined above.

Finally, Chapter 10 concludes this doctoral thesis.

1.5 Publications from this Doctoral Thesis

Large parts of Chapters 2 and 3 are forthcoming in the *International Review of Financial Analysis* {ABS3} as:

- Lucey, B., O'Connor, F., Vigne, S., and Yarovaya, L., The Financial Economics of White Precious Metals - A Survey. *International Review of Financial Analysis* (2017).

Different econometric procedures presented formally in Chapter 6 have been used for an article on volatility spillovers forthcoming in the *International Review of Financial Analysis* {ABS3}:

- Lau, M., Vigne, S., Wang, S., and Yarovaya, L., Return Spillovers Between White Precious Metal ETFs: The Role of Oil, Gold, and Global Equity. *International Review of Financial Analysis* (2017).

The applicability of time-variation procedures presented in Chapter 6 were used for an article forthcoming in the *Journal of International Financial Markets, Institutions and Money* {ABS3} as:

- Bilgin, M., Gogolin, F., Lau, M., and Vigne, S., Time-Variation in the Relationship between White Precious Metals and Inflation: Evidence from 11 Countries. *Journal of International Financial Markets, Institutions and Money* (2017).

The big data implications of the econometric procedures presented in Chapter 6 and used in Chapter 8 were the essential element of a Keynote speech at the 2016 Macromodels Conference in Łódź.

Large parts of Chapter 7 were presented at the KLU Finance Meeting in Hamburg in March 2015, at the 2015 INFINITI Conference in International Finance in Ljubljana, and at the February 2016 Applied Financial Modeling Conference in Melbourne.

The results obtained about the relationship between gold and inflation in Chapter 7 are forthcoming in *Economic Modeling* {ABS2} as:

- Lucey, B., Sharma, S., and Vigne, S., Gold and Inflation(s) - A Time-Varying Relationship. *Economic Modeling* (2017).

Chapter 8 was presented and discussed at the 2016 INFINITI Conference in Dublin and at the 2016 Overseas INFINITI conference in Ho Chi Minh City.

CHAPTER 2

A Brief History of Gold, Silver, and Money

The role of precious metals in currency systems reaches back to the early days of civilisation. This chapter provides a brief historical overview of the role of gold and silver in money creation from its very start until the modern days of *fiat money*.

2.1 About the Origins of Money

The monetary policy of Dionysius the Elder of Syracuse in the 4th Century BCE is probably the first historical example of currency devaluation. Facing an unsustainable amount of debts, Dionysius commanded the confiscation of all the coins in his jurisdiction after which he doubled the value printed on the coins. He then returned half of the coins, this allowed him to retain half the value without dispossessing the citizens (Lynn (2011)).

Despite being one of the actions that caused Dionysus the Elder to be referred to as a tyrant throughout his reign (Alighieri (1995)), the action of devaluating a currency began a trend in history that would repeat itself over millennia.

2.1.1 Early Beginnings and the Role of Croesus

Herodotus believes that the first precious metal coins were minted in the Kingdom of Lydia around 700 BCE (Blanco (2013)), they were oval and much thicker than modern coins (Weatherford (1997)). The advantages of using precious metals as a currency lay in their rarity and their quality of being unaffected by corrosion, while other nations, such as Byzantium, used iron coins which proved to be too heavy and to rust too easily to be used as an effective currency (Averbury (1903)).

During the reign of Gyges of Lydia, from 716 BCE to 678 BCE, one of the most important decrees issued by the King prohibited private issue of coins (Bernstein (2000)). Henceforth, only the State was allowed to mint coins from a gold and silver alloy found in the bed of a river nearby; the different quantity of gold in every coin led to an uneven quality amongst the coins called *electrum* (Averbury (1903)). His son Ardys printed values on the coins to guarantee weighting and value, while Alyattes, grandson of Ardys, minted the first coins made of pure gold.

Finally, Croesus son of Alyattes, recalled all *electrum* coins produced and separated both metals in order to produce distinct gold and silver coins. The gold coins were used for foreign commerce while the silver coins satisfied the domestic market: the bimetallic system was born (Vaupel and Kaul (2016)).

2.1.2 Athens and Rome Adopt the Monetary Policy of the Kingdom of Lydia

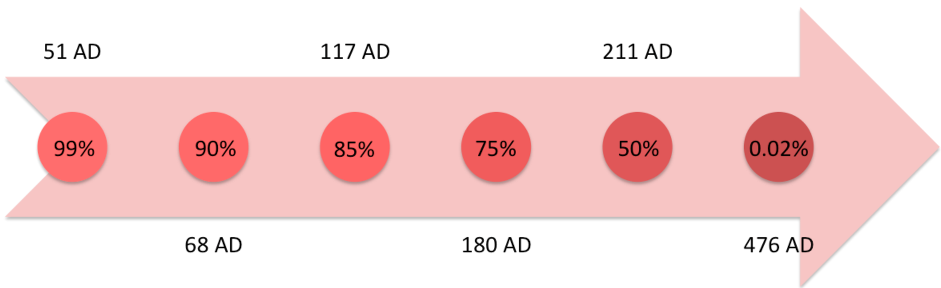
About the same time, the city of Athens used thin silver bars as a currency. Six of these bars were called *drachma* (a handful) and would later become the name of the official Greek currency (Averbury (1903)). About 600 BCE, Athens started minting coins with a content of 4.34 grams of silver, a value that would only decrease by about 3% until the end of the Athenian *drachma* six hundred years later (Vaupel and Kaul (2016)).

Taking over the concept of the Athenian *drachma*, the Roman Republic started minting the *denarius* about 268 BCE with the exact same weight and value as the Greek model. The Roman victory over the Greeks at the battle of Pydna 168 BCE sealed the supremacy of Rome in modern day Greece. A growing empire called for an organised and efficient coinage system that was placed in the temple of Juno on the Capitoline Hill in Rome for more than four hundred years (Aicher (2004)). The Goddess Juno was also known as *Moneta*, from *monere*: to warn, after saving Rome from a surprise attack by the Gauls around 390 BCE. The English word *money* is derived from Juno's alternative name and the Juno temple housing the mint of the Roman Empire (Averbury (1903)).

2.1.3 The Roman Empire Abolishes the Face-value Currency

Between 54 and 68 CE, Emperor Nero reduced the amount of silver in the *denarius* to 90%, and between 98 and 117, Emperor Trajan reduced it to 85%, while Marcus Aurelius reduced the amount of silver to 75% between 161 and 180 and when Emperor Septimius Severus died in 211, the amount of silver in the *denarius* was at 50% (Vaupel and Kaul (2016)) while a growing number of countries stopped accepting the Roman currency - leading to severe problems for Rome's ability to finance its expenses. Finally, when Romulus Augustulus was deposed as the last Emperor of the Western Roman Empire in 476, the amount of silver in the *denarius* was at a mere 0.02% (Bonner and Wiggin (2009)).

Figure 2.1: The Percentage Amount of Silver contained in the *Denarius* during the Roman Empire



The downfall of the Roman Empire goes hand in hand with the devaluation of the *denarius*. On the other hand, the *solidus*, a gold coin of 4.55 grams that replaced the *aureus* in 312 survived for nearly seven centuries due to its constant weight and amount of gold it contained (Bernstein (2000)).

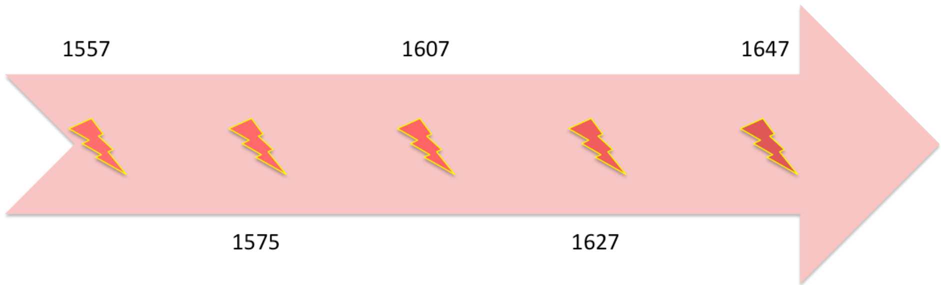
2.2 Developments in the Early Modern Ages

During the Middle Ages, the Commercial Revolution (de Roover (1942)), international trading flows (North (1994)) and regional differences in the access to natural resources led to a monetary schism of more than five centuries in which the Christian world used a silver currency and the Islamic world a gold currency. This division would only be broken up in 1252, when the cities of Genoa and Florence introduced gold coins (North (2009)).

2.2.1 1492: The New World revolutionises the Spanish Monetary System

The discovery of America gave Spain access to enormous new precious metal reserves. It is estimated that between 1500 and 1540 approximately 1,500 kilograms of gold and 300 tons of silver were shipped to Spain every year (Davies (2002)) - doubling the amount of silver in Europe in only a few decades (Vaupel and Kaul (2016)). This immense access to new gold and silver led to growing imports in Spain and to a severe economic crisis when the precious metal flow started falling towards the end of the 16th century. Spain decided to borrow money from abroad in order to continue the importation of goods which led to a chain of insolvencies (Figure 2.2) in the 16th and 17th centuries (Vaupel and Kaul (2016)) and to price inflation of 400% in the 16th century alone (Bonner and Wiggin (2009)).

Figure 2.2: Years at which the Spanish Government declared to be Insolvent



2.2.2 The Peace of Madrid allows English Access to Silver from the New World

While it took the Roman Empire nearly four hundred years to reduce the amount of silver in the *denarius* from 99% to 0.02% (Figure 2.1), it took the Tudor Monarchy nine years, between 1542 and 1551, to cut the amount of silver in the *pound* by more than 80% (Reinhart and Rogoff (2009)), flooding the English domestic market with low quality coinage.

However, part of the English peace treaty with Spain which ended the Anglo-Spanish War of 1625 was the Establishment of the *Cottington Treaty* in 1630, allowing the English mint to have direct access to Spanish silver arriving from the New World (Davies (2002)). With a considerable part of the silver obtained used for the minting of new coins (Craig (1953)), the quantity of coins minted under the reign of Charles I amounted to £9,000,000 (Davies (2002)); almost twice the amount coined during the entire reign of Queen Elizabeth I (Feavearyear (1963)). Since the new coins entering the English domestic market contained more silver, *Gresham's Law* led to a hoarding of the new coins and to an increased usage of the old coins as the regular method of payment (Britannica Concise Encyclopedia (2006)).

2.2.3 Charles I and the Creation of Banks in England

Even though an equivalent of modern banks existed in continental Europe since the 12^{th} century (North (2009)), the development of modern banks in England occurred only during the 17^{th} century.

King Charles I of England, before his execution in 1649, had severe problems in financing his expenses and decided in 1640 to mint three hundred thousand pounds with a silver content of only 25% (Davies (2002)). Anticipated inflation was immediately noticeable with prices increasing in the very short term (Andréadès (1966)). King Charles I decided, therefore, to reverse the original plan and simply confiscated an amount between £100,000 and £130,000 deposited in the Tower of London by goldsmiths and merchants of London (Davies (2002)). The King was only willing to return the money if granted a credit of over two hundred thousand pounds (Andréadès (1966)).

The loss of trust from English citizens in the Tower of London as a safe haven for their wealth was sealed; henceforth, Londoners decided to deposit their precious metal with goldsmiths in possession of a vault.

2.2.4 Goldsmiths Receipts evolve to become Paper Money

The citizens who deposited their money with goldsmiths received a receipt for the amount of *pounds* entrusted in their vault. This piece of paper, which guaranteed that the bearer could obtain a fixed amount of *pounds* from the goldsmith, evolved to become a smooth and uncomplicated median for financial transactions, and paper money gained acceptance in England.

Furthermore, the goldsmiths realised that more money was deposited in their vaults than was withdrawn, allowing them to lend money to clients (Skousen (1996)) and hence producing more receipts than the amount of precious metals actually held in their vault; this was the birth hour of modern banking (Withers (1920)).

2.2.5 1672: *The Great Stop of the Exchequer* and the Creation of the Bank of England

Financing his state affairs by borrowing excessive amounts from goldsmiths, Charles II of England ordered the *Great Stop of the Exchequer* in January 1672 in order to freeze interest and redemption payments from the Crown (Ferguson (2008)).

The result was a substantial wave of exchange of goldsmith receipts back into precious metals; an early days *bank run*. Since the gold and silver was mainly lent to the King, the goldsmiths were unable to honour their debts and became insolvent (Goodman (2009)). Whilst there were forty-four active goldsmiths in London in 1677, only twelve or fourteen were still operating in 1695 (Vaupel and Kaul (2016)).

In 1691, Scottish trader William Paterson suggested a bank that would lend money to the Government at a reasonable interest rate and issue bank notes backed by Government debt (Goodman (2009)). Three years later, the *Ways and Means Act* would turn this idea into reality and give birth to the Bank of England, which would over the centuries obtain the monopoly to print money.

2.3 The Development of Fiat Money

The economic growth of British colonies was compounded by the fact that Great Britain forbade the export of English coins as well as the establishment of a mint in the colonies (Hummel (1978)). Despite the coins brought over by settlers, the only way for the American colonies to obtain coins was through trading with European merchants (Kemmerer (1944)).

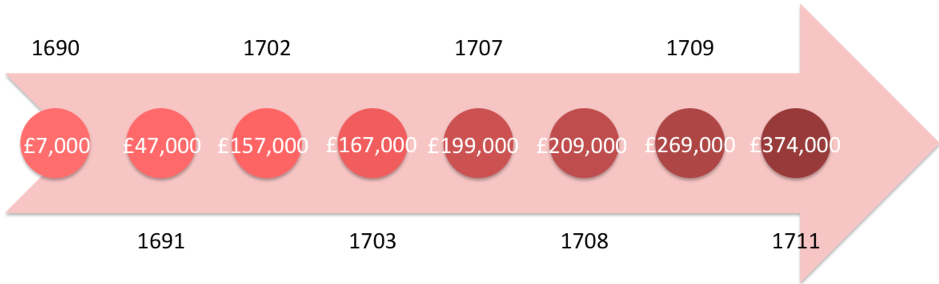
2.3.1 Massachusetts starts Printing Money in the Colonies

After a military expedition against Quebec in 1690 resulted in an extraordinary failure (Peckham (1964)), the Government of Massachusetts was unable to pay the returning troops. The Massachusetts Administration therefore decided to print £7,000 in December 1690 under the condition of being able to exchange the paper money against precious metals obtained from taxes, and to guarantee the uniqueness of the measure (Rothbard (2002)).

Despite the self-imposed restrictions, the Administration of Massachusetts continued to print money less than one year later, with £40,000 printed in February

1691 alone; again, not backing the money with gold and silver and assuring that such measures would not be repeated in the future (McLeod (1898)). Figure 2.3 shows the amount of fiat money in circulation in Massachusetts between 1690 and 1711 and underlines the easy money policy the Government engaged in.

Figure 2.3: Amount of Fiat Money in Circulation in Massachusetts between 1690 and 1711



In order to fight the value depreciation of paper money, the *Massachusetts pound* was declared legal tender in 1712 (McLeod (1898)). Furthermore, a value bonus was added on the nominal amount when paper money was used to settle transactions with the Government. Massachusetts postponed its promise to exchange paper money into precious metals to the year 1747 and it was declared illegal not to accept paper money at nominal value at risk of facing financial penalties (Vaupel and Kaul (2016)). By 1748, paper money in circulation amounted to £2,500,000 (Rothbard (2002)).

Other colonies followed Massachusetts' example: South Carolina started printing fiat money in 1703, Connecticut and Rhode Island started in 1711, Pennsylvania in 1723, followed by New Jersey and Delaware - Virginia was the last colony to print fiat money, starting in 1755 (Vaupel and Kaul (2016)).

Leading to severe inflation across all territories, Great Britain issued the *Currency Act of 1764* forbidding the declaration of fiat money printed in the colonies as legal tender (Hummel (1978)). By that time, Massachusetts had printed over £2,500,000 of fiat money (Rothbard (2002)).

2.3.2 The French Revolution brings Fiat Money to Europe

The financial and economic dilemma of France was not resolved at the beginning of the French Revolution in 1789. In order to decrease the national debt and to refinance the State, the French National Assembly decided on the 2nd of November 1789 to confiscate and sell all ecclesiastic property (Duvergier (1834)).

Amounting to 10% of all the French territories, the suggested sale could have been able to drastically decrease the national debt (Levasseur (1894)). However, selling all the land at once would have severely pushed down the value of the land and, therefore, the profits the National Assembly hoped to realise (Vaupel and Kaul (2016)). The French Government decided to print *assignats*, paper money backed by ecclesiastic property, with the amount capped at 400 millions *livres* (Vaupel and Kaul (2016)), corresponding to an expert valuation of the land (Levasseur (1894)).

In April 1790 the *assignats* were declared legal tender and their purchasing power fell by 5% (Levasseur (1894)). Henceforth, *assignats* became a fiat currency; with 1.2 billions *livres* worth of *assignats* in circulation in September 1790 and 1.8 billion *livres* worth of *assignats* in circulation in June 1791. The *livre* was the standard unit of silver in force during that time. *Assignat* printing continued and the purchasing power of French paper money dropped to 22% of its nominal value in August 1793 (Vaupel and Kaul (2016)).

Several laws were issued by the National Convention to strengthen the *assignats*: a decree declared on the 11th of April 1793 obliging the trade of *assignats* and precious metal coins at par (Duvergier (1825)), was later intensified by a further decree in August that forbade differentiation between coins and *assignats*, and finally a last decree declared on the 8th of September 1793 imposing the death penalty on whoever favoured payment in coins rather than in *assignats* (Hawtrey (1918)).

These, amongst other drastic measures, were still unable to prevent the downfall of the *assignats*: by March 1796, the purchasing power of *assignats* was at 0.33% of their nominal value (Aftalion (1987)). About that time, the French Government simply decided to replace the *assignats* with a new currency, the *mandats territoriaux*, based on the same unsuccessful principles as the previous currency. By May 1796, the purchasing power of the *mandats territoriaux* was at 5% of their nominal value (Vaupel and Kaul (2016)) and by May 1797 they were virtually worthless (Miller (2002)).

2.3.3 1797: A French *Invasion* brings Fiat Money to Great Britain

The French Revolutionary Wars and the associated expenses were disastrous for the gold reserves of the Bank of England. By the 31st of August 1796, the Bank of England was holding gold worth £2,100,000 against liabilities of about £16,000,000 (Cannan (1919)).

A French *invasion* of approximately 1,400 men in February 1797 on the shores of Wales immediately spread panic across Britain and led to a bank run (Vaupel and Kaul (2016)). Facing a situation of being unable to exchange all liabilities into gold, an Order in Council was issued on the 27th of February 1797 forbidding the exchange of paper money into gold (University of Northern Iowa (1867)). Different reasons assured a certain stability of the fiat *pound* in comparison to the previous examples in America and France. On the day of the announcement, 3,000 London traders declared to accept all payments in paper money at the nominal value, furthermore, in the medium and long term, the early days of industrialisation and the implementation of the income tax led to an increase of the national wealth (Vaupel and Kaul (2016)).

With the increase in money supply leading to an increase of the gold price (Ricardo (1810)) and the general public getting accustomed to the use of paper money (Vaupel and Kaul (2016)), the Government passed a law obliging the Bank of England to exchange paper money against gold coins on demand from the 1st of May 1823 onwards. After 25 years of fiat money, Great Britain returned to the gold standard.

2.4 The International Gold Standard

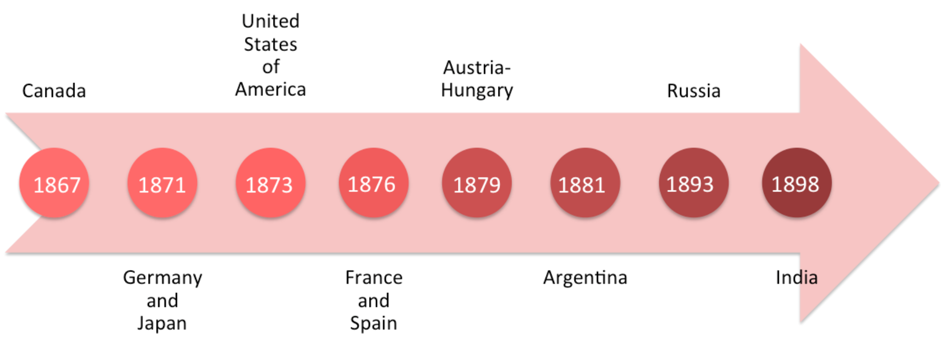
The *Coinage Act of 1873* technically ended bimetallism in the United States of America and laid the foundation of the American *gold standard* by abolishing the right of bullion holders to strike silver into legal tender US Dollar coins (United States of America (1904)). While the silver Dollar didn't play a role under the new regulations set out in 1873, old silver coins were used predominantly as shrapnel (Friedman (1990)). However, as their metal value was far higher than their nominal value most of the coins were melted to extract their silver content (Vaupel and Kaul (2016)).

2.4.1 The World turns to Gold

While the United States of America turned to gold in order to erase the price fluctuations of gold in trading with the United Kingdom, other countries introduced the *gold standard* as well, in order to have a currency linked to that of the British hegemon.

The diagram below illustrates which country introduced the *gold standard* in which year (Vaupel and Kaul (2016)):

Figure 2.4: Introduction of the *Gold Standard* by Country over the 19th Century



A direct result of the gold standard was a drop in the silver price due to the large quantities of the white precious metal being thrown on the market in the light of the non-necessity of silver as a currency (Friedman (1990)).

2.4.2 The World depends on a Rare Natural Resource

An event that clearly facilitated the establishment of the global *gold standard* was the *gold rush* of the 1840s, with great mine discoveries in Australia, Russia, and, notoriously, California. However, with more and more economies in need of gold to feed their monetary systems, the amount of gold available declined around the 1880s and therefore, the money supply. This led to a deflation in the USA of about 1.7% per year and of 0.8% per year in the United Kingdom between 1875 and 1896 (Friedman (1990)).

In the United States of America, some politicians suggested a partial return to a silver linked currency, which was very cheaply and easily available due to the price plunge in the previous years. Indeed, while this very idea was a fighting point in the campaign of Democratic Presidential Election candidate William Jennings Bryan, his defeat by the Republican William McKinley in 1897 destroyed all hopes of the silver lobbyists to see the white precious metal exercise a more important role in monetary policy (Friedman (1990)).

2.4.3 The Gold Standard in Times of Crises

In 1887, the invention of the MacArthur-Dingus cyanidation process by Scottish chemists John Stewart MacArthur and Dr. William Dingus led to a boom in gold production in South Africa and allowed the United States and the United Kingdom to considerably increase their money supply (Friedman and Schwartz (1963) and Friedman (1994)).

However, the First World War led many countries to abandon the *gold standard*, such as Germany as early as 1914. Reparation costs faced by the *Mittelmächte*, alongside precarious central bank liquidity positions on the side of the *Triple Entente* led to an end of the European *gold standard* during the interwar period (Officer (2005)).

2.4.4 World War II and the Bretton Woods System

In July 1944, delegates of all the 44 Allied Nations met in Bretton Woods (NH) and agreed to follow a new set of rules and guidelines for international financial and commercial relations amongst each other. The *Bretton Woods System* was very similar to the *international gold standard* in that it fixed the exchange rates of individual national currencies to the US Dollar which could then be exchanged to gold at a fixed ratio (Gale Encyclopedia of U.S. Economic History (1999)).

While the system was arguably successful, it virtually assigned the US Dollar the same power as physical gold, leading many countries, France in particular, to exchange their Dollar holdings into gold around the late 1960s (Garber (1993)). The unwillingness of the USA to significantly drive down the amount of gold it held in order to meet the demands of other countries, coupled with a persistent balance of payment deficit due to the Vietnam War, led President Richard Nixon to end the convertibility of the US Dollar into gold on the 15th of August 1971; leading to an international *fiat money* system still in place today.

Chapter 3

Literature Review

A thorough literature review assures that the contribution of this thesis can be pinpointed to certain gaps found in academic knowledge. While the review of the literature about gold is kept rather short on purpose, the literature review on silver is very extensive and presents every paper published in the field. With about 150 publications presented in the chapter, the financial implications of silver are far more studied than one might initially believe.

3.1 Gold

An excellent review on the literature published on gold is provided by O'Connor et al. (2015) and for brevity sake, the literature review on gold is kept short on purpose in this thesis and will only consists of summarising the mainstream state of the art knowledge.

3.1.1 About the Relationship between Gold and Macroeconomic Variables

Academic and practitioner literature finds that many variables influence the price of gold (O'Connor et al. (2015)). Given the large number of potential variables, most papers focus on a few, determined ex ante by reference to other papers or a theoretical model. The overall strength or weakness of the relationships thus remains unclear, as a relationship found may in fact not be robust to alternative model specifications Baur (2013a).

Due to its alleged money-like characteristic, a large amount of literature focuses on the relationship between gold and inflation. Papers such as Levin and Wright (2006), Wang et al. (2011) and Erb and Harvey (2012) all suggest a positive relationship between the price of gold and inflationary pressure. Others, such as Blose (2010) or Erb and Harvey (2013) question such conclusions. Recognising that a relationship, if any, may well be time varying (considering that the period of the free float of gold was drawn by episodes of severe inflation and more recently dis- or deflation) papers such as Beckmann and Czudaj (2013); Batten et al. (2014); Bampinas and Panagiotidis (2015) have examined time variation issues in the relationship of gold and inflation. The last paper goes deeper into the definition of inflation and suggests that examining a country's monetary supply might be a better representation of an economy's increase in consumer prices than officially published inflation which might be subject to selection bias.

The relationship between gold and currencies has been in the focus of many papers though a special interest was always put on the US Dollar more than on other currencies (Capie et al. (2005); Joy (2011) among others). Tully and Lucey (2007) work with an Asymmetric Power Generalised Autoregressive Conditional Heteroscedasticity (APGARCH) model to show the importance of the US Dollar in the determination of the gold price - results supported by Sjaastad (2008) and Sari et al. (2010) who also find the Yen to be an important factor influencing the price of gold. Studying the relationship between gold and currencies, Pukthuanthong and Roll (2011) and O'Connor and Lucey (2012) add in more currencies deemed to be affecting the price of gold; namely: the UK Pound, the Swiss Franc, the Euro, the Australian Dollar and the Canadian Dollar. Their main finding is that positive gold returns can be explained through a currency's depreciation against the price of gold and that a loss of the US Dollar against a currency will also result in a lost of the Dollar against the price of gold.

The relationship between gold and other precious metals has been widely studied with a focus on the existence of possible spillovers among the metals. Escribano and Granger (1998) compare the returns of gold and silver and find evidence for a strong simultaneous relationship between both metals - a finding contradicted by Ciner (2001) who studies gold and silver futures contracts traded in Tokyo from 1992 to 1998 and finds no evidence for a long run cointegrating relationship. Lucey and Tully (2006b) conclude their work by indicating that the gold-silver parity did indeed weakened during the 1990's. In a paper focusing on the relationship between gold and platinum, Kearney and Lombra (2008) find the relationship between gold and platinum to be negative in general, though it happen to go through runs of positivity. Taking a wider look at possible interactions between all four precious metals, Batten et al. (2010) find that between 1986 and 2006, precious metal individual volatility was influenced by the volatility of the other three precious metals - results augmented by Batten et al. (2015) who point towards the existence of constant spillovers between gold and silver, but state that the findings are very different for platinum and palladium. Finally, Antonakakis and Kizys (2015) show that the Global Financial Crisis weakened the spillovers of gold while it strengthened the spillovers from platinum.

Despite its moniker of *black gold* there is surprisingly little research on the relationship between gold and crude oil. In a paper for the World Bank, Baffes (2007) finds that an increase of the oil price by $1 increases the gold price by $0.34. Arguing that oil drives inflation while inflation drives the price of gold, Narayan and Popp (2010) find that oil and gold are cointegrated and that the markets are mutually efficient - results confirmed by Zhang and Wei (2010); Malliaris and Malliaris (2013) and Ewing and Malik (2013). Although focusing on the safe haven argument for gold, Ciner (2015) finds linkages between gold and oil.

When looking at the relationship between gold and stock markets, it is mostly done under a safe haven aspect - to understand whether or not gold can offer protection against a drop in equity prices (Baur and Lucey (2010); Baur and McDermott (2010)). However, Batten et al. (2010) augment the focus on equity returns and find that both stock market returns and dividend yield affect the price of gold.

Staying in a safe haven framework, Cohen and Qadan (2010) suggest that during market turmoils, gold leads the VIX and is therefore a better safe haven asset. The relationship between gold and the VIX was also studied by Hood and Malik (2013) who try to understand whether gold can outperform the VIX as a safe haven asset taking into account data from 1995 to 2010.

As a part of their study on gold's ability to act as a safe haven against a number of financial instruments, Baur and Lucey (2010) also look at the relationship between gold and bonds while Baur and McDermott (2010) focus on gold's hedging and safe haven abilities against several international stock markets. However, Sumner et al. (2010) look at volatility spillovers from gold to US stocks and bonds between 1970 and 2009 and find evidence that no such spillovers occurred.

Rooted in the philosophy of gold as an international currency, the interest rate obtained on a bond can be considered as the opportunity cost of holding gold. This negative relationship between interest rates and gold is observed by Abken (1980) on one month US treasury bill rates between 1973 and 1979, by Koutsoyiannis (1983) on daily US Dollar denominated commercial papers between 1979 and 1981, and by Fortune (1987) on long term US government bonds using quarterly data between 1973 and 1980. The negative relationship between gold and interest rates is however contrasted by more recent papers, such as Lawrence (2003) finding no statistically significant evidence for a relationship between gold and 3 month US Certificate of Deposit rates, or Tully and Lucey (2007) applying an asymmetric power GARCH model to monthly gold prices between 1984 and 2003 and finds no statistical relationship between gold and interest rates.

The influence of macroeconomic forces on the price of gold has received increased attention in the last years. Christie-David et al. (2000) use intraday futures data between January 1992 and December 1995 and find evidence for a strong response of gold to releases of the CPI, the PPI, capacity utilisation, the unemployment rate and the GDP. Batten et al. (2010) prolonges the time span considered and finds evidence that monetary variables influence the volatility of the price of gold. Building upon the work of Christie-David et al. (2000), Roache and Rossi (2010) extend the set of influencing macroeconomic variables on the price of gold by adding industrial production and changes in non-farm payrolls. It should be noted however, that these variables are not significant in a model specification controlling for a US Dollar effect.

The recent availability of economic uncertainty measures led to an increase in interest of the behaviour of gold in difficult economic environments. Aye et al. (2015) take into account the Kansas City Fed's financial stress index as well as the US economic policy uncertainty index and find that they have a strong ability to predict the price of gold across different models and time horizons. Jones and Sackley (2016) include a European economic uncertainty index in the gold predictability equation and find evidence for correlation. Finally, Gao and Zhang (2016) focus on UK economic uncertainty and find evidence for a higher correlation with gold when the UK Economic Uncertainty index is higher.

3.1.2 Gold and Inflation

The question of gold's ability to offer financial protection in troublesome times has received significant attention and was briefly mentioned above. However, in the light that a chapter of this thesis looks into the formal relationship between gold and inflation, a more detailed literature review should be provided.

A striking feature is that a variety of different inflation indices have been suggested. This harks to the problem noted in Lucey and O'Connor (2011), namely the difficulty of finding an appropriate inflation rate for gold. Given that it is a quasi-currency, the ideal situation would be to find a measure of its eroding purchasing power over time, but this is fraught with difficulty.

Using the CPI rate to proxy inflation and a Commodity Research Bureau (CRB) commodity futures index to represent commodity prices, Ciner (2011) finds no evidence for a long term, positive relationship between commodity prices and inflation when working with a conventional time series regression. However, a relationship is detected when relying on frequency domain period proving the existence of a nonlinear dynamic between gold and inflation.

Focusing on the price of gold in contrast to a more general commodity price index, Wang et al. (2011) study the long run relationship between gold and inflation and augment the results with a linear cointegration test to examine the hedging ability of gold. Their study is very relevant as the authors work with non-linear tests and focus on threshold cointegration, in contrast to time-varying cointegration. Apart from their methodological contribution, the authors also suggest that changes in the price of gold reflect inflationary pressure. Wang et al. (2011) examine from January 1971 to January 2010 and for the United States of America and Japan. The inflation proxy used is the CPI sourced from the International Financial Statistics of the International Monetary Fund (IMF).

In a very extensive study on the relationship between gold and inflation, Erb and Harvey (2012) focus on 23 different countries to support their finding that gold reports inflation more objectively than State institutions. In their work, the authors define inflation as the country's individual CPI rate obtained from the IMF.

Examining the macroeconomic drivers of the gold price, Baur (2013a) finds that gold is driven by two categories of drivers; the first being traditional drivers such as inflation, the other one being new drivers like central bank demand. Apart from using the American CPI rate, the author also works with a Global CPI index.

More recently, Sharma (2016) studies 54 different countries to understand the ability of the CPI indices there to predict the US Dollar price of gold. Results show that the UK and the US CPI rates have, among others, predictive powers for the London gold price while this evidence is found to be stronger for out-of-sample tests than for in-sample tests.

In contrast to the above works, some papers categorically reject the existence of a positive long-run relationship between gold and inflation.

In one of the few papers to examine physical gold demand, Starr and Tran (2008) work with panel data on physical gold imports of 21 countries and find evidence for a different behaviour of physical in comparison to portfolio demand. A notable finding is that the authors find macroeconomic factors not to be a determinant of physical gold demand; only in one model specification inflation is found to be a driver at the 10% significance level. Working with *Wall Street Journal* survey data, Blose (2010) uses a very different method to calculate inflation and finds evidence that surprises in the CPI do not affect gold spot prices and that investors cannot determine expected inflation solely by observing the price of gold. Erb and Harvey (2013) find that there is little evidence for gold to be an effective hedge against unexpected inflation measured both on the short and on the long term. In a recent paper looking at the relationship between gold and inflation in China, India, Japan, France, the United Kingdom and the United States (between 1978 and 2015 for both the UK and the US), Hoang et al. (2016) works with a nonlinear autoregressive distributed lags (NARDL) model and prove that gold was not a hedge in the long-run for all the observed countries. It seems however, that gold was a hedge against inflation in the short-run in the UK, the USA and India. The time span for Japan ranges from 1992 to 2015 and a negative relationship between gold and the CPI is observed due to the deflationary episodes Japan went through in the given observation period.

The last pillar of the literature applies a time-variation framework when looking at cointegration between gold and inflation.

Beckmann and Czudaj (2013) study the relationship between inflation and the price of gold to show gold's partial ability to hedge against the CPI and the PPI in the USA, the UK, the Euro Area and Japan. They are one of the early contributors to time-variation in cointegration, working with a Markov-switching vector error correction model in a time-window from January 1970 to December 2011. A further paper looking at time-varying cointegration is Batten et al. (2014), who find that excluding data from the early 1980's eliminates the cointegration relationship between gold and the American CPI. They derive time varying cointegration parameters and an inflation sensitivity factor from a Kalman filter, and illustrate how the relationship between gold and inflation changes over time. Also set within a time-varying framework are Bampinas and Panagiotidis (2015) who work with over 200 years of data and focus on the relationship between gold (and silver) and inflation. The time-variation framework follows the approach set out by Bierens and Martins (2010) and is also run with expected inflation measures provided by a Christiano and Fitzgerald (2003) band pass filter and a Hodrick and Prescott (1997) time-series filter. Due to the very long time window under study, the authors work with inflation series obtained from Reinhart and Rogoff (2011).

3.2 Silver

The work that has been done about silver is far greater than one might initially believe. Though silver is clearly overshadowed by gold as an investment vehicle, it's importance in the financial world seems recognised when one considers the amount of academic literature published on its economic role over the past few years. This section is providing the reader with an overview of all of the existing literature about the financial economics of silver until March 2017[1]. We try to produce an overview as thorough as possible about previous research on the economic and financial aspects and implications of silver as an asset, but have deliberately left out papers dealing with historical aspects of silver in both monetary policy aspects and in the economy in general. Here, the cutoff line was made depending on the era studied. Recent events and implications of silver for currencies that are believed to still have an effect on today's economy will be presented further down. Other historical aspects, such as the importance of silver imports for the English economy in the late 13th century (Nightingale (2013)) or the tenfold increase of silver English currency between 1158 and 1290 (Allen (2001)) were, though fascinating, deliberately excluded from our research.

[1]A survey on the financial economics of white precious metals containing all academic findings until March 2017 based on this chapter is forthcoming in the *International Review of Financial Analysis*.

3.2.1 About the Historical Aspects of Silver and its Role in a Bimetallic System

One of the many aspects that silver is sharing with gold is the historical importance it played for currencies over the past centuries, where a prominent example of a country that gave up an arguably effective silver standard is China, who switched to a fiat currency in 1935.

3.2.1.1 The Historical Aspects of Silver

In a paper that benefited from comments by Milton Friedman, Brandt and Sargent (1989) argue that the U.S. Silver Purchase Act of 1934 is not entirely responsible for having forced China into fiat money, but that the departure from a silver linked currency in China was endogenous and brought upon by the Chinese Government. The authors argue by saying that even though the U.S. silver purchase programme did cause an increase in the price of the precious metal, and that this led to a fall in the Chinese price level and a chain of bad economic events, it was the Chinese Government that decided to break away from a silver backed currency in order to mark profits by selling its silver at the new appreciated market price. However, when considering this conclusion, one should keep in mind the uncertainty of both the economic and the political environment of China throughout the 1930's.

Another paper to look at China and the implications of commodity money is from Cheng et al. (2013) who explain that the positive correlation of the price level with nominal interest rates is not only a gold standard phenomenon but can also occur in other commodity money systems. This formerly mentioned relationship between the price level and interest rates, also known as the *Gibson Paradox*, is proved to have appeared during the silver backed currency era of China between 1873 and 1924. Results from both a recursive ordinary least squares specification and a vector autoregression that takes into account the Shanghai Yinchai Rate and the Chinese Wholesale Price Index uncover a weak correlation between the two variables. However, the recursive OLS reveals evidence for the existence of a Gibson Paradox in China during parts of the period under study - though this relationship is much stronger during some years more than others. The authors offer an explanation for this time-varying relationship with the argument that the quantity of money in circulation being strictly limited, the interest rate level regulates the amount of the precious metal held for non-monetary use. The disappearance of the Gibson correlation amongst the two time series is considered to be evidence that during some subperiods, the metallic standard became unsupportable for the Chinese economy.

Keeping a focus on China while extending their research to other Asian countries such as Hong Kong and Indochina, Bailey et al. (2003) take into account data from December 1872 to November 1941 in order to understand the effect that switching between silver and paper money had on stock returns in Asia. Empirical findings are obtained through a bivariate GARCH in order to derive the joint distribution of two series and measure their correlation. Results point towards a higher volatility of stock market returns under fiat money regimes, thought this finding must be considered in the light of global political unrest which occurred simultaneously to the switch from a silver backed currency to a fiat currency.

Looking away from the Far East while keeping a focus on Asia, Hasan (2006b) examine the relationship between the silver-based Pound Sterling and the intrinsic value of silver in India and Iran. In a fashion similar to Bailey et al. (2003), bivariate models indicate evidence of cointegration between the exchange rate of the British Pound and the intrinsic value of silver in India and Iran, though further results indicate a feedback relationship between the exchange rate of the Pound Sterling and the intrinsic value of silver for both countries under study.

In another paper taking into account the same dataset for India and Iran, Hasan (2006a) reconfirms the existence of a long-run cointegration relationship between the exchange rates of silver-based currencies and the intrinsic value of silver. Hasan (2006a) builds upon Hasan (2006b) by using a cointegration equation to derive the equilibrium relationship and efficiency between silver-based exchange rates and the intrinsic value of silver, as well as validating the necessary and sufficient conditions of the market efficiency hypothesis.

3.2.1.2 The Role of Silver in a Bimetallic System

Some empirical work has been done on the implications and effects of bimetallism, where the paper by Oppers (1996) is an early example. Looking into both the causes and the consequences of the switch from bimetallism to the gold standard in the early 1870s, the author argues that the German demonetisation of silver after the unification caused the fall of the price of silver in 1871. Looking at a bigger and more global picture via a composite-good model consisting of money supply, price level, the interest rate and the exchange rate between the gold and silver currencies of the different areas under study, the author challenges the belief that the end of bimetallism in the early 1870s was inevitable since it was accompanied by neither an excessively abundant supply of silver nor by a shortage of gold.

A few years later, the same author published a further paper focused on issues revolving around bimetallism - namely at the apparent stability of the ratio between gold and silver in the absence of arbitrage possibilities for bimetallic countries in the 19th century. Oppers (2000) believes that Gresham's law should be reviewed in the light of *arbitrage anticipation*. Stating that *good money drives out bad money* (Greenfield and Rockoff (1995)), Gresham's law affirms that in a bimetallic system, coins trade at a fixed official relative price whereas the price of the precious metal is linked to fluctuations in the commodity markets. If the market price of silver would deviate from the mint ratio, a profit could be realised by transferring the more valuable coin *(good money)* into the commodity market. Considering data from the major bimetallic economies of the past centuries, Oppers (2000) argues that anticipation of arbitrage opportunities occurring from Gresham's law act as a stabilising power for both the gold and silver price.

Velde et al. (1999) work with a more complex economic model in order to offer support to the findings of Oppers (1996), namely that the sudden end of bimetallism in the 1870s was by no means inevitable. The authors take into account a large selection of countries within a steady-state analysis but fail to find a rational explanation for the simultaneous abandonment of bimetallism by so many countries in 1873; even more puzzling, evidence show that the shift of Germany in 1871 from a silver linked currency to a gold linked currency relaxed the constraints exercised on bimetallism.

A recent paper that has a far more pessimistic view on the possible future of bimetallism is that of Meissner (2015) who predict a collapse of bimetallism would have occurred by latest 1875. The author bases his conclusion by working within a conditional model developed by Flandreau (1996), and finds an explanation for the sudden global exit of bimetallism in 1873 in the apparent lack of monetary and economic knowledge of most actors at the time and their poor willingness to cooperate. An interesting outlook accompanied by words of warning is provided in regard to the actual European monetary crisis.

A final paper we like to present in this section is a paper quite outside our subject area, but still very relevant for understanding the determinants of the price of silver and especially for predicting the future of the silver price in the years to come is that of Sverdrup et al. (2014). Having collected a very vast amount of data on the market size, stock of silver in society, mine reserves and silver supply amongst others, Sverdrup et al. (2014) estimate that the amount of recoverable reserves of silver are around 2.7 to 3.1 million tonne, of which approximately 50% have already been mined. The authors believe all silver mines to be exhausted by 2240.

3.2.2 The Structural and Behavioural Aspects of the Silver Price

Similar to other assets that draw the attention of academic researchers over the years, there have been some attempts to model the price of silver using various econometric tools. This section will present some of the work on structural issues revolving around the price of silver and also focus on the research output that behavioural finance added to the knowledge on silver.

In an early paper on the rates of return of gold and silver, Frank and Stengos (1989) examine possible predictability of the rate of returns of the two precious metals. Results from daily, weekly and biweekly data between the mid 1970's and the mid 1980's for silver point to the possibility of an underlying martingale process, indicating the likelihood that a nonlinear process generates observed gold and silver returns and that a certain degree of randomness is present in generating the price of silver.

Lashgari (1992) takes into account daily, weekly and monthly gold and silver prices between January 1970 and December 1989. Optimal silver price forecasts are obtained based on prior observed values by minimising the amount of information inaccuracy resulting from the divergence between actual and forecasted price changes; essentially relying on a exponential smoothing time series model. Results indicate that the information of past prices for gold and silver is stronger when short-term previous prices are considered, while this effect vanishes away when looking at weekly and monthly prices. While the dependence on past prices is found to be stronger for gold than for silver, no trading profits can be realised for both gold or silver.

Another early paper to look into the structural aspects of silver is that of Liu and Chou (2003) employing a general method of fractional cointegration analysis to study the spreads between gold and silver prices; in both cash and futures markets.

Results indicate that gold-silver and silver-gold parities are slow-adjustment long-memory processes and that the futures and cash spreads between gold and silver are cointegrated. Further results point towards the ability of future spreads to reflect information before cash spreads.

Roberts (2009) is looking more into the behaviour of the price of silver by working with monthly data from January 1947 to December 2007. Considering highs and lows in the price of precious metals, amongst which silver, the author finds that the duration of these phases can be explained through cyclicality and not through mere randomness. The mentioned cyclicality is supported by evidence from a Bry and Boschan (1971b) procedure that identifies turning points in time series by adjusting them for outliers and replacing these outliers to create a smoothed time series. Looking more into silver and at how to model the duration of both phases and cycles of high and low prices, results from a batteries of tests indicate that a random walk is not the optimal formalisation to apply to the London Price of Silver.

A further paper that looks into a better understanding of the structure of precious metal prices is of Fassas (2012). Looking back at the period between the 1st of May 2007 and the 28th of February 2011, the author argues that the price increase in precious metals was partly due to the flow of precious metals into Exchange-Traded Products (ETPs). Looking at 28 precious metal ETPs and the weekly spot returns of silver, evidence suggests a statistical significant positive correlation between silver returns and the flows into silver Exchange-Traded Products exists, though this relationship is stronger for gold. The evidence for correlation between the two variables should, however, be considered in the light that a Granger causality test (Granger (1969)) rejects the hypothesis that precious metal ETPs flows caused the return of silver.

A few years later, Demiralay and Ulusoy (2014) published an applied risk-management approach to predict the value-at-risk (VaR) implications of gold, silver, platinum and palladium. Working with daily data of both long and short trading positions between the 4th of January 1993 and the 29th of November 2013 and the daily PM US$/Troy ounce silver price as quoted in the London Bullion Market, Demiralay and Ulusoy (2014) fit the data into three different non-linear long memory volatility models (FIGARCH, FIAPARCH, HYGARCH) and find that a FIAPARCH model with Student *t* distribution is able to capture long memory and asymmetry as well as fat tails and outperforms the other long-memory volatility models in predicting one-day-ahead VaR positions for trading. The fractionally integrated asymmetric power ARCH (FIAPARCH) model was proposed by Tse (1998) and is a more complex case of the fractionally integrated GARCH (FIGARCH) model proposed by Baillie et al. (1996) that can distinguish between short and long memory in the conditional variance process.

In a recent article looking at the pricing structure of gold, silver, rhodium, platinum and palladium, Gil-Alana et al. (2015b) rely on a fractional integration modelling framework in order to identify structural breaks in the monthly data of the series between January 1972 and December 2012. Results indicate evidence of long memory processes for platinum, in contrary to silver and palladium where strong evidence for mean reversion is obtained. However, taking into account the respective structural breaks identified for the three white precious metals, all series seem to be non-stationary, so that exogenous shocks will affect the long memory behaviour of the series - hence advising policy makers to adopt measures in case white precious metals drift away from their original trend.

In another paper looking at long memory behaviour of the price of silver, Gil-Alana et al. (2015a) take into account annual silver prices between 1792 and 2013 and find that real silver prices are mean reverting; indicating that no long-run memory behaviour exists in the silver inflation rate. This result indicates that exogenous shocks will affect silver prices less intensely than gold prices.

Remaining in a focused framework of autoregressive conditional heteroscedasticity (ARCH) models, Nadarajah et al. (2015) build upon the work of Zhu and Zinde-Walsh (2009) and Zhu and Galbraith (2010) in order to test which GARCH specification performs better when modeling the returns of five different commodities amongst which gold and silver. A GARCH model is composed of two components: the volatility component and the innovation component. The latter is assumed to come from either the Gaussian distribution or the Student *t* distribution; or from a skewed extension of these distributions. Considering daily price returns from the 12^{th} of March 1993 to the 13^{th} of March 2013, Nadarajah et al. (2015) find that the best fitting model for silver price returns is the Skewed Exponential Power (SEP) distribution, results in line with Cheng and Hung (2011). The SEP distribution is a particular case of the Asymmetric Power Distribution (APD) (Zhu and Zinde-Walsh (2009)) - the most general form of the Normal Distribution.

Though the findings of Nadarajah et al. (2015) suggest to model the return of silver with a Gaussian Distribution, Cochran et al. (2016) model the return of four metals using an asymmetric GARCH (AGARCH) model with a conditional skewed generalised t (SGT) distribution. Similar to Demiralay and Ulusoy (2014) before them, the authors study the performance of value-at-risk measures obtained from an AGARCH model with a SGT distribution to results obtained from an AGARCH model with a normal and student t distribution. For the case of silver, an AGARCH model with the SGT distribution offers the best fit. An interesting difference to both Demiralay and Ulusoy (2014) and Nadarajah et al. (2015), who take into account a similar time frame, is the much shorter period of time used by Cochran et al. (2016): daily spot returns of silver between the 2^{nd} of January 1999 and the 29^{th} of January 2010. Further findings point towards time-variation in the skewness for silver, as well as in the peakedness and tail thickness parameters of silver returns. Results from a Wald test (Engle (1984)) implies that higher order moments of silver returns, like skewness and kurtosis, are time-varying.

In a recent paper attempting to forecast the returns of gold and silver prices, Pierdzioch et al. (2016) discuss the statistical and economic performance of different forecasting models in regard to the choice of the Information Criteria selected to determine the boosting algorithm. Using monthly data from January 1987 to September 2014 and using a large set of predictors to forecast the excess return of silver to the 1-month LIBOR, the authors develop a trading algorithm in which an investor should buy silver if the forecasted excess return is above the historical real-time mean of excess returns. In such a scenario, the trading rule performs better under the Akaike Information Criterion (AIC) then under the Minimum Descriptive Length (MDL) proposed by Bühlmann and Hothorn (2007). Even though the forecasting model for silver performs well, Pierdzioch et al. (2016) warn the readers that the outlined model might not survive an economic performance evaluation.

A growing amount of work was done about the behavioural aspects of the price of silver, which is in line with the observed expansion of research in behavioural finance over the past years. Whereas early papers tend to focus on the efficiency of the silver market, the trend shifted towards the study of seasonality and trading behaviour of investors during the recent years.

In a rather early paper, Solt and Swanson (1981) analyse if the efficient-markets theory (Fama (1970)) can be applied to the gold and silver market and the results of their endeavour lead to several conclusions. First of all, the author finds evidence for strong heteroscedasticity in the variances of the price changes for silver, except for the logarithmic price series, where the mean of these price changes are nonzero and not stationary, as well as not merely drifting. Also, even though there seems to exist a positive dependence in each of the price change series, this dependence cannot be used to generate abnormal returns. Solt and Swanson (1981) conclude by saying that the silver market does not conform with traditional market efficiency models and that trading silver could be considered more a speculative endeavour rather then an investment activity.

Only a few years later, Goss (1983) builds upon the findings of Solt and Swanson (1981) and focuses on two different questions. First, if actual futures prices of silver are unbiased anticipations of consequent cash prices, and second, whether or not the silver market is efficient in a weak form sense. A market is efficient in the weak form of the term if silver futures prices reflect all information contained in past silver futures prices (Jensen (1978)). The first question is addressed through a General Instrumental Variable Estimation (GIVE) which corrects for autocorrelation and is not limited to first order processes (Hansen and Singleton (1982)). Evidence shows that futures prices of silver overstate the maturity date cash prices at levels below \$3.82 to \$4.42 depending on the lag length, and understate maturity date cash prices above these levels. Regarding the Efficient Market Hypothesis (EMH) for silver, the author worked with silver futures daily closing prices between 1973 and 1979 and addresses the question by testing the random walk hypothesis; assessing that subsequent price changes are independent and identically distributed - they can never be described as either *too high* or *too low* (Shiller and Perron (1985)). Results point towards a rejection of the Efficient Market Hypothesis, a finding in line with Solt and Swanson (1981) who looked at period between 1971 and 1979.

A rather new paper to look at the efficiency of the silver market is that of Charles et al. (2015). The authors take into account log returns of daily closing spot prices for silver between the 3^{rd} of January 1977 and the 23^{rd} of October 2013 and apply an automatic Portmanteau test and a variance ratio test to check for weak-form efficiency of the silver market. The automatic Portmanteau test builds upon a robustified Box-Pierce Q statistic (Lobato et al. (2001)) in which the optimal value of p is determined by the data fed into the system (Escanciano and Lobato (2009)). The automatic Portmanteau testing procedure has multiple advantages: the order of the autocorrelation tested doesn't need to be specified, there is no need to use a bootstrap procedure to estimate critical values and the test is robust to the presence of conditional heteroscedasticity of unknown form. The automatic variance ratio test used builds upon the findings of (Kim (2009)) who developed a way to improve the performance of the Choi (1999) testing procedure. It should be pointed out however, that Kim (2009) developed their testing procedure for *small samples*, Charles et al. (2015) work with 9,603 observations, which arguably qualifies as a *small sample*. Charles et al. (2015) conclude their findings by saying that the market for silver fits the criterion of the *adaptive market hypothesis* (Lo (2004)) that takes into account behavioural economics, and that the silver market has gradually shifted towards the efficient market requirements over the time period considered.

Yang and Brorsen (1993) focus on futures prices as well and argue that past models have failed to successfully explain non-normality and dependence in speculative price changes. The authors apply a GARCH model and deterministic chaos processes to daily closing futures prices of silver between January 1979 and December 1988 in order to detect market anomalies. Building upon a GARCH model that generates data with fatter tails than the Gaussian distribution (Bollerslev (1986)) and reviewing previous research on the application of stochastic processes in finance, the methodology proposed by Yang and Brorsen (1993) captures day-of-the-week effects (Junkus (1986)), seasonality in variance (Anderson (1985) and Kenyon et al. (1987)) and maturity effects (Milonas (1986)) of silver futures prices. The GARCH model is augmented with a Residual Test in order to limit forecasting errors (Brock et al. (1996)). Test results indicate a strong calendar-day effect for silver since the variance of silver futures prices is larger on certain days of the week and after holidays. Further results point towards seasonality in the variance.

Focusing as well on seasonality effects is a paper by Lucey and Tully (2006a) that studies daily COMEX silver cash and futures contracts between January 1982 and November 2002. More specifically, the authors test both the unconditional and conditional means and variances of silver cash and futures prices. The *unconditional* means and variances are modelled with a dummy variable regression and tested via the t and the F Statistic; where robustness is ensured through the iterative re-sampling model proposed by Rousseeuw and Leroy (2005) that captures outliers better. The approach of Lucey and Tully (2006a) also controls for heteroscedasticity and autocorrelation (White (1980)) and tests for seasonality in the unconditional variance (Levene (1960)). The *conditional* means and variances are modelled starting with a GARCH-in-mean (GARCH-M) framework adding a heteroscedasticity term into the mean equation (Elyasiani and Mansur (1998)) and accounting for potential asymmetric responses in the conditional variance by adding a leverage term to the variance itself (Glosten et al. (1993)), hence resulting in a Leveraged GARCH (LGARCH) model. Results point towards a Monday effect that increases the variance of silver cash prices, findings in line with Yang and Brorsen (1993), and a Wednesday effect decreasing the variance of silver futures prices. In a next step, Lucey and Tully (2006a) augment their GARCH framework by including day-of-the-week dummy variables in both the mean and the variance (a procedure similar to Clare et al. (1998) and Lucey (2000)) and find that the seasonality in silver price returns is not due to daily variation in risk - an important conclusion for silver investors as this means the risk-return relationship does not hold.

A recent paper looking at calendar-effects in precious metal returns is that of Auer (2015) finding no Friday the 13th effect for silver returns. The author builds upon the findings of Kolb and Rodriguez (1987) and works with a dummy-augmented GARCH model to understand the impact that certain days exercise on the conditional means of silver returns. The methodology used is slightly different from Lucey and Tully (2006a) and relies upon the Generalised Autoregressive Conditional Heteroscedasticity model with time-varying Skewness and Kurtosis (GARCHSK) proposed by León et al. (2005) and estimated under the assumption of a Gram-Charlier expansion of the normal density function for the error term (Jondeau and Rockinger (2001)) - a series easier to estimate than the non-central t distribution proposed by Harvey and Siddique (1999). Auer (2015) extends the GARCHSK model by adding lagged returns to the mean equation in order to capture potential serial correlation (a method similar to Bhattacharya et al. (2003)) and by adding two dummy variables in the mean equation according to calender-days of interest. Even though the main finding of the author is that no Friday the 13th effect can be observed in silver returns, another important conclusion is that there is significant evidence of time-variation for both the skewness and the kurtosis of silver returns.

In the same year, Caporin et al. (2015) focus on the behaviour of silver spot prices return, volatility and liquidity. A first major contribution to the field is the data used in the paper: trading quotes issued by the Electronic Brokerage Services (EBS) and provided by ICAP plc. The time frame observed ranges from the 27th of December 2008 to the 30th of November 2010, where 100,962,954 quotes were observed for silver, amounting to 27,638 trades and a volume of 1,173,425,000 oz of silver traded. Caporin et al. (2015) develop a battery of well fitted models depending on the feature of silver under study. When looking at return and volatility, the authors specify an Exponential Generalised Autoregressive Conditional Heteroskedasticity (EGARCH) model as proposed by Nelson (1991) and superior to traditional GARCH models when exogenous variables are included. Even though the authors are aware of the issue of presence of long memory in high-frequency returns volatility (Andersen and Bollerslev (1997a,b, 1998); Bordignon et al. (2007, 2009)), Caporin et al. (2015) argue that introducing long memory in the conditional variance equation would further increase the model's complexity - hence resorting to a solution proposed by Corsi (2009) specifying the dynamic of the variance following a Heterogeneous Autoregressive (HAR) structure. The approach of Corsi (2009) allows the researcher to approximate the long-memory behaviour by reproducing the volatility persistence term of the HAR model. Results from modeling the return and volatility time series indicated the presence of a stochastic periodic behaviour and the possible presence of long-range dependence in the volume time series. In response to these features, Caporin et al. (2015) work with a multi-factor Generalised Autoregressive Moving Average (GARMA) model as proposed by Woodward et al. (1998) which allows for long-memory behaviour associated with specific periodic frequencies. The silver volume GARMA modeling approach of Caporin et al. (2015) can be used to forecast both volume levels and volume density if upgraded with a GARCH or EGARCH equation. The authors conclude their work by saying that silver has features comparable to those of more traditional assets, mainly in terms of the characterisation of liquidity from intraday seasonalities, and that their endeavours is a stepping stone to research about price discovery processes of precious metals.

Another paper that looks at trading data is that of Mutafoglu et al. (2012) focusing on the question if trader positions can predict the direction of gold, platinum and silver spot price movements. The authors take into account the weekly Commitment of Traders (COT) reports for silver prices obtained from the Commodity Futures Trading Commission (CFTC) between January 1993 and December 2009. Mutafoglu et al. (2012) build their methodology upon a basic VAR model with two variables: silver spot price returns and trader positions. Unclear about exogeneity issues of system parameters, they treat each variable symmetrically (Enders (2014)); furthermore, as argued by Harvey (1997) and Clements and Hendry (2001), failures of economic forecasts can be due to structural breaks and hence lead to unreliable estimation results of model parameters. Mutafoglu et al. (2012)

address this by using a generalised structural break test with unknown break points (Andrews (1993)) to test the stability of model parameters over the entire sample period. If structural breaks are detected in the manner of Bai (1994, 1997b), the VAR analysis is repeated for each sub-sample period. Results from the entire sample show that silver market returns explain trader's positions and that a major structural break happened in the early 2000's, after which the tendency of trader positions to follow returns became much stronger.

One paper that stands out, though technically concerned with calendar-effects as well, is the work from Lucey (2010) finding evidence for the existence of a lunar cycle on precious metal returns. Considering daily PM fixing prices for silver traded in London between January 1998 and September 2007 against lunar phases from the Munich Astronomical Archive, Lucey (2010) applies a battery of classical descriptive and analytic tests and finds that returns around the full moon tend to be negative in contrast to positive returns around the new moon. The existence of lunar seasonality for silver is in line with previous findings from Dichev and Janes (2003) and Yuan et al. (2006) who did similar work on stock market returns.

Two papers emerge from the field of behavioural aspects of white precious metals by looking at the forecasting abilities of survey forecasts of the price of silver. Fritsche et al. (2013) consider silver price forecasts obtained from Consensus Economics Inc. for different forecast horizons between June 1995 and August 2012 and rely on the market-timing approach proposed by Pesaran and Timmermann (1992, 1994) in order to test for the accuracy of silver price forecasts. Results for silver are different than those obtained for gold; indeed, it is proven that silver price survey forecasts contain information on the subsequent price changes, while forecasts on the price of gold are not accurate in predicting future price movements.

Working with the exact same data set provided by Consensus Economics Inc. between June 1995 and August 2012, Pierdzioch et al. (2013) model the behaviour of the authors of gold and silver price forecasts and find evidence for irrational behaviour on both markets. More specifically, results based on the asymmetric loss function proposed by Elliott et al. (2005) to test for the rationality of forecasts, indicate a herding behaviour of some forecasters, while others tend to issue more *extreme* forecasts in order to differentiate themselves from others. Indeed, this change in behaviour tends to occur depending on the customers of silver price forecasts, resulting in biased forecasts in order to assure a loyalty of the main group of customers.

3.2.3 The Investment Benefits of Silver

Similar to other financial assets, a lot of research was done about the possible investment benefits of silver. In line with academic publications on other alternative investments, one can observe an increase in publications about this subject in recent years. This subsection presents what is known, or more so *believed* to be known, about the benefits and drawbacks of an investment in silver.

3.2.3.1 Portfolio Aspects of Silver

A very early classic on the matter is the paper from Jaffe (1989), which looks at implications of adding gold to hypothetical portfolios of varying risk. In his work, Jaffe (1989) also considers the monthly silver price from September 1971 to June 1987, a time frame during which the average monthly return of silver was about 1.50% and the beta (Markowitz (1952); Sharpe (1964)) to the S&P 500 was of 0.34 (considerably higher than that of gold at 0.09) while the standard deviation was of 11.58% (against 7.88% for gold). Looking at the relationship between precious metals and other assets in a next step, silver shares a rather high correlation coefficient with gold (0.744) and with Toronto Stock Exchange (TSE) gold stocks (0.589); the lowest correlation coefficient is that between silver and the German Mark/US Dollar exchange rate (-0.252).

McCown and Zimmerman (2007) also investigate the inflation hedging abilities of silver but also look into the investment performance of the metal by using multiple asset pricing models. The data used is the monthly spot price of silver and the US CPI between January 1970 and December 2006. When looking at investment performance, McCown and Zimmerman (2007) start by estimating the Capital Asset Pricing Model (CAPM) of Sharpe (1964), Lintner (1965) and Mossin (1966) for silver. The risk-free rate considered is the yield on 30 days US Treasury Bills and the market portfolio is given by three different proxies: the Morgan Stanley Capital International (MSCI) World Index, the MSCI World Index denominated in US Dollars (showing the returns a US investor would get if he does not hedge foreign exchange risks), and finally, the MSCI World Index denominated in local currencies (showing the return an investor would get if he completely hedged foreign exchange risks). The Beta results for silver are quite similar independent of the index used as market portfolio proxy; small Betas (around 0.33) are recorded for a period of up to six months and they become negative after one year. The findings suggest that silver is a less volatile investment to the market on the short-run, and that it moves in opposite direction than the market on the long-run - arguments in support of silver's ability to be used as a hedging tool against stock markets. In a next step, McCown and Zimmerman (2007) model the return on silver using the multiple-factor Arbitrage Pricing Theory (APT) proposed by Ross (1973, 1976). The APT models the return of an asset through a linear combination of macroeconomic variables; a discussion about which variables to use can be found in Chen et al. (1986), Chen (1991) and Shanken and Weinstein (2006) amongst others. The results of the APT point towards the growing importance that inflation has on silver when a larger time set is considered. In a final step, the authors look more into the relationship between silver and expected inflation. Based on the Fischer (1930) equation, they derive expected inflation as the spread between US Treasury securities and Treasury Inflation Protected Securities (TIPS). Results point towards a high correlation between the price of silver and expected inflation, making it a good indicator of the latter, though gold proved to perform better at this role than silver.

Bruno and Chincarini (2010) focus on calculating the ideal amount of commodities in a portfolio by generating optimal mean-variance portfolios. Even though the authors look at more than 15 different countries between 1930 and 2009, the only national portfolios explicitly advised to have holdings in silver where the cases of Germany, Mexico and the United States of America between 1970 and 2009. For both Germany and the U.S.A., an optimal allocation of 0.01% to silver is advised (along with 4.36% and 3.07% in gold for Germany and the US respectively), whereas Mexico stands out with a much higher proportion of 1.98% of silver (along with 5.95% of gold).

Hammoudeh et al. (2013) look at the daily downside risk associated with gold, silver, platinum, palladium, oil and the S&P 500 Index between the 2^{nd} of January 1995 and the 5^{th} of July 2011 within a Value-at-Risk (VaR) framework. The VaR metrics are computed at the 99% confidence level (in accordance with the Basel Accord rules for computing capital requirements (Basel Committee on Banking Supervision (1988, 1995, 1996, 2006)) and the RiskMetrics model from J.P. Morgan (1996) which proved to be superior to eight other proposed models. Two Asymmetric Power Autoregressive Conditional Heteroscedasticity (APARCH) models proposed by Ding et al. (1993) are used to forecast results. The difference in the two APARCH models lies in the distribution, where the first one follows a normal student-t distribution and the second a skewed-t distribution (Tu et al. (2008) look at Asian markets and provide evidence for the superior performance of the skewed-t distribution - results in line with Mittnik and Paolella (2000) and Giot and Laurent (2003)). With VaR results on hand, Hammoudeh et al. (2013) follow the portfolio construction approach proposed by Campbell et al. (2001) using a performance metric based on the mean-variance approach. Three optimal portfolios are constructed: the first consisting only of the four precious metals, the second consisting of all six assets under study, and the third consisting of gold, oil and the S&P 500. Portfolio one has the highest annual return, around 9%, but also a higher standard deviation then the second, containing the greatest amount of different assets, which scored an average yearly return of 8.625%. Looking at portfolio efficiency, the authors conclude that an optimal portfolio should hold a higher proportion of gold than any other asset (even though silver was the best performing asset over the time frame observed), and that overall, the pure precious metal portfolio proved to be the least efficient one.

3.2.3.2 Silver and Inflation

Published nine years later, Taylor (1998) is the first paper to look at the inflation hedging ability of silver. The dataset used by the author is rather extensive and covers the US Consumer Price Index and monthly silver returns between January 1914 and April 1996, broken down into subperiods. A Jarque-Bera test (Jarque and Bera (1980, 1987)) indicates non-normality as well as high leptokurtosis across the time series, therefore, an Ordinary Least Squares (OLS) method would minimise the sum of the squared residuals and yield inefficient coefficient estimates. Especially when working with precious metal prices, Weston (2012) points towards the importance of outliers caused by intense speculative activity. Dielman and Pfaffenberger (1990) propose a Least Absolute Deviations (LAD) procedure proven to be more powerful in presence of outliers for it minimises the sum of absolute deviations instead of minimising the sum of squared residuals. A second procedure used by Taylor (1998) is the Huber M-Estimation (Huber (1964, 2011)), minimising the sum of a function of the residuals, a mixture between OLS and LAD estimations. Both procedures are augmented with a Granger and Newbold (1974) test for non-stationarity to ensure that the relationship is not spurious in nature. The results for silver indicate that it was a long-run hedge over the period observed, but that it also served as a short-run hedge against the US CPI over many subperiods of the sample. A noteworthy finding is that silver was a hedge during the second *Organisation of Oil Exporting Countries (OPEC) crisis* of 1979, but not during the first *OPEC crisis* of 1973.

A few years later, Adrangi et al. (2003) continue the investigation into the relationship between silver and US inflation. The authors work with monthly averages of London Fix silver prices between April 1967 and November 1999 as well as the American Industrial Production Index (IP) and the Consumer Price Index - both issued by the International Financial Statistics of the International Monetary Fund (IMF). Adrangi et al. (2003) build their methodology upon two theoretical frameworks. The first one, based on the works of Fama (1981), Fama and Gibbons (1982) and Geske and Roll (1983) predicts that a rising inflation rate leads to a reduction of both the economic activity and the demand for money (Motley (1998) provides evidence that persistent inflationary pressures could lower US Gross Domestic Product (GDP) growth) - hence to a reduction of corporate profits and their stock price; an impact known as the *proxy effect* (Fama (1981)). Adrangi et al. (2003) argue that this would on the one hand lead to a reduction of industrial demand for silver, but might lead to an increase of the investment demand side due to silver's alleged ability to act as a hedge during inflationary times. The second framework is build upon the portfolio equilibrium model of Feldstein (1980) who developed it looking at gold only, though Adrangi et al. (2003) apply it to silver as well. The framework is based on the assumption that the demand for gold and bonds in a portfolio is a function of expected real after-tax returns of the two assets. However, Feldstein et al. (1977) showed that the net after-tax return on gold is higher than the after-tax return of bonds as long as the capital gains tax is lower than the ordinary income tax rate; therefore, during inflationary periods, the relative price of gold rises, making it a good inflation hedge. Checking for cointegration (Johansen (1991)) and causality (Granger (1969)), results for silver are multiple. First of all, evidence proves that silver was a good hedge against inflation over the time period observed. Second, the Fischer (1930) hypothesis holds, in other words: real silver returns are not adversely affected by inflation. However, econometric results do no offer support in favour of the Fama (1981) *proxy hypothesis*. A final finding is the positive relationship between silver and the CPI in the long-run equilibrium and the short-run dynamics derived from it.

A recent paper that added to the knowledge of silver as a tool against inflation is by Bampinas and Panagiotidis (2015) taking into account annual data of the price of gold and silver and consumer prices in the United Kingdom and the United States of America between 1791 and 2010. Reinhart and Rogoff (2011) work with historical inflation data going back this long and their work is used as a data source for the paper of Bampinas and Panagiotidis (2015). Both the linear Hodrick and Prescott (1997) filter and an asymmetric Christiano and Fitzgerald (2003) band-pass filter were used to derive expected CPI series. Bampinas and Panagiotidis (2015) are one of the few papers to look at the relationship between silver and inflation in a time-varying manner; the methodology is based upon the Johansen (1991, 1995) cointegration framework and upgraded with a Bierens and Martins (2010) test for time-varying cointegration. For both countries, the UK and the US, silver shares no long-run relationship with inflation; however, in a time-varying framework, a strong long-run relationship does exist between silver and UK inflation. Since a time-varying relationship still fails to exist for the US, the authors conclude that silver was not an effective inflation hedging instrument against American inflation in the past 200 years.

3.2.3.3 Debt- and Equity-Hedging Abilities of Silver

Quite some attention was given to the performance of silver as a hedging tool against stock market movements over the past years. Hillier et al. (2006) look at the return of the Zurich silver price in US Dollar per kilogram against the S&P 500, the MSCI Europe, the MSCI Australia and the MSCI Far East Index between the 1st of January 1976 and the 1st of April 2004 and apply a GARCH(1,1) model proposed by Bollerslev (1986). During the period observed, silver has proven to be a very volatile asset, with a daily standard deviation of about 2.15% - about twice the standard deviation of the S&P 500. Subsample analyses indicate a decreasing correlation with the price of gold but a constant very small correlation with the S&P 500 of an order between -0.05 and 0.01. Looking into the diversifying properties of an investment in precious metals, the persistent negative elasticity of silver at the 1% confidence level presumes that it was a valuable diversifying asset against an S&P 500 portfolio between 1976 and 2004 but not so in regard to the MSCI indices. Focusing in a next step more on periods of high volatility and poor returns of stock markets, silver's hedging abilities prove to be very strong. However, when looking at what metals to optimally hold in a portfolio, silver did not perform as well as both gold and platinum which scored higher returns over the period.

A few years later, Conover et al. (2009) continue the discussion about the investment benefits of precious metals by taking into account daily returns of silver between the 17th of January 1973 and December 2006, but also by looking at equity performance of precious metal companies. The tactical allocation of assets in the portfolio is made based on changes in the direction of the Fed discount rate. This technique suggested by Jensen et al. (1996) propose that a direction change of the Fed discount rate marks a turning point in the Fed's monetary policy (the close alignment between discount rate turning points and federal fund rate turning points is discussed further in Thornton (1998) and Jensen and Mercer (2006)). Multiple findings emerge from the results of Conover et al. (2009). First of all, an investment into the equity of precious metal firms proves to be much more efficient than a direct commodity investment; adding a proportion of 25% of the mentioned stocks to a portfolio of US equities leads to an increase in return by 1.65% and a decrease in the portfolio's standard deviation by 1.86%. A further finding is the superiority of an investment in gold against an investment in silver, results in line with Hillier et al. (2006), also, the investment benefits held by precious metals varied over time and grew during the later years of the sample (a formal derivation of the time-varying nature of silver's investment benefits is provided by Bampinas and Panagiotidis (2015)). The last finding is about the relation between the Fed policy and precious metals. Adding silver to a portfolio is much greater when the Fed policy is restrictive rather than expansive, findings somewhat in line with Conover et al. (2008) who advise investors to use monetary conditions as a guideline for portfolio allocation; however, Conover et al. (2009) point towards the impossibility of knowing that return patters are caused by monetary policies.

Also focused on a portfolio framework are Belousova and Dorfleitner (2012) who look at traditional assets held by a European investor: a mixture of global stocks, European sovereign debt and the money market. Looking at monthly data between January 1995 and December 2010, the authors build upon the framework of Markowitz (1952) and apply a mean-variance spanning method introduced by Huberman and Kandel (1987) and formally developed by Kan and Zhou (2012) to check the impact that the introduction of an asset has on the portfolio performance. Results are divided into bull and bear markets and show that adding silver to a portfolio during bull markets reduces volatility and enhances return. During bear markets on the other hand, silver is shown to reduce portfolio risk, results somewhat in line with Hillier et al. (2006) who look at a different time frame and conclude that even though adding silver to a portfolio is beneficial, gold and platinum are more beneficial investments.

Taking again a VaR approach in the quest of optimising portfolios, Sarafrazi et al. (2014) focus on daily downside risk of euro-zone national equity and sovereign bond markets by classifying the countries in two distinct groups: the *PIIGS* (Portugal, Italy, Ireland, Greece and Spain) and the *Core* (Germany, France, Austria, The Netherlands and Finland). The period observed ranges from the 31^{st} of March 1999 to the 20^{th} of November 2012 and the methodology used is the same as Hammoudeh et al. (2013). The results point to multiple interesting findings. By means of the Sharpe (1966, 1975, 1994) ratio, the optimal portfolio over the full period is composed of 4% Austrian bonds, 2% Finnish bonds, 3% French bonds, 34% German bonds, 5% Dutch bonds, 13% of gold, 11% of copper, 11% of oil, 9% of silver and 7% of platinum (sic). When looking at the very troublesome subperiod between July 2007 and November 2012, results show that from all the commodities observed (gold, silver, platinum, palladium, copper and oil), only gold and silver prove to contribute to diversification benefits to stock and bond portfolios - adding silver to both portfolios increases the Sharpe ratio.

Another paper of the same year to look at the hedging capacities of silver against sovereign bonds is that of Agyei-Ampomah et al. (2014) questioning the commonly held belief that gold is a good protection against bonds (see Baur and Lucey (2010) and Baur and McDermott (2010)) by looking at whether or not other metals might not have proven to be more effective in the time period from July 1993 to June 2012. The methodology used is that of Baur and McDermott (2010) capturing extreme movements of the bond prices by assigning a dummy variable corresponding to a return in the lowest 1^{st}, 5^{th} or 10^{th} percentile. On average, the returns of silver are negatively correlated with bond returns; looking at the 95% confidence level through a Wald (1943, 1949) test, the hedging ability is particularly strong for Austria, Belgium, Germany, Italy, Portugal and the UK. However, silver is a statistically significant safe haven asset for Italian sovereign bonds only, findings contrasted in a sub-period analysis. Looking into three different sub-periods, July 1993 to December 2000, January 2001 to December 2006, and finally, January 2007 to June 2012, the hedging ability of silver against sovereign bonds was only statistically significant between July 1993 and December 2000 and during no other period. A very interesting finding is the great hedging potential from industrial metals over the time period.

Auer (2014) looks at the hedging ability of diamonds against stock market and currency risk and contrasts the performance with both gold and silver; hence also deriving implications for the two precious metals. Looking at weekly data from January 2002 to July 2012, the author builds upon a Multivariate GARCH model of constant conditional correlations (CCC-GARCH) proposed by Bollerslev (1990) that he augments with a time-variation element proposed by Engle (2002) to capture volatility and correlation amongst the series. The results from different popular performance measurements indicate that even though some individual diamonds (in regard of their quality grade) are more volatile than precious metals, a well diversified diamond portfolio bears less risks than investments in precious metals. An investment in silver however offered the better investment performance and should be preferred against diamonds as a portfolio component.

Another paper to use the methodology from Baur and McDermott (2010) is the paper of Lucey and Li (2015) who look at the potential of the four precious metals to act as a safe haven against the S&P 500 and US 10 year bonds taking into account daily data between January 1989 and July 2013. The methodology is upgraded with the approach of Ciner et al. (2013) to identify time-variation in the safe-haven property of silver and graphically depict it. Results for silver have interesting implications for investors; concerning equity, silver was only a safe haven during the last quarter of 2009 and the first quarter of 2010, gold's performance was much better and it had safe haven properties during more quarters - concerning bonds though, silver was a safe haven at times during which gold failed to be. Empirically however, gold should be considered the better safe haven investment for it acts as one more often than silver.

In a recent paper, Mensi et al. (2015) look at the linkages between silver and other commodities and develop implications for Saudi-Arabian investors derived from daily data between the 1^{st} of June 2005 and the 13^{th} of August 2013. The FIAPARCH model is a symbiosis between the FIGARCH model proposed by Baillie et al. (1996) and the APARCH model proposed by Tse (1998). The FIAPARCH model allows: asymmetric volatility responses to both positive and negative shocks, an endogenic determination of the power of returns by the data itself, and finally, long memory in the volatility dependence (Conrad et al. (2011) applied and tested the efficiency of FIAPARCH models on different national stock markets and find the forecasting ability to be superior). In the paper of Mensi et al. (2015), a traditional FIAPARCH model is then upgraded with a DCC model by Engle (2002) to identify time-varying correlations amongst the variables. Initial results point towards a negative linear correlation between silver and Saudi Arabian stock returns - a finding upgraded by the DCC-FIAPARCH model showing evidence for time-varying conditional correlations between both series, disproving the capacity of silver to be used as a hedge or a safe haven against the Tadawul. In order to extract structural breaks in the correlation relationship, Mensi et al. (2015) work with a modified Inclan and Tiao (1994) Iterated Cumulative Sums of Squares (ICSS) test proposed by Sansó et al. (2004) to detect structural breaks in the volatility (applications of the ICSS test can be found in Rapach and Strauss (2008), Vivian and Wohar (2012) and Ewing and Malik (2016) amongst others). Two structural break dates are observed between silver and the Tadawul: the first in November 2005 and the second in July 2012.

Bredin et al. (2017) continue the investigation into the more general equity hedging abilities of silver by considering daily, weekly and monthly price returns between 1980 and 2014. The hedging potential is identified via a Value-at-Risk (VaR) procedure detecting the level of tail- and downside risk associated with silver investments, and measures the respective cost or benefit of such investments by considering risk-adjusted returns against an S&P 500 portfolio. Results indicate the superiority of gold to act as a hedge, while the equity risk reduction potential of silver and platinum only seems to be strong on a short time horizon but not on long time horizons.

3.2.4 Volatility Issues Around Silver and the Impact on Exchange-Traded Funds

In finance, volatility is the most prominent proxy used to quantify risk. Many paper have focused on volatility issues revolving around silver and these findings have important implications when trying to erect an empirical picture of the hedging potential of silver.

3.2.4.1 Silver Price Volatility

An early paper to look at silver price volatility is that of Barnhill and Powell (1981) building upon the silver market crash of March 1980. More specifically, the authors derive which determinants caused the great volatility of the silver price between July 1979 and April 1980 by looking into the demand and supply for silver, as well as into the relationship between the price of silver and macroeconomic indicators

- amongst which the yield on 3 months Treasury Bills and the CPI. Barnhill and Powell (1981) point towards multiple explanations for the sharp increase of the silver price in late 1979. A first reason was a constant and considerable shortfall of silver production relative to the commercial demand for silver, leading to the belief that silver was undervalued. A second reason is found to be the important acquisition of silver by certain parties, the most prominent being the Hunt family (implications of the role of the Hunt family on the silver market can be found in Fay (1982), in Krehbiel and Adkins (1993) and in Williams (1995)). Other driving forces identified were a rising investment demand for silver due to unattractive real returns offered by conventional investments and political actions undertaken by the government of India and the United States of America restricting both access and reallocation of a large portion of above-ground silver stocks. In a next step, Barnhill and Powell (1981) identify the reasons leading to the collapse of the silver price in early 1980: on the demand side, a fall in industrial U.S. commercial demand by 40% accompanied by a slow-down of cash silver acquisition by the Hunt family is observed. On the supply side, an increase of 200% in scrap supply as well as an increase of 80% in recycled silver overshadowed the demand. Finally, a growing attractiveness of alternative investments mixed with a negative investor sentiment against silver led to a very heavy drop of the price in late March 1980.

Focusing more on volatility implications for the industry, Labys et al. (1998) derive evidence for the existence of business cycles in the price of silver in order to obtain greater forecasting information to improve investor's behaviour. The data observed is the monthly Handy and Harman silver price quoted in US Dollars between January 1960 and December 1995 and the methodology used in the paper is threefold. First, a standard business cycle identification procedure developed by the National Bureau of Economic Research (NBER) looking at turning points and time series peaks is used (more details can be found in Bry and Boschan (1971a) and in Moore (1983)). This procedure is upgraded with a Weibull test of cyclical duration proposed by Davutyan and Roberts (1994) and assuming a linear relationship between the duration and the hazard function (Zuehlke (2003)), finally, cyclical components of the silver price series are modelled through the Structural Time Series (STS) model proposed by Harvey (1985, 1990, 1994) that divides a time series into the trend component, the cyclical component, and the irregular component. The statistical properties necessary to specify and interpret the model are outlined in Harvey (1989, 1994) and the data was divided into sample periods to assure that the irregular component meets the required conditions of non-autocorrelation and homoscedasticity (Harvey and Koopman (1992)). Results for silver point towards a decrease in volatility over the period under study and a total of 17 individual cycles observed though they are largely time-invariant. On average, contraction phases of the silver price tend to be longer then the more seldom occurring expansion phases.

Plourde and Watkins (1998) study the volatility of the monthly oil price between 1985 and 1994 and compare it to other commodities, hence also drawing conclusions for the price of silver. The notion of volatility is detected via three different aspects: first, the dispersion of the monthly price changes, second, the size of the absolute value of the price changes, and third, the frequency distribution of the absolute value of the price changes. Results for the dispersion of monthly price changes are obtained through a modified Levene (1960) proposed by Brown and Forsythe (1974) and a Fligner and Killeen (1976) test, as they allow for variation amongst the data of the different variables observed and perform better in terms of both robustness and power (Conover et al. (1981)). The location of absolute values of monthly price changes are derived through a Mann-Whitney-Wilcoxon (MWW) test (proposed by Wilcoxon (1945) and Mann and Whitney (1947)) verifying if the measures of central tendency of the time-series have the same value by generating a normally distributed test statistic for each individual sample. Finally, the distribution of absolute values of monthly price changes are obtained via a specific χ^2 test proposed by Mosteller and Rourke (1973) and focused on the overall shape of the distributions, assigning less weight to individual outliers. Results point towards a consistency of the volatility between oil and industrial metals, but large volatility differences between oil and silver. Not surprisingly, oil is found to be far more volatile than silver in both the short- and the long-term.

Nowman and Wang (2001) look at the monthly price of silver between February 1970 and May 1997 using a battery of nine continuous time models. The authors follow the previous work of Nowman (1998) on interest rate models and build upon the general stochastic differential equation proposed by Chan et al. (1992) that consists of a drift component, a mean reversion parameter and a variable measuring the dependence of the conditional volatility on the level of the price modelled via a Wiener process (Wiener (1930, 1938, 1949)). By assigning different values to the individual component of the equation from Chan et al. (1992), nine testing models can be designed to analyse the volatility of the price of silver. Results of the different models for silver show that the volatility of the price depends strongly on the price level, furthermore, a rather interesting finding from an econometric point of view is that both the drift and mean reversion parameters are insignificant at the 5% level across all models.

A few years later, Hammoudeh and Yuan (2008) focused on the volatility of the daily price of silver in the presence of crude oil and interest rate shocks between the 2nd of January 1990 and the 1st of May 2006. The authors work with three different models when looking at different aspects of silver price volatility: a standard GARCH model to study the impact and the persistence of oil and interest rate shocks on the volatility of silver future prices, an EGARCH model to understand the effect of both good and bad news on silver price volatility, and finally, a Component Autoregressive Conditional Heteroscedasticity (CGARCH) model to study the extent and persistence of transitory and permanent volatility in the short- and long-run. Both the regular GARCH (Bollerslev (1986)) and the EGARCH (Nelson (1991)) models have been presented earlier in this literature review; it should however be mentioned, what specifications the CGARCH contains. A Component GARCH allows mean reversion to be time-varying (Grier and Perry (1998)) and to distinguish between convergence and persistence of volatility on the short- and long-run (Guo and Neely (2008), Bauwens and Storti (2009), Engle and Sokalska (2012)). Results point towards a certain cyclicality and volatility persistence for silver (findings in line with Roberts (2009)), alleged to it's feature as being both a precious and an industrial metal. Furthermore, the EGARCH results point towards silver's ability to be a good investment in anticipation of bad news and to a cooling effect that past positive oil shocks have on the volatility of silver.

Sari et al. (2010) look at information transmission amongst the daily spot prices of gold, silver, platinum, palladium, oil and the US Dollar/Euro exchange rate between the 4th of January 1999 and the 19th of October 2007. Methodologically, the authors use a generalised impulse response functions proposed by Koop et al. (1996) and the generalised impulse response function from Pesaran and Shin (1998) in order to extract and analyse the impact and responses to shocks. The main advantage of the methods used is that the ordering of the variables in the VAR is not relevant any longer; the numerical results extracted show how much of the variance of a variable can be explained by shocks to another variable. The long run impact of gold on silver is quite important, explaining about 16% of the variation in silver; findings in line with Lucey and Tully (2006b). Interestingly, this relationship is also observed the other way around: silver explains 23% of the variance in the gold price (results later rejected by Balcilar et al. (2015)). On the short-run, unexpected shocks of gold, platinum and palladium have a positive and significant impact on the price of silver and vice versa - further evidence point towards a positive short-run impact of the exchange rate on the silver price.

As a reaction to metal prices reaching new record highs and facing a very uncertain future, Chen (2010) work with a very large data set of more than a hundred years to derive volatility insights for silver amongst other metals. Chen (2010) uses annual silver prices between 1900 and 2007 obtained from the US Geological Survey (USGS) and groups different precious metals together in order to gain insights of the price volatility of precious vs. industrial metals. The results indicate much higher volatility figures for industrial metals, probably pointing towards the ability of precious metals to act as hedges and safe havens (see Baur and Lucey (2010) and Baur and McDermott (2010)). In a second step, Chen (2010) uses a sub-section analysis proposed by Chan and Clements (2007) to understand the importance of within- and between-group volatility and shows that the volatility is higher within the metal groups than between the metal groups; in other words: the volatility is higher amongst precious metals than between precious and industrial metals. In a final step, Chen (2010) applies a single factor asset pricing model and finds that the importance of global macroeconomic factors in explaining silver price volatility has increased over the time period observed. Between 1900 and 1971 (the year the USA departed from the Bretton Woods system) over 90% of the price volatility of silver can be attributed to commodity-specific risk against under 10% to be attributed to global macroeconomic risk factors; between 1972 and 2007, these numbers shifted and the global macroeconomic risk share is above 36% against nearly 62% for commodity-specific risk factors.

In the same year, Choi and Hammoudeh (2010) look at the importance of financial and geopolitical crises on the volatility of commodity prices and extend previous studies by looking at correlation amongst commodity prices. Looking at weekly closing spot prices between the 2nd of January 1990 and the 1st of May 2006, Choi and Hammoudeh (2010) use distinctive methodologies to assess the issues of volatility and correlation. In order to measure the switch in return volatility between variance regimes and quantify their duration, the authors work with a univariate Markov-switching heteroscedasticity model (Krolzig (2013)) allowing to distinguish between high- and low-variance regimes (Haas et al. (2004)) where the probability of each regime is given by Kim (1994). Results of the Markov-switching model point to a duration of the low volatility state for silver of about 50 weeks against a duration of the high volatility state of about 25 weeks. Also, even though silver seems to be highly volatile around the same time periods as gold, it is especially in the early 2000's that silver was much less volatile than gold. In a second step, Choi and Hammoudeh (2010) work with a DCC multivariate GARCH (Engle (2002)) to understand the development of the correlation between gold and silver. Though the correlation between them is always fairly high and remains constant through time, a peak in correlation is observed in the second half of 1992 while the lowest correlation is observed around late 1996.

Focusing on interactions between precious metals, Morales and Andreosso-O'Callaghan (2011) investigate the nature of volatility spillovers amongst daily precious metal returns between the 1st of January 1995 and the 4th of November 2010 by means of a GARCH (Bollerslev (1986)) and an EGARCH (Nelson (1991)) model. Results of their work are multiple. First of all, descriptive statistics indicate that only palladium has a higher standard deviation than silver; furthermore, the standard deviation of daily silver returns is more than two times bigger than the standard deviation of gold returns. A second finding is that over the entire period, there is evidence of volatility running from gold to silver but not the other way around. Results from the GARCH model point towards a significantly positive relationship between precious metal returns, where the prices of gold, silver,platinum and palladium tend to appreciate simultaneously and also depreciate at the same time. On the other hand, results from the EGARCH model show that bad news have a greater impact on the silver market than good news.

A few years later, the same authors upgraded their work by adding oil and equity returns to their choice of variables under observation. Morales and Andreosso-O'Callaghan (2014) examine volatility persistence on precious metal returns and derive the relationship amongst the commodities up until the global financial crisis of 2008 by looking at daily returns between the 1st of January 1995 and the 25th of May 2008. The methodology is similar to that of Morales and Andreosso-O'Callaghan (2011) but upgraded with an Iterative Cumulative Sums of Squares (ICSS) algorithm to identify structural breaks and sudden changes in the variance of returns. The ICSS algorithm was designed by Inclan and Tiao (1994) and assumes that a time series has a stationary unconditional variance over a given time period until a break takes place. After such a break is detected, the unconditional variance is again assumed to be stationary until the next change occurs and so on - a method leading to a possible overstatement of the actual number of breaks in variance (Fernández (2004)). Also, ICSS results are not reliable under the presence of conditional heteroscedasticity (Bacmann and Dubois (2002)), Morales and Andreosso-O'Callaghan (2014) solve this problem by filtering the series with a GARCH(1,1) model. Results point towards 25 breaking point for silver series, less then for gold and platinum. Concerning the relationship between silver and equities, the GARCH and EGARCH results point toward an insignificant relationship with the Dow Jones index, but to a significant positive relationship with both the FTSE100 and the Nikkei225. A significant positive relationship between silver returns and Brent returns is also indicated at the 5% significance level.

A paper that uses a very similar approach as Morales and Andreosso-O'Callaghan (2014) two years beforehand is that of Vivian and Wohar (2012). The authors look at daily spot prices of different commodities between the 2nd of January 1985 and the 30th of July 2010 and work with a GARCH(1,1) model and an ICSS algorithm to capture volatility and structural breaks of the series. Even though the time period under observation is longer than that of Morales and Andreosso-O'Callaghan (2014), Vivian and Wohar (2012) find evidence for fewer breaking points in the silver series while the GARCH model results indicate high volatility persistence of the silver price.

Arouri et al. (2012) analyse the return and volatility of gold, silver, platinum and palladium in order to investigate both long memory properties and the potential of structural changes of the price series. The authors take daily spot and futures prices between the 4th of January 1999 and the 31st of March 2011 into account and use squared returns to test for long memory (Lobato and Savin (1998) and Choi and Hammoudeh (2009) amongst others use squared returns as well as a proxy for conditional volatility). Testing for long memory components in return and volatility is done via the Geweke and Porter-Hudak (1983), the Robinson and Henry (1999) and the Sowell (1992) test statistics, as they are all extensively used in relevant literature. Structural breaks are identified through an ICSS algorithm (Inclan and Tiao (1994)), similar to Vivian and Wohar (2012) and Morales and Andreosso-O'Callaghan (2014). The distinction between long memory and structural breaks is assured through the tests proposed by Shimotsu (2006) comparing full- and sub-sample parameters and testing them for stationarity (in a manner proposed by Phillips and Perron (1988) and Kwiatkowski et al. (1992)). Finally, fractionally integrated models are build into an Autoregressive Moving Average (ARMA) model (Whitle (1951); Box et al. (2008)) and a GARCH model (Bollerslev (1986)). The ARFIMA-FIGARCH model allows to test the accuracy of long memory because it should be considered fallacious if due to the presence of structural breaks. Results from Arouri et al. (2012) indicate long memory properties only for spot silver and not for silver futures, results rejected by the ARFIMA-FIGARCH model that finds no long memory evidence for spot silver. The ICSS test results indicate only three breaks for each the silver spot and future price; the breaks found are not in line with Vivian and Wohar (2012), but the spot price breaks on the 21^{st} of June 2001 and the 2^{nd} of January 2004 are also observed by Morales and Andreosso-O'Callaghan (2014).

In the same year, Cochran et al. (2012) also work with a FIGARCH model to examine the return and long memory properties of daily return volatility for copper, gold, platinum and silver between the 4^{th} of January 1999 and the 10^{th} of March 2009. Testing for the existence of long memory in the return of silver is done through a modified *Range over Standard Deviation* (R/S) test proposed by Lo (1991). The silver return series is not modelled as an autoregressive process, but as a multi-index CAPM proposed by Chang et al. (1990) in which the MSCI World Index serves as the market proxy, the VIX is the level of implied equity market volatility, and macroeconomic variable proxy the economic environment. Finally, volatility processes are captured via a FIGARCH approach (Baillie et al. (1996)), in a method similar to Arouri et al. (2012). Results point towards a negative effect of interest rates movement on silver (results in line with Jaffe (1989) and Hammoudeh and Yuan (2008)) and a negative relationship between exchange rates and silver returns, proving that the law of one price holds for silver. FIGARCH results show evidence of long memory characteristics for silver, while the metal's return volatility shares a positive relation with changes in the VIX. Finally, seasonal dummies indicate an increase in volatility of the silver price since the Global Financial Crisis.

One year later, Sensoy (2013) contrasts the findings of Cochran et al. (2012) and finds that the Global Financial Crisis of 2008 has no effect on volatility levels of silver. The data taken into account is the daily silver spot price between the 2^{nd} of January 1999 and the 15^{th} of April 2013 filtered through an ARMA(p,q) process. The methodology from Lavielle (2005) is used to automatically detect mean shifts in dynamic correlation levels and volatility shifts in precious metal returns. In a next step, the consistent Dynamic Conditional Correlation (cDCC) from Aielli

(2013) is used to detect relationships between precious metals price fluctuations; the cDCC build a parameter combining a GARCH like model and an innovation criterion into the traditional DCC model of Engle (2002). The results show that while the turbulent year 2008 has no effect on volatility levels of silver, silver is found to have a volatility shift contagion effect on platinum and palladium.

Papadamou and Markopoulos (2014) look at volatility transmission between currency exchange rates and precious metals using hourly data between the 1st of January 2010 and the 27th of March 2012. In a first step, a Quandt-Andrews test for parameter instability (Quandt (1960); Andrews (1993, 2003)) indicates no structural breaks for the time series; an unrestricted BEKK-GARCH model proposed by Engle and Kroner (1995) is used to obtain information about the conditional covariance and explain volatility transmissions amongst the series. The BEKK-GARCH model allows the researcher to define both the conditional variance and covariance of the time series in order to capture possible asymmetric effects. Evidence point towards volatility transmission from gold, the EUR/USD exchange rate and the GBP/USD exchange rate to silver.

Another paper to look at volatility transmission between exchange rates and precious metals is that of Antonakakis and Kizys (2015) taking weekly data between the 6th of January 1987 and the 22nd of July 2014 into account. The methodology applied is that of Diebold and Yilmaz (2009, 2012), using a generalised VAR framework in which Forecast Error Variance Decomposition (FEVD) is invariant to the order of the variables. Silver is a net transmitter to the FEVD of other variables. On average, silver returns contributes to the FEVD of other variables by 52.78% and receives an average of 50.90% from other variables making silver a net transmitter of return spillovers. A similar picture is observed for volatility spillovers, where silver's contribution is at an average of 32.29% against an average reception of 31.38%. Even though the Global Financial crisis of 2008 weakened the role of silver returns as a net transmitter of shocks, it did not affect the net transmitting role of silver volatility.

Another paper to use the methodology from Diebold and Yilmaz (2009, 2012) is that of Batten et al. (2015) taking into account monthly futures closing prices for silver traded on the New York Mercantile Exchange between 1984 and 2012. The results contrast the findings of Antonakakis and Kizys (2015): on the one hand, silver is found to be a net transmitter of return spillovers because it contributes 52% to the return of gold, platinum and palladium and only receives 49%; but in contrary to the findings of Antonakakis and Kizys (2015), silver proves to be a net receiver of volatility spillovers, it contributes 29% to the volatility of the other three metals and receives 31%. A time-varying approach shows that the Global Financial Crisis of 2008 increased the importance of silver as a net recipient of spillovers - a finding somewhat in line with Antonakakis and Kizys (2015) who observe a weakening transmission of shocks for silver during that time.

Also looking at commodity prices on the COMEX, Bunnag (2015) examine volatility co-movements and spillovers for gold, silver, platinum and palladium using daily data between the 28th of October 2009 and the 21st of August 2014. The authors works with three Multivariate GARCH models (Kroner and Ng (1998)) amongst which the BEKK-GARCH model (Engle and Kroner (1995)) previously used by Papadamou and Markopoulos (2014). The other two models are the diagonal VECH model and the CCC model. The VECH approach was proposed by Bollerslev et al. (1988) and models every conditional variance and covariance as a function of lagged conditional variances and covariances in addition to lagged squared returns and cross-products of returns. The diagonal VECH model tends to be quite restrictive as it doesn't account for the interaction between the different conditional variances and covariances. Another drawback of the system is the necessity to impose nonlinear inequality restrictions because the model might otherwise not yield a final positive covariance matrix (Kraft and Engle (1983)). The Constant Conditional Correlations (CCC) model was proposed by Bollerslev (1990) and models the covariance matrix by estimating a conditional correlation matrix - therefore, the conditional correlation is assumed to be constant while the conditional variances are varying and follow a univariate GARCH process. Results point towards an important short run persistence of shocks on the dynamic conditional correlation for gold with silver, and towards an important long run persistence of shocks on the dynamic conditional correlation for palladium with silver.

Balcilar et al. (2015) study information transmission between oil, precious metals and the US Dollar/Euro exchange rate of daily spot prices between January 1987 and February 2012 using a methodology different to that of Sari et al. (2010) - the methodology from Balcilar et al. (2015) builds upon a Bayesian Markov-Switching Vector Error Correction (MS-VEC) model. Hamilton (1990) introduced a Markov switching approach that can deal with structural changes in time series models which was later applied to VEC models by Krolzig (1996, 2013). Markov switching series are generated by nonlinear dynamic properties (Fan and Yao (2003)) and are very efficient to apply on data that includes very influential events; multiple studies used MS models to analyse macroeconomic time series (Diebold et al. (1994); Kim and Yoo (1995); Filardo and Gordon (1998)) and stock returns (Pagan and Schwert (1990); Kim and Nelson (1998); Kim et al. (1998)). The VEC model used relies on time-varying parameters to reflect regime switching and allows for regime dependent conclusions for the impulse response analysis; MS-VEC models have been used by Krolzig et al. (2002), Francis and Owyang (2003) and Psaradakis et al. (2004) amongst others. Results show that during high volatility regimes, the impact of change of the gold price on silver is about 1.25%; against an impact of about 0.07% from silver on gold - results contrary to Sari et al. (2010) who found that the effects of changing gold and silver price returns mirror each other. Another noteworthy finding is the relatively important impact of an exchange rate shock on silver in both low and high volatility periods, of about 0.4% and 0.8% respectively.

Bosch and Pradkhan (2015) take a different approach to volatility and examines if the position of speculators can be used to predict returns and return volatility of precious metal futures. The authors work with futures contracts traded on the COMEX between the 13th of June 2006 and the 31st of December 2013 and use a Brunetti and Buyuksahin (2009) rolling procedure to create a continuous series. The data of trading positions is obtained from Disaggregated Commitments of Traders (DCOT) and COT reports, similar to Mutafoglu et al. (2012) who also work with Commitments of Traders reports. The relationship between the variables is detected through a Johansen (1991, 1995) and an Engle and Granger (1987) test followed by a Vector Error Correction Model (VECM) and a VAR Model to detect short-term impacts. Results point towards a herding behaviour of traders on the silver market between October 2007 and December 2013 and to trend-following behaviour of non-commercial traders, a finding in line with Mutafoglu et al. (2012).

A recent paper by Luo and Ye (2015) looks at predictability potential of the Shanghai silver futures market using the CBOE Silver ETF Volatility Index (VXSLV). The authors take into account 139,500 observations between the 10th of May 2012 and the 31st of December 2014 and differentiate between realised volatility and implied volatility. Realised volatility is defined as the root of the sum of squared returns (Andersen and Bollerslev (1998)) using a sampling frequency of 25 minutes (Zhang et al. (2005)). Previous literature showed that option-implied volatility contains information on future volatility (see Blair et al. (2001), Busch et al. (2011) and Benavides and Capistrán (2012) for examples), Luo and Ye (2015) believe this information can be found in options on the iShares silver trust fund. Following Gallant et al. (1992), Andersen (1996), Girma and Mougoué (2002) and Doran and Ronn (2005) amongst others, trading volume, open interest and a momentum variable are added in the empirical model. Results show that the VXSLV has significant power in predicting daily and weekly volatility forecasts. Furthermore, adding trading volume, open interest and momentum leads to a significant improvement in forecasting the volatility of the Shanghai silver futures market.

Kang et al. (2017) examine volatility spillover effects on six commodity futures markets, amongst which gold and silver, by relying on the DECO-GARCH model (Engle and Kelly (2012)) eliminating computational and presentational difficulties of high-dimension systems. Results obtained from weekly silver futures prices between the 4^{th} of January 2002 and the 28^{th} of July 2016 indicate that equicorrelation between commodity futures increased during the recent Global Financial Crisis , and remains high during periods of economic and financial turmoil. Across all commodities considered, evidence points towards bidirectional return and volatility spillovers that again increased during the crisis; from a more silver-specific point of view, it is found that silver is a net information transmitter to other commodity futures markets while further evidence points towards a flight-to-quality phenomenon for both gold and silver during the financial crisis.

3.2.4.2 Exchange Traded Products on Silver

The earlier mentioned iShares silver trust fund is part of the study of different other papers looking at the performance of silver Exchange Traded Funds (ETFs). One such example is Ivanov (2013) who study the relationship between silver ETFs, future prices and spot prices using 1 minute intradaily data between the 1^{st} of March 2009 and the 31^{st} of August 2009. The relationship between the variables is given via the Hasbrouck (1995, 2003) methodology representing a VECM as a vector moving average in order to extract the information share as a function of the impact of the change in standard deviation from one variable on another and the variance of each series itself. Silver ETFs largely dominate the information share in contrast to spot and futures prices with a value above 89%; interesting findings knowing that Ivanov (2013) claims that price discovery traditionally originates in futures data.

Taking an investment perspective on gold and silver ETFs, Naylor et al. (2011) look at daily returns of three silver ETFs traded on the NYSE between the 5^{th} of May 2006 and the 31^{st} of December 2009 to understand whether or not abnormal returns could have been realised via an investment in these securities. The methodology is based upon a CAPM and a Classic Linear Regression Model (CLRM). Building the CAPM, the market under consideration is the S&P 500 and the risk-free rate is given as the US 90 day Treasury bill rate. Results show that the behaviour of silver ETFs is very similar to that of physical silver returns, particularly, the price movements do not follow a random walk. An important conclusion for investors is that using a filter trading rule (Fama and Blume (1966); Solt and Swanson (1981)), abnormal returns can be generated through ETFs, hence outperforming a passive investor.

A few years later, Naylor et al. (2014) investigate the microstructure of silver investment funds and look more closely at tracking ability, tracking deviation, and the impact of market panics on ETF dynamics. Daily share prices, trading volumes and assets under management of the Silver Trust and the Physical Silver Shares fund starting from the 21^{st} of April 2006 and the 24^{th} of July 2009 respectively are taken into account, where the timeframe spans to December 2011. Following Frino and Gallagher (2001), results point towards an average daily tracking error of 112 basis points for silver ETFs which is maximised in times of high market volatility. Furthermore, following Baur (2013b) a monthly February effect is found, in which returns of silver and silver ETFs are positively significant.

Similar to Luo and Ye (2015) who look at the iShares Silver Trust, but looking more specifically at market contagion during the 2010 Flash Crash, MacKenzie and Lucey (2013) use 4,695 one minute intraday observations between the 26^{th} of April 2010 and the 12^{th} of May 2010. Results point towards the vulnerability of the iShares Silver Trust to contagion, hence questioning the portfolio theory of Markowitz (1952) since historically uncorrelated assets can become susceptible to contagion in financial turmoils.

Lau et al. (2017) opens the ETF investigation to platinum and palladium and considers daily ETF prices for gold, silver, platinum, palladium, oil and global equity between the 19^{th} of June 2006 and the 18^{th} of June 2016. An E-GARCH procedure is used in order to ensure that the conditional variance is strictly positive and augmented with a frequency dynamics of connectedness procedure and a hidden semi-Markov model to measure the dynamics and intensity of return spillovers as well as to analyse the return characteristics of white precious metals. Results identify a strong relationship between gold and silver ETFs, but a relatively unimportant relationship between oil and white precious metals, where oil price movements spill over on silver and platinum but not on palladium. Regarding the relationship of white precious metal ETFs with the global equity ETF, results do point towards a cointegration relationship between equity and precious metals, but the effect of equity ETFs on white precious metals ETFs are relatively unimportant.

3.2.5 The Macroeconomic Determinants of the Price of Silver

Understanding which factors drive the price of silver is a key question when trying to make any prediction of future prices. The question has been addressed from different angles though the focus of previous research is very much on American macroeconomic indicators.

Very early on, Radetzki (1989) looks at the factors influencing the price of gold, silver and platinum in the medium and long term. The analysis is done by differentiating between driving forces of supply and driving forces of demand between 1972 and 1987. In contrary to gold, mine production is found to be a more important factor of supply and is also more evenly spread across countries. On the demand side, the importance from industry is dominating; namely from the photographic, the electrical and the jewellery industry. These findings lead Radetzki (1989) to conclude that two factors drive the price of silver: demand from industry and private inventories. On the other hand, oil prices and official inventories are not believed to be amongst the major driving forces of the silver price, even though they are important in determining the price of gold.

Christie-David et al. (2000) use 15 Minutes intraday data between the 3rd of January 1992 and the 29th of December 1995 to determine the effect of macroeconomic news announcements on the price of gold and silver futures. The authors work with the Brown and Forsythe (1974) modified Levene (1960) statistic, a methodology used by fellow researchers for similar works (see Lockwood and Linn (1990) and Ederington and Lee (1993)). Results show that silver future prices respond strongly to the announcement of capacity utilisation and the unemployment rate. Weak responses are found for the announcement of the CPI (a finding in line with Frankel and Hardouvelis (1985) who use daily data between the 7th of July 1980 and the 5th

of November 1982), hourly wages, business inventories, and construction spending. Announcements for durable goods orders, nonfarm payroll, the GDP, housing starts, merchandise trade deficit, leading indicators, the PPI, retail sales, industrial production, factory inventories, NAPM survey, new single home sales, personal income, personal spending, federal deficit, installment credit and consumer credit are not found to have an effect on the price of silver futures.

A few years later, Thorbecke and Zhang (2009) build upon two hypotheses in order to understand the effect of monetary policy surprises on commodity prices, amongst which silver. The first theory, by Romer and Romer (2000) states that federal funds rate increases might lead to an increase in inflation by revealing the Fed's private information about inflation. The second theory, by Gürkaynak et al. (2005) presents evidence that an increase of the federal funds rate leads to a decrease in long-term expected inflation. Thorbecke and Zhang (2009) consider the time period between 1974 and 1979 as well as between 1989 and 2006; the period between 1980 and 1989 is omitted because the Fed abandoned fund rate targeting in 1979, and only since the appointment of Alan Greenspan as Chairman in the late 1980s did the fund rate become the leading indicator of Fed policy (Jones (1994)). For the first period, the changes in the Fed's target for the federal funds rate are obtained from Cook and Hahn (1989) and augmented with an unrestricted ordinary least squares prediction equation to measure the anticipated change in monetary policy. The data for the second time window is obtained from Kuttner (2001). Regression results differ substantially for both time periods considered. Between 1974 and 1979, an increase in the federal funds rate led to an increase in the price of silver as a reaction to an increased demand in answer to anticipated inflation. Between 1989 and 2006 however, an increase in the federal funds rate led to a decrease in the price of silver in expectation of increasing short-term real term interest rates; a finding in line with Frankel (2008).

Focusing more on explaining the price volatility of gold, silver, platinum and palladium through macroeconomic determinants, Batten et al. (2010) work with monthly data between January 1986 and May 2006 and express the expected return of silver as a function of the information available at a previous time interval while estimating the conditional standard deviations with the methodology of Davidian and Carroll (1987). The following macroeconomic variables are considered in the analysis: the S&P 500 and it's dividend yield, the World excluding US stock index and it's dividend yield, the difference in interest rate yields between a US 10 years bond and a US 3 months Treasury bill, US M2 money supply, US industrial production, US inflation, the US Dollar index, and finally, US consumer confidence. The authors argue that these variables contribute to the effects of the business cycle, monetary environment and financial market sentiment on asset returns. Results show that neither monetary nor financial market variables are significant for silver price volatility. Instead, the volatility from the other precious metals markets has an effect on silver price volatility. These findings are in line with Sensoy (2013) concluding that the same macroeconomic factors do not jointly influence the price series of the four main precious metals.

In the same year, Roache and Rossi (2010) examine the effect of macroeconomic news announcements on the price of silver futures relying on daily data between the 1st of January 1997 and the 31st of December 2009 using a GARCH model that accounts for the US Dollar effect in order to assure that the sensitivity observed reflects the relationship between the commodity and the macroeconomic announcement and not between the commodity and other financial assets. Similar to Christie-David et al. (2000), the set of macroeconomic variables under observation is quite extensive but only the German IFO survey and the US Dollar index, both lagged by one day, have an effect on the price of silver over the entire time period considered. During the subperiod between 2002 and 2009, the CPI, the lagged ISM manufacturing survey, the lagged German IFO survey and the lagged US Dollar index are found to have an effect on the price of silver. Without accounting for the US Dollar effect, only the lagged Federal Open Market Committee (FOMC) interest rate decision and the lagged German IFO survey have an effect on the price of silver.

Similar to the work from Christie-David et al. (2000), Elder et al. (2012) work with intraday data between January 2002 and December 2008 to analyse the impact of US macroeconomic news announcements on the return, volatility and trading volume of silver futures. After cleaning the data by removing week-end announcements, the authors build a control sample of trading intervals free of announcements (a method proposed by Ederington and Lee (1993)) to assure the robustness of the results. Advance retail sales, changes in nonfarm payrolls, durable goods orders, business inventories, construction spending, and new home sales announcements have a statistically significant negative influence on silver futures prices; only trade balance announcements are positively associated with silver futures prices. These results are in contrast to the findings of Christie-David et al.

(2000) who observe an importance for the announcements of capacity utilisation, the unemployment rate and the CPI, all of which are not found to be statistically significant in influencing the price of silver futures in the work of Elder et al. (2012); indicating time-variation in the importance of macroeconomic announcements on the price of silver.

Apergis et al. (2014) look into the nature of spillovers between the prices of gold and silver, stock markets, and different macroeconomic variables of the G7 countries using monthly data between January 1981 and December 2010. The authors use the Zurich silver price in US Dollar per kilogram and consider a vast amount of variables reflecting industrial production, inflation, unemployment, exchange rates, commodity prices, interest rates, government debt, money supply, equity prices, market capitalisation, price/earnings ratios, and price to book ratios. Apergis et al. (2014) work with a Factor-Augmented Vector Autoregressive (FAVAR) approach proposed by Bernanke et al. (2005) and better suited then a standard VAR model when considering large amounts of variables. Results indicate that the price of silver responds negatively to positive shocks of industrial production and interest rates, furthermore, a higher inflation and unemployment rate have a negative impact on the price of silver. The authors explain this negative relationship with inflation by saying that a higher inflation rate deteriorates the macroeconomic environment while adding to macroeconomic uncertainty, hence turning investors away from precious metal markets. On the other hand, FAVAR test results indicate that both positive money supply shocks and positive stock market shocks lead to higher silver prices.

Adrangi et al. (2015) consider intraday data of silver futures prices traded on the COMEX between January 1999 and December 2008, as well as 18 macroeconomic variables believed to influence the behaviour of financial markets in the United States. The results are then divided into different categories: thirty-minute return responses, thirty-minute return responses taking into account the surprise element, standardised inventory holdings and return responses, and finally, local inventory clustering and return responses. Across all different categories, capacity utilisation and industrial production have a positive significant relationship with the price of silver, results somewhat in line with Christie-David et al. (2000), but contrary to Elder et al. (2012) who find no significant relationship between either capacity utilisation nor industrial production with silver futures prices.

Fernandez (2017) focuses her research on gold, silver and *Platinum-group* elements, amongst which platinum and palladium, and derives the differences in macroeconomic determinants for annual prices between 1930 and 2014 and for monthly and weekly prices between July 1992 and July 2016. On a yearly basis, a relationship between white precious metals prices and both global production and US consumption is identified. On a monthly basis, a strong relationship is identified between white precious metals and US industrial production as well as US monetary supply; the effects of South African mine production are also revealed. Finally, a very strong relationship is identified between the prices of gold and silver on a weekly basis during bullish environments, while platinum and palladium have a strong relationship with silver during bearish periods. A very interesting finding is the rise in importance of the price of white precious metals and consumer confidence and exchange rates in the United States, in line with the rise in importance of white precious metals as an investments asset.

Ciner (2017) takes a very specific approach and predicts the price of silver, platinum and palladium by looking at the level of the South African Rand in relying on daily data between the 7th of October 1996 and the 29th of July 2016. Results indicate a unilateral effect from exchange rates to the price of white precious metals but not the other way around, while the effect is strongest on palladium, than platinum and finally silver, in that order. Indeed, the ability of exchange rates movements of the Rand to forecast palladium prices remains significant under different model specifications, which it doesn't for both platinum and silver.

3.2.6 The Relationship between Silver and other Commodities

The previous section focused on macroeconomic variables influencing the price of silver and omitted the relationship amongst silver and other commodities, mainly between silver and other metals and between silver and oil.

3.2.6.1 The Relationship between Silver and other Metals

Early on, Koutsoyiannis (1983) considers daily commodity prices between the 29th of December 1979 and the 31st of March 1981 to erect a short-run pricing model for gold. Amongst different macroeconomic variables, the relationship between the price of gold and the price of silver is assessed through an OLS regression. Although Koutsoyiannis (1983) argues that silver, alongside stocks, offers an alternative speculative investment opportunity to gold, the low value of elasticity of the price of gold to changes in the price of silver ($\eta = 0.08$) suggests that gold and silver are not very close substitutes.

Looking at the alleged characteristic of silver to be considered a substitute of gold, Ma (1985) tests if a trading strategy can be derived based on changes in the equilibrium parity ratio between gold and silver. Lang (1983) states that an investor should buy gold and sell silver if actual parity drops below the equilibrium level, and sell gold to buy silver when the parity is above the equilibrium level. Ma (1985) looks at daily gold and silver prices between January 1974 and October 1984 and tests whether a technical trading rule would generate profits based on gold/silver ratio spreads. A CAPM framework indicates that substantial excess profits can be generated before transaction costs if the investor executes trades on a frequent basis; underlining the very fast adjustment of the market to a new equilibrium parity.

A few years later, Ma and Soenen (1988) extend the findings of Ma (1985) and find that the parity between gold and silver is also observed for futures prices. Daily closing prices from January 1976 to October 1986 fitted in an autoregressive model are used to investigate the parity between both securities. The results suggest that a profitable trading strategy can be derived; where a leveraged position linked to lower transactions costs in the futures market proves to be more profitable than executing the given strategy on the spot market.

In an attempt to understand the relationship between gold and silver prices, Chan and Mountain (1988) consider the price of gold and silver traded in Toronto and the Canadian bank rate using weekly basis between March 1980 and February 1983 and test for causality amongst these variables using the approach proposed by Granger (1969). The optimal lag structure for each variable in the equation is determined by the Schwarz Bayesian Information Criterion (SBIC) (Schwarz (1978)), and by Akaike's minimum Final Prediction Error (FPE) criterion (Akaike (1969, 1970)). In the later method, a major advantage is in the choice of the significance level based on minimising the mean squared prediction error (Hsiao (1979, 1981)). Results point towards a feedback causal relationship between the price of gold and the price of silver. Furthermore, interest rates exert a causal influence on the price of silver while this relationship is not reciprocal: the price of silver does not determine changes in interest rates.

Wahab et al. (1994) build upon the Efficient Market Hypothesis of Fama (1970) and argue that given risk neutral investors and perfect markets, the EMH implies that futures prices, or a linear combination of them, should evolve as a simple martingale process over time. Arguing that market participants could employ two sets of information: the first one contained in the price history of each time series, and the second one contained in the price history of other relevant time series, Wahab et al. (1994) examine the relationship between gold and silver prices with a focus on intertemporal behaviour and the predictability of the gold-silver spread. The authors work with daily cash and futures prices between January 1982 and July 1992 and use a variety of classical econometric approaches such as the Dickey and Fuller (1979) procedure to test for unit roots, the Engle and Granger (1987) test of cointegration, and an Autoregressive Integrated Moving Average (ARIMA) model to predict the behaviour of the time series. The main contribution of the paper is the construction of a moving average model generating trading signals based on the unconstrained spreads between gold and silver prices. Though adopting the proposed trading strategy generates profits, these profits come at high risk. Further results point towards a very high correlation between gold-silver cash and futures prices.

A few years later, Escribano and Granger (1998) study the long-run relationship between gold and silver prices by focusing on three aspects in particular. First, the authors look at the effects of the 1979 silver price bubble on the cointegration relationship, in a second step, Escribano and Granger (1998) test whether or not including error-correction terms in a non-linear way performs better than an out-of-sample random walk model, and finally, the authors focus on the existence of a simultaneous relationship between the rates of return of gold and silver. Escribano and Granger (1998) use monthly data from 1971 to 1990 and address each individual question using a different econometric approach. Evidence is found for a long-run cointegration relationship between the two precious metals which is especially strong during the silver price bubble from September 1979 to March 1980. Furthermore, a battery of testing procedures indicates that non-linear forecasting models for silver perform better than random walk processes; however, this is only the case for in-sample analyses, as the predictive power vanishes for the out-of-sample period. Finally, a linear regression indicates a strong simultaneous relationship between gold and silver returns across the entire time period considered.

Ciner (2001) looks at gold and silver futures prices and examines the long run relationship between those. The author works with daily data between 1992 and 1998 and a Johansen (1991, 1995) cointegration test to show that no cointegration relationship existed in that given time period; findings consistent with Escribano and Granger (1998) who show that the stable relationship between gold and silver broke in the 1990s. Ciner (2001) also concludes that a trading strategy based on the gold-silver parity would not be profitable, a finding in direct contradiction with Ma (1985), Ma and Soenen (1988), and Wahab et al. (1994). An interesting final comment of Ciner (2001) based on his findings of no cointegration between gold and silver, is that of advising market participants not to consider gold and silver as substitutes when hedging against similar risks.

Lucey and Tully (2006b) review the findings of Ciner (2001) and extend the data period considered. Lucey and Tully (2006b) take into account weekly COMEX prices between January 1978 and November 2002. In contrary to Ciner (2001), Lucey and Tully (2006b) examine cointegration between the time series through a dynamic cointegration analysis proposed by Hansen and Johansen (1992), involving estimations of the Johansen (1988a) and the Johansen and Juselius (1990) cointegration approaches over various time windows. A visual application of the Hansen and Johansen (1992) method (used before by Rangvid (2001) for example) shows that the stable relationship between gold and silver prevails over time. Concidering that results indicate no cointegration between gold and silver from 1992 to 1998, Lucey and Tully (2006b) concludes that the findings of Ciner (2001) might only be driven by the choice of the time period considered and should not be regarded as empirical.

Gerolimetto et al. (2006) extent the time window considered by studying monthly gold and silver prices between 1971 and 2004. In order to detect cointegration properties, Gerolimetto et al. (2006) apply a Relevant Vector Machine (RVM) proposed by Tipping (2001), which relies on a Bayesian framework in order to derive rigorous prediction models. A major advantage of the RVM is that density functions over the model weights depend on parameters which are endogenously estimated from the data; this methodology enables Gerolimetto et al. (2006) to contrast previous findings and claim that a dynamic long run relationship between gold and silver exists.

Hammoudeh et al. (2010) look at conditional volatility, correlation dependency and interdependency for all four major precious metals and the US Dollar/Euro exchange rate using daily spot prices between the 4th of January 1999 and the 5th of

November 2007. A VARMA-GARCH model (Ling and McAleer (2003)) and a Multivariate Dynamic Conditional Correlation GARCH (DCC-MGARCH) model are used to detect coherences between the metals. Results point towards high conditional correlation between gold and silver; furthermore, silver exhibits strong sensitivity to exchange rate volatility during monetary policy regimes, underpinning gold's safe haven characteristic.

Looking again at volatility and correlation dynamics of gold, silver, platinum and palladium, Hammoudeh et al. (2011) base their methodology on the VaR approach using daily spot prices between the 4th of January 1995 and the 12th of November 2009 - hence including the financial crisis. The VaR specifications are similar to those of Hammoudeh et al. (2013) and fitted for daily data following Christoffersen (2009). Relevant results for portfolio managers show that a VaR GARCH-t specification delivers the best prediction results even though they are linked to lower profitability. Regarding silver specifically, the high VaR values observed in 2006 are linked to the launch of the first silver ETF on the American Stock Exchange.

Chng and Foster (2012) argue that gold is demanded by investors during good economic times as a safe haven (see Baur and Lucey (2010) and Baur and McDermott (2010)), but that during good economic times, firms stockpile silver, platinum and palladium for industrial consumption. Using daily data between January 1996 and July 2010, Chng and Foster (2012) test whether or not the implied convenience yield of precious metals affect the return, volatility and volume dynamics of other precious metals. The authors derive time series for the implied convenience yield of a precious metal taking into account both the spot and futures prices of the metal, as well as the sum of the risk-free rate (Bank of England official bank rate) and the percentage storage costs of the metal (0.43% annual fee charged by ETF Securities Ltd. on their Physical Precious Metal Basket ETF). A VAR model augmented with a sub-sample analysis point towards significant cross-metal interactions amongst convenience yields of precious metals, though gold and silver seem to be more influential depending on the state of the economy. Silver is more convenient to hold during positive economic times since it carries the heaviest industrial usage. Regarding the relationship between gold and silver, it seems that a long-run equilibrium relation is only observed during normal economic times.

Batten et al. (2013) consider daily gold and silver futures prices between January 1999 and December 2005 to investigate the dynamics of the bivariate relationship between both metals. Looking at spread returns, Batten et al. (2013) detect long-term dependence by using statistical techniques proposed by Hurst (1951, 1956). The Rescaled Adjusted Range (RAR) technique of Hurst is flexible in setting the sample period considered and provides a comprehensive understanding of the direction of the equilibrium reverting process. Results indicate a dominant positive dependence between the spread returns, even though negative dependence is also observed during the sample. An important result for investors is the proposed trading strategy derived from Hurst coefficients which indicate when to buy or sell and out-perform both a simple buy-and-hold strategy and a moving-average strategy.

Building upon the results of Escribano and Granger (1998), Baur and Tran (2014) enlarge the sample considered and look at monthly gold and silver prices between January 1970 and July 2011 in order to analyse their potential long-run relationship. Closely following the method proposed by Escribano and Granger (1998), results show that the price of gold drives the price of silver and therefore the long-run relationship. Time-variation is observed in the relationship, namely the disconnection of gold and silver prices in the 1990s.

In light of the growing amount of papers studying time-variation in the cointegration relationship between gold and silver, Pierdzioch et al. (2015) propose to use a different methodology to gain further insights into the gold-silver relationship. Considering monthly data between January 1970 and May 2015, Pierdzioch et al. (2015) work with a Residual Augmented Least Squares (RALS) test for noncointegration. The RALS is a correction of the standard test for noncointegration proposed by Dickey and Fuller (1979) and revises the equation with new regressors accounting for skewness and excess kurtosis (Im and Schmidt (2008)). Pierdzioch et al. (2015) stay in line with previous studies by computing the RALS test following the specifications of Taylor (1998). Even though gold and silver are cointegrated during major parts of the whole sample, evidence for noncointegration is found in the mid 1990s and the early 2000s.

3.2.6.2 The Relationship between Silver and Oil

Even though oil is often considered to be a proxy for industrial production and could hence reflect the industrial usage of silver as an industrial commodity, the research on the relationship between oil and silver is not extensive. Surprisingly, some papers studying the relationship between silver and *black gold* do it within a focus on a specific economy and a specific currency.

An example of such a paper is that of Soytas et al. (2009) who base their research on the Turkish economy. The authors examine both short-run and long-run information transmission between the Brent oil price, the Turkish interest rate, the Turkish Lira/US Dollar exchange rate, and finally, the domestic spot price of gold and silver. Soytas et al. (2009) consider daily data between the 2^{nd} of March 2003 and the 1^{st} of March 2007 and examine the long-run relationship between the series through a Toda-Yamamoto procedure (Toda and Yamamoto (1995)) allowing to run a VAR model in levels, therefore avoiding information loss from differencing. Also, the Toda-Yamamoto procedure does not require testing the congregation properties of the system, hence avoiding biases associated with unit roots and cointegration tests (Zapata and Rambaldi (1997) and Clarke and Mirza (2006)). Short-run dynamics are identified using generalised impulse responses in a VAR model, as proposed by Koop et al. (1996) and Pesaran and Shin (1998) who overcome the orthogonality problem of traditional VAR models, therefore making the ordering of the variables irrelevant. Results show that Turkish interest rates Granger cause silver prices and that there is evidence for unidirectional causality from gold to silver in the long-run. Concerning oil, evidence shows that price shocks have a negative impact on the price of silver, pointing to silvers' industrial importance in Turkey. On the other hand, the silver spot price quoted on the Istanbul Gold Exchange (IGE) is found to have a significant positive impact on the Brent oil price in the short-run.

A few years later, Bhar and Hammoudeh (2011) take a more global approach and look at the relationship between WTI oil, copper, gold, silver, short-run US interest rates, a trade-weighted average index of the value of the US dollar, and finally, the MSCI world equity index. Bhar and Hammoudeh (2011) fit weekly data between the 2^{nd} of January 1990 and the 1^{st} of May 2006 into a regime-dependent VAR model based on the Markov Switching (MS) configurations outlined by Hamilton (1989, 1994) and Kim and Nelson (1999) (a similar approach can be found in Alexander and Kaeck (2008) on the Credit Default Swap (CDS) market). Results relying on different model specifications show no evidence for a significant relationship between oil prices and silver. However, a positive relationship between silver and the US Dollar exchange rate is observed, indicating that silver can't be considered a hedge against a depreciating dollar.

Jain and Ghosh (2013) conduct an analysis similar to that of Soytas et al. (2009)

and focus their endeavours on India by looking at cointegration relationships and Granger causality between daily prices of Brent oil, gold, silver, platinum, and the Indian Rupee/US Dollar exchange rate between the 2nd of January 2009 and the 30th of December 2011. Testing for cointegration is done via an Auto Regressive Distributed Lags (ARDL) approach relying on appropriate critical F values for large samples (Pesaran and Shin (1998); Pesaran et al. (2001)), while a Toda and Yamamoto (1995) version of Granger causality identifies causation amongst the variables. Finally, a Generalised Forecast Error Variance Decomposition (GFEVD) analysis measures how a change in one variable affects the value of another variable. Evidence points towards a strong relationship between gold and silver - also in explaining each others error variances. Granger causality is observed between oil and three variables (exchange rates, gold and silver), implying that the silver price has predictive powers for international oil prices.

Charlot and Marimoutou (2014) work with daily time series between the 3rd of January 2005 and the 19th of October 2012 in order to examine the volatility and correlation amongst WTI oil, gold, silver, platinum, the Euro/US Dollar exchange rate and the S&P 500. The methodology used is an extension of the Hidden Markov Model (HMM) (see Baum and Petrie (1966); Baum and Eagon (1966); Baum et al. (1970) and Rabiner (1989)) and provides a fully probabilistic decision tree. Charlot and Marimoutou (2014) work with the Hidden Markov Decision Tree (HMDT) proposed by Jordan et al. (1997), that reconciles the Factorial Hidden Markov Model (FHMM) of Ghanhramani and Jordan (1997) and the Coupled Hidden Markov Model (CHMM) of Brand (1997) in order to maximise the amount of possible interactions of the variables. Decision tree results indicate that the volatility of silver responds strongly to economic shocks and is linked to specific events such as the Financial Crisis of 2008. Further results indicate a low correlation between oil and silver (0.41) that increased since 2009 and a high correlation between silver and platinum/gold (0.74 and 0.83 respectively).

Focusing more on the effect that Brent oil price shocks have on the volatility of precious metal prices, Behmiri and Manera (2015) consider daily spot prices of aluminum, copper, lead, nickel, tin, zinc, gold, silver, platinum and palladium between July 1993 and January 2014. Volatility persistence is revealed through a GARCH model allowing to detect regime dependency of price changes and rate of returns (Bollerslev (1987)) and augmented with the Glosten-Jagannathan-Runkle GARCH (GJR-GARCH) model (Glosten et al. (1993)) to analyse asymmetry and leverage effects in the GARCH process. Outliers in the GARCH model are detected via the Doornik and Ooms (2005, 2008) procedure inspired by Chen and Liu (1993) allowing to distinguish between outliers affecting the levels of the series and outliers affecting future conditional variances (a discussion on the different types of outliers and their effects on GARCH models can be found in Sakata and White (1998) and in Hotta and Tsay (2012)). This approach provides Behmiri and Manera (2015) with two sets of data: the original time series and a data set corrected for outliers. Finally, the Mork (1989) method developed for oil prices is used to differentiate between positive and negative shocks. Empirical results indicate that negative oil price shocks do not affect the volatility of silver, while positive oil price shocks decrease the volatility of silver prices. However, considering the data set corrected for outliers, only the positive oil price shocks remain significant in affecting silver price volatility. Behmiri and Manera (2015) give two possible reasons for the fact that negative oil price shocks become insignificant when the series are corrected for outliers: first, detected outliers in the silver market are due to shocks in the oil market, and second, the volatility of both the silver and the oil price are likely to be affected by the same events.

Similar to Jain and Ghosh (2013), the paper by Bildirici and Türkmen (2015a) analyses cointegration and causality relationship between oil, gold, silver and copper using monthly data between January 1973 and November 2012. The oil price considered is the equally weighted average of the spot price of Brent, Dubai and West Texas Intermediate (WTI) oil. A Brock et al. (1996) test indicates nonlinearity in the series, hence leading Bildirici and Türkmen (2015a) to perform a nonlinear ARDL test of cointegration: an asymmetric extension of the linear ARDL approach proposed by Pesaran et al. (2001) (examples of nonlinear ARDL tests and their applications can be found in Katrakilidis and Trachanas (2012) and Bildirici and Türkmen (2015b)). Regarding causality amongst the variables, Bildirici and Türkmen (2015a) argue that a standard linear Granger approach might not be appropriate due to the nonlinear nature of the series. The authors therefore propose to work with a Hiemstra and Jones (1994) modified Baek and Brock (1992) test to reveal information about the positive and negative nature of shocks, and a Kyrtsou and Labys (2006) test to detect response asymmetry from one variable to another. Results indicate a positive long-run relationship between oil and silver, where a 1% increase in the price of oil results in a 1.33% increase in the price of silver. However, the different causality tests indicate conflicting results about the relationship between oil and silver; Bildirici and Türkmen (2015a) therefore advice the reader to be cautious when interpreting these results.

3.2.7 Research on Silver Futures

Considering the relatively small amount of research that focuses on the macroeconomic drivers of silver, it is somehow surprising that the amount of papers looking at silver futures is so important. The fact that silver futures have a longer history than gold futures (Chang et al. (1990)) points towards the importance of industrial demand for silver, and hence the need for producers to hedge pricing risks.

An early paper by French (1983) focuses on the relationship between silver futures and forward prices. Arguing that both contracts are similar in nature, French (1983) examines the relationship between both types of contracts from 1968 to 1980 relying upon different pricing models assuming neither taxes nor transaction costs. In the light that the daily return from a futures contract is transferred between the traders on a daily basis, whereas the return from holding a forward contracts accumulates until maturity, the first two models used (proposed by French (1982) and Cox et al. (1981)) presume that the price for a futures contract is equal to the present value of the product of the underlying's maturity spot price and the return from rolling over one-day bonds, while the price of a forward contract is related to the interest rate of a long-term bond with comparable maturity date. The last model used, proposed by Richard and Sundaresan (1981), emphasises that the marginal utility of a sum of dollars today must be equal to the expected marginal utility of that same sum of dollars in the future as an investor could otherwise increase his life-time expected utility with a portfolio of bonds and forward contracts to transfer money across time. Even though the models used are not able to explain but only to detect intra-sample variations in futures-forward prices differences, the results emphasise that the two type of contracts are to be considered different assets for the case of silver.

In the same year, Garbade and Silber (1983) study the extend at which hedgers use futures contracts to shift the price risk of silver. Building upon the assumption that the futures price for a commodity should be equal to the cash price plus a premium reflecting the deferred payment on the futures contract (see McCallum (1977), McCormick (1979) and Phaup (1981) for a similar assumption on different futures markets), Garbade and Silber (1983) develop a pricing model that is able to assess whether or not futures contracts are good substitutes for a cash market position and detect in which market price changes first appear. Results for silver indicate that the elasticity of supply is quite high, the authors argue that this is due to the low storage costs for silver and the ability to sell short silver very easily. Another interesting finding indicates that in contrary to gold, where the spot price depends largely on the futures price, price discovery for silver is more evenly distributed amongst the spot and the futures price.

Aggarwal and Sundararaghavan (1987) work with silver futures contracts between 1980 and 1984 and test for the efficiency of the silver futures market in regard to the information contained in the time series. Markov chain models are used to study price changes in the series (a method previously used by Fielitz and Bhargava (1973) and Fielitz (1975)) and derive upward and downward cycles that could possibly be exploited by traders. Results point towards a change in behaviour of silver prices since 1981 due to the Hunt brothers investments. Considering the cycles pointed out by the methodology applied, traders could have earned excess returns, pointing to weak-form inefficiency in the silver futures market between 1981 and 1983.

Chang et al. (1990) build upon the theory of normal backwardation (Keynes (1930)) stating that due to the volatility of futures prices, long traders must be rewarded with a risk premium for carrying the risk of investing in futures contracts. The authors test this hypothesis by applying the CAPM model of Sharpe (1964) and Lintner (1965) and estimate if investing in silver futures between January 1964 and December 1983 was linked to carrying systematic risk and whether or not carrying such risk was rewarded. The Dow Jones Cash Commodity Index is used as a proxy for the market portfolio and the risk-free rate used is the end-of-period return on one-month Treasury-bills. Results show that investing in silver futures yielded higher returns than investing in futures contracts of other metals, but was also linked to higher volatility. Furthermore, silver outperformed the stock market over the period observed and has a β close to 1 (a finding later supported by Cochran et al. (2012)). Chang et al. (1990) conclude by finding that based on standard deviations of returns, silver futures are riskier than common stocks but earn less return per risk unit than equity - therefore strongly challenging the attractiveness of silver futures as an investment asset.

Looking again at risk premium in the silver futures market, Kocagil and Topyan (1997) follow Bessembinder (1992) on currency and agricultural futures and analyse the possible relationship between risk premium, futures trading and the S&P 500 by Kalman filtering the time series (Kalman (1960)). A theoretical model is used to illustrate the equilibrium relationship between cash and futures prices and fitted with daily data between 1990 and 1994. Evidence uncovers a positive relationship between risk premium and daily futures trading and to a negative relationship with the S&P 500, pointing towards silver's role as an inflation hedge (Kocagil and Topyan (1997)).

Ntungo and Boyd (1998) consider weekly silver futures and try to understand whether or not neural network models (Kaastra and Boyd (1995)) outperform traditional ARIMA models in predicting silver prices. Neural network procedures were designed based on the structure of the brain and consists of a collection of input units and processing units receiving the data. In contrary to other forecasting procedures, neural networks compare the results of their analysis with the desired output, adding a *machine learning* element to the procedure (Hecht-Nielsen (1990)). While the predictive models generated positive returns, neural network results for silver indicate that the more complex models did not perform better than the traditional ARIMA model considered; an explanation provided by the authors is that the data considered might not have been highly nonlinear.

In a more technical paper, Longin (1999) derives optimal margin levels required in silver futures contracts in the light that it should be high enough to protect brokers against insolvent customers, but also low enough to minimise the additional costs for investors and hence keep the market attractive. Longin (1999) works with observations derived from the COMEX between the 3rd of January 1975 and the 30th of June 1994 and develops a new method for setting optimal margin levels. Considering extreme price movements, the author takes an atypical approach and examines price changes observed over a given period rather than general price changes as such. Results for long investors show that optimal margins are smaller than the historically observed margin requirements for a probability of margin violation above 10%, a similar observation is found for short investors where the optimal margin requirement is smaller than the historically observed margin requirements for a probability of margin violation above 25%. Results to handle with care, since correlation between different futures markets might require higher margin levels (Edwards and Neftci (1988)).

Varela (1999) examines the relationship between 15-, 30-, 45-, and 60-day silver futures and their realised cash and delivery settle prices. The period considered ranges from July 1971 to September 1995 and the results rely on a Phillips and Perron (1988) unit root test and an augmented Dickey and Fuller (1981) test. Silver series are found to be stationary in levels, making it impossible to predict cash prices with futures using cointegration and Error Correction Models (ECM). However, a simple regression model indicates that closest to delivery silver futures are a good predictor of the future cash price; similar results are observed with gold futures, pointing to the parity between gold and silver cash (Ma (1985)) and futures (Ma and Soenen (1988)) prices.

Looking at a smaller time window between the 27th of December 1993 and the 30th of December 1995, Adrangi et al. (2000) collect 15 minutes intraday data of silver futures amounting to 11,979 observations. A bivariate GARCH model is used to examine the relationship between gold and silver futures and takes into account time varying volatility, volatility spillovers, and asymmetrical effects of spreads variation. Results point towards a bicausal relationship between gold and silver returns where the silver contracts carry the burden for spread convergence - Adrangi et al. (2000) believe that this is due to a faster reaction of the gold market to macroeconomic factors. Also noteworthy are the strong volatility spillovers from the gold to the silver market.

Another paper that looks at margin levels of silver futures is that of Chatrath et al. (2001a) using daily data between January 1986 and March 1995. Market volatility is measured with two different models: the first method follows Hoaglin et al. (1986) and Hoaglin and Iglewicz (1987) and is based on the dispersion of prices, while the second method is based on a GARCH model. The costs imposed by futures margins are estimated with a Two Stage Least Square (2SLS) model and differentiates between different types of traders. Chatrath et al. (2001a) open up the results section to a debate: if margins are considering opportunity costs, the trading activity will be affected by margin changes far from the contracts maturity date; if, however, margins impose only transaction costs, the trading activity will be affected by margin changes close to maturity. Empirical results for silver futures reveal that open interest and trading volume are relatively insensitive to margin changes far away from the maturity date - evidence not in harmony with the opportunity-cost hypothesis. Finally, regarding differences amongst traders, results show that small traders and speculators are more sensitive to margin changes than hedgers and spreaders.

In another paper from the same year, Chatrath et al. (2001b) consider daily prices of gold and silver futures between January 1975 and June 1995 and apply a battery of tests in order to understand the structure of both futures markets. In a first step, Chatrath et al. (2001b) test for correlation dimension following the specifications of Grassberger and Procaccia (1983), while estimating the test statistic following the proposition of Brock and Sayers (1988) and Frank and Stengos (1989) for limited data samples. In a second step, the authors build upon the correlation integral and use a Brock et al. (1996) test to detect nonlinearity and deterministic chaos in the time-series. Finally, a Kolmogorov entropy measures the degree at which the time series movements are predictable. Results reveal that the silver series has nonlinear dependencies, but that these are not consistent with chaos, therefore allowing for a certain degree of predictability.

Looking at the silver futures market in the United States and Japan in particular, Xu and Fung (2005) analyse daily data between November 1994 and March 2001 to detect across-market information flow amongst the contracts through a bivariate asymmetric ARMA-GARCH model. The methodology used is effective in detecting interactions between time series (Karolyi (1995) and Kearney (2000)) and augmented with a factor allowing for a long-run equilibrium error in the conditional mean equation (Engle and Granger (1987)) and a specification differentiating between positive and negative shocks of asymmetric impacts on volatility (Glosten et al. (1993)). Intraday information transmission is measured with a Seemingly Unrelated Regression (SUR) framework consisting of a multitude of regressions (Zellner (1962)). Results show that pricing transmission is strong between the markets and originates in the USA, pointing towards the leading role of the American market. Furthermore, SUR results point towards the speed at which new information is incorporated in the market - usually not longer than a day.

Erb and Harvey (2006) take a portfolio approach and analyse the benefits of silver futures for an investor. Data between December 1982 and May 2004 shows that silver has very low correlation with other major commodities except gold (0.66) and has had constant negative excess, spot, and roll returns. An interesting finding is the statistically significant negative relationship between silver and inflation, pointing to the inability of silver to serve as a hedge against rising prices. However, R^2 results seem to indicate that inflation is only able to explain a moderate portion of silver's return variation. Regarding silver's ability to serve as a hedging instrument against sovereign debt, Erb and Harvey (2006) apply the liability hedging technique proposed by Sharpe and Tint (1990) based on the risk tolerance-adjusted covariance of an asset's return and the return of a given liability. Credit for silver to be used as a hedge is given for Treasury Inflation Protected Securities (TIPS) and 10 Year Treasury Bonds between 1997 and 2004 but not for long term US debt between 1982 and 2004.

Believing that WTI oil futures contracts can help estimate the price of silver futures, Cortazar and Eterovic (2010) work with different daily in- and out-of-sample panels between 2004 and 2007 fitted into two different methodological approaches. The first one, a two-factor model proposed by Schwartz and Smith (2000), considers the long-term equilibrium spot price as well as short term deviations. However, Cortazar et al. (2008) argues that individual-commodity models make poor extrapolation for long maturities and propose multicommodity models as a solution; Cortazar and Eterovic (2010) therefore consider the price of copper futures and Brent futures in the model as well. Results show that due to silver's low correlation with WTI oil, a multicommodity model is recommended when using WTI futures prices to accurately predict the long-term price of silver futures.

Similar to Xu and Fung (2005) before them, Aruga and Managi (2011) focus on the relationship between the US and the Japanese silver futures market. Johansen test results indicate that the daily prices considered between January 2001 and June 2010 are cointegrated while a causality test indicates that American prices are dominant in driving the cointegration relationship. Furthermore, results indicate that the Law of One Price (LOP) did not hold over the entire period, hence allowing investors to realise profits through arbitrage.

Paschke and Prokopczuk (2012) consider daily data of crude oil, copper, gold and silver between the 1st of January 2006 and the 30st of June 2008 in order to understand whether or not continuous time pricing models can be used to reveal mispriced commodity futures prices. A set of different models reveals that excess returns can be realised based on the pricing errors present in the silver futures market - the evidence for gold is much weaker, which the authors blame on the much bigger size of the yellow precious metal market.

Considering the futures market of precious metals, Narayan et al. (2013) look at whether or not daily futures prices of gold, silver, platinum and oil predict the spot prices of their respective market. The window considered is the longest for gold and silver, ranging from 1980 to 2011, while it is somewhat shorter for platinum, starting in 1983. Results of linear and non-linear models show that futures returns only predict spot returns in the case of silver but not in the case of platinum, leading to a potential of profit realisation in the case of silver, but not in the case of platinum. However, time-variation results indicate that the profit potential was lowest during the Global Financial Crisis.

Cifarelli and Paladino (2015) analyse the behaviour of futures returns for five commodities amongst which silver, by relying on daily data between the 3rd of January 1990 and the 26st of January 2010. The motivation on the paper relies in differentiating between the two main agents on the futures market, hedgers and speculators, in order to understand how they affect the functioning of the individual commodity market. More specifically, Cifarelli and Paladino (2015) rely on a non-linear CCC-GARCH to model the reaction of hedgers and speculators to volatility shifts in the silver futures markets; furthermore, a two-state Markov-switching procedure highlights the impact of changes in the behaviour of futures markets. Finally, individual periods of high futures return volatility are associated to specific intensified trading activities from hedgers or speculators respectively. Results for silver indicate that the effect of hedgers on the futures market is far more important than the effect of speculation activities, while the behaviour of speculators is very much depending on the level of volatility in the silver futures market. It is also noteworthy to mention that the optimal spot-futures hedge ratio for silver increases during high volatility periods.

CHAPTER 4

Research Philosophy

Academic output is influenced by the philosophical assumptions and views of the individual researcher. This section introduces the philosophical stance relied on throughout this thesis and presents the *positivist* theory.

4.1 Positivism

According to Guba and Lincoln (1982), positivism implies observing phenomena objectively as the researcher and the researched are independent of one another. Indeed, positivism implies that the reality is composed of independent variables that can be studied separately, making this philosophical theory the most common one in financial economics research (O'Connor (2015)).

In line with the methodology formally introduced in Chapter 6, a positivist approach implies that this thesis was conducted and executed in such a way that undertaking the work itself was not linked to any direct interaction with the phenomena studied.

4.2 Positivist Research Output

According to Hume (2004), observed occurrences can be considered the result of a cause that precedes an outcome, or is simultaneous to it. This theory implies that knowledge is developed by observing objective facts, enabling the researcher to create generalisations about specific relationships (O'Connor (2015)).

In stark contrast to positivism, the subjectivist method believes that the values of the researcher will always somehow influence the research outcome; two independent positivists should however always come to the same conclusion as their research is independent of the outcome (Blumberg et al. (2008)).

4.3 Results Obtained Under the Positivist Paradigm

O'Connor (2015) divides the usefulness of positivist research results in three criteria: Reliability, Validity and Generalisability.

Reliability implies that the research methodology used assures consistency of the answer found - results obtained must be repeatable and yield the same answer. Furthermore a reliable test gives the most precise answer (Gujarati (2009)), so that if a test is undertaken twice, both observed measurements are identical disregarding when or where they were taken (Sekaran and Bougie (2009)).

Validity implies that inferences made from a test are appropriate, meaningful and useful. Internal validity questions the design and implementation of the testing procedure, while external validity requires the researcher to question the findings in order to understand whether the findings observed could be due to other explanatory variables omitted in the system.

Finally, generalisability implies that results obtained from the testing procedure on a sample can be generalised to make inferences about the entire population of the data.

CHAPTER 5

DATA

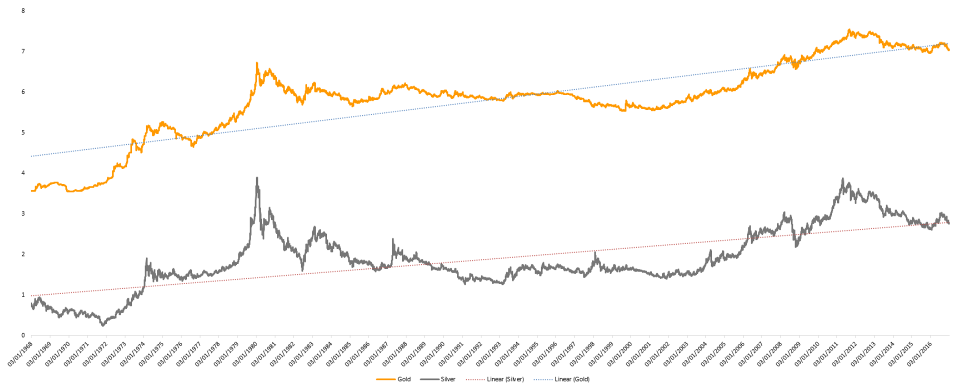
This chapter presents the data considered throughout thesis. Different time windows and types of data were considered across the three different research chapters and this section will shed some light on why a specific data source was considered. While the section starts by presenting the price pattern of gold and silver, later sections will directly link the data used to the individual chapters of this thesis.

5.1 The Price of Gold and Silver

The London Bullion Market Association (LBMA) is setting the official US Dollar price of gold since 1919 (Caminschi and Heaney (2013)), and also divides the price of silver in both an *AM Fixing* at 10:30am, considered the *official fixing*, and a *PM Fixing* at 3pm. The price is fixed according to five participants in the process and usually takes between 10 and 15 minutes (Caminschi and Heaney (2013)).

Figure 5.1 displays the daily changes in the natural logarithm of the US Dollar price of gold and silver between 1968 and 2016, revealing not only a trend between the series but also a certain degree of comovements.

Figure 5.1: Natural Logarithm of the Gold and Silver Price between 1968 and 2016



5.2 An Investigation into the Relationships Between Precious Metals and Inflation

Chapter 7 is analysing the relationship between gold and silver in three different countries: the United States of America, the United Kingdom of Great Britain and Northern Ireland, and Japan. The choice of countries is motivated in a variety of reasons. First, the UK and the USA are the leading centers for global gold trade. As discussed in Hauptfleisch et al. (2016) these two markets dominate global gold price setting. Japan provides an interesting counterpoint with the Tokyo exchange also operating as part of the global gold price making system (Xu and Fung (2005), Morales and Andreosso-O'Callaghan (2011)), but set in a country with very different inflation experiences than the UK and USA. Recent literature tends to look at a broader set of countries (Hoang et al. (2016) and Sharma (2016) for example); the decision to focus on a smaller set of countries is made in order to conduct a different type of analysis: an augmentation of the work of Hoang et al. (2016) by identifying breaks, periods and reasons for cointegration, and a different approach than Sharma (2016) by converting the Dollar price of gold into local currencies in order to study gold's potential as a hedge for national investors. The gold price considered is the US Dollar and pound sterling per Troy-ounce official monthly price issued by the London Bullion Market Association. Considering Japan, the US Dollar price of gold is converted into Yen. The official CPI and PPI rates for all the three countries are published by the respective authorities. While *official inflation* is often victim of criticism, it is the most appropriate and reliable measure for this endeavour. Concerning money supply, the most liquid measure available for all countries is taken into account. All time series are obtained from Thomson Reuters Datastream except for American Money Zero Maturity downloaded from the St. Louis FRED Database. All time series range from January 1974 to January 2014 apart from the UK CPI, where data is only available since January 1988.

5.3 Extreme Bounds Analyses of Gold and Silver

Building upon the literature outlined in a previous section, a large set of data is selected in understanding changes in the price of gold and silver. All data are sampled on a monthly frequency, expressed in natural logarithm, differentiated, and run from January 2003 to November 2015. Working with a weekly frequency is not possible due to data availability, also data before 2003 is not available for certain series, therefore obliging me to start in January 2003 in order to align all series.

Inflation: Inflation pressure is reflected in the model through a number of variables. Increases in consumer price inflation is approximated by the official CPI rates of the following countries: the United States of America, the United Kingdom of Great Britain and Northern Ireland, Japan and China. Also, in order to have an exposure to Europe, the Euro-zone CPI is built in. The Global CPI, as well as Agricultural and Raw Material price Index and the Food price index provide a good proxy for worldwide inflationary pressure (Baur (2013a)).

Money Supply: A further exposure to inflationary pressure is given via the amount of money in circulation in an economy. The following variables are built into the model: the US monetary base, United Kingdom M1 Money, Euro-zone M1 Money, Indian M1 Money, Japanese M1 Money and Chinese M1 Money. The variables for China and India are built in for two reasons: first, it gives an exposure to two rising economies, and second, both countries are significant sources of demand for gold.

Currencies: As highlighted in the literature review, the role played by currencies on precious metals cannot be neglected (Pukthuanthong and Roll (2011)). The following currencies are therefore examined: the US Dollar, the Swiss Franc, the Euro, the Yen, the Australian Dollar, the Canadian Dollar and the Pound Sterling.

Commodities: Investors are also advised (see Hillier et al. (2006) and Chng and Foster (2012)) to maintain exposure to precious metals as an asset class. Silver (and gold) are therefore included as possible explanatory variables as well as the US

Dollar price of palladium per Troy ounce and the US Dollar price of platinum per Troy ounce. The WTI Crude Oil price per barrel and the S&P GSCI Non-precious Metal Index are also built in to gain exposure to commodities essential to industry.

Equity Markets: An international focus is kept when considering stock market variables by looking at: the S&P 500, the MSCI World, the FTSE100, the Euro Stoxx 50, the Nikkei 225 and finally, the BSE and the SSE, Indias' and Chinas' national stock indices.

Uncertainty: Gold has not only a safe haven element, it is also often seen as a economic safe haven (McCown and Zimmerman (2006)), a similar reasoning might hold for silver. Economic uncertainty is identified via Economic Policy Uncertainty Indices for the United States of America, the European Union, the United Kingdom of Great Britain and Northern Ireland, India and China. The US Economic Recession Probability Index from the St. Louis FRED database is also built in to gain more exposure to the American economy.

Debt Markets: Four 10 Year Government Bond Indices are included, namely that of the United States, the United Kingdom, Japan and the European Economic and Monetary Union. The Federal Fund Rate of the United States is also considered in order to get a sense for short term interest rates.

Central Bank Reserves: Two variables illustrate the global reserve level of central banks: worldwide foreign exchange currency reserves and the global amount of gold held by central banks.

Real Estate: The price level of Real Estate in the United States of America is built into the system via the S&P Case-Shiller National Home Price Index.

5.4 A Panel Approach on the Physical Demand Drivers of Gold and Silver

The annual Gold Fields Mineral Services (GFMS) surveys published by Thomson Reuters provide an overview of the amount of gold supplied and demanded across various countries over the past calendar year. A similar publication exists for silver: the World Silver Survey computed by the Silver Institute and published by Thomson Reuters on an annual basis. Possible data noise exists in term of data collection from the Thomson Reuters economists, but is negligible.

Plotting the demand for gold and silver respectively (Figures 5.2 and 5.3) indicates a shift in the demand towards a rising importance of the investment side.

The graphs are also revealing that jewellery consumption is the most important factor in demand for physical gold, while industrial demand is the most important player on the silver market.

It should be noted that Figures 5.2 and 5.3 are computed taking into account the global demand for both precious metals. However, the regression results in Chapter 9 are computed considering only a subset of countries, which were chosen because of their relative importance on either the supply or the demand side of the gold and silver market respectively. For gold, these countries are: Australia, Canada, China, Egypt, Germany, India, Italy, Japan, Mexico, Russia, Saudi Arabia, South Korea, Switzerland, Thailand, Turkey, the United Kingdom of Great Britain and Northern Ireland, and finally, the United States of America.

The selection for silver is slightly different, where the following countries are considered: Australia, Canada, China, Germany, India, Italy, Japan, Mexico, Russia, South Korea, Thailand, the United Kingdom of Great Britain and Northern Ireland, and finally, the United States of America.

While the research of Starr and Tran (2008) is the only paper focused on the drivers of physical demand for gold, it is indeed the only source that can be used as a stepping stone when deciding what data to consider. In line with Starr and Tran (2008), the CPI, the GDP and the exchange rate to the US Dollar have been considered. The level of the national equity indices have also been considered, as well as both long term and short term interest rates in order to get a feeling for the state of the underlying economy. Here, the short term interest rates considered are the 3 Months Interbank Lending Rate, while 10 Years Government Bond Yields are used as a proxy for long term interest rates. The dataset is also augmented with narrow money supply as well as the Economic Uncertainty Index if such an index is available for the country considered.

Figure 5.2: Global Demand for Gold by Type in Tonnes

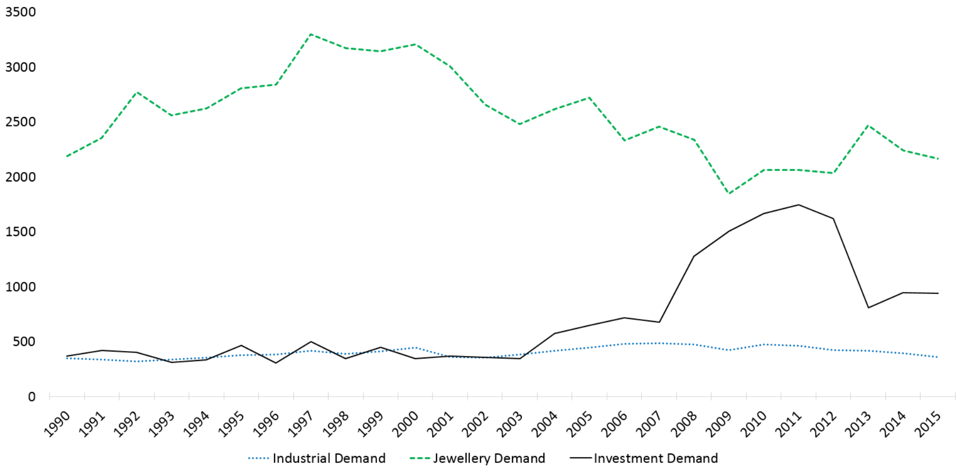
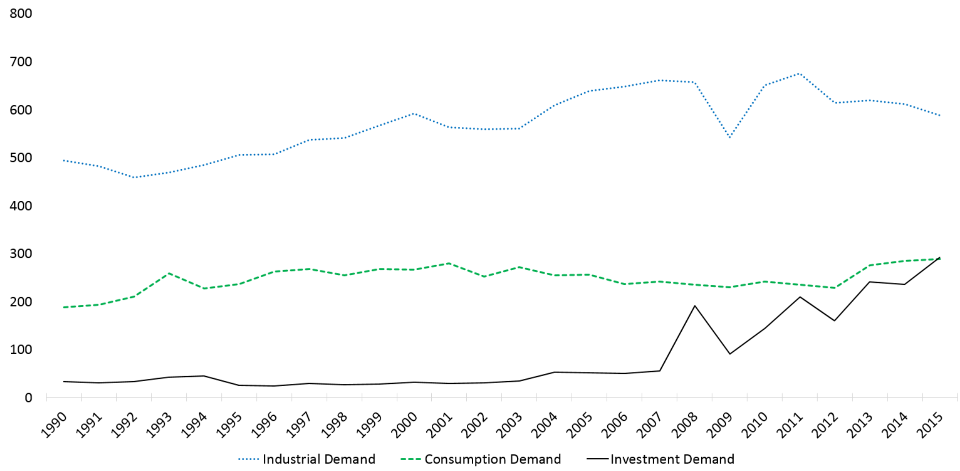


Figure 5.3: Global Demand for Silver by Type Mio. Oz



All data are annually and run from 1990 to 2015.

Chapter 6

Methodology

A thorough methodology assures that the analyses undertook are in line with the mathematical customs and rules of the field. This chapter presents and discusses all the econometric methodologies and procedure considered throughout the thesis, while defending why a choice for a specific procedure was made.

6.1 Model Selection

A key task in the process of undertaking empirical research, is the formulation of a good and clean econometric model in the light of a given dataset. In the classical sense, model selection should be undertook in the light of an optimal balance between goodness of fit and simplicity. While evaluating the simplicity of an econometric module is a straightforward endeavour, determining the goodness of fit of a model is slightly more cumbersome and is a much researched field in statistics and econometrics. While the goodness of fit of a model is generally speaking evaluated via some sort of likelihood ratio approach, some classic procedures stand out in the lag-order selection process for Vector Autoregression (VAR) models: the Log Likelihood (LL) procedure, the Likelihood Ratio (LR) test, the Akaike Final Prediction Error (FPE) criterion, the Akaike Information Criterion (AIC), the Schwarz Bayesian Information Criterion (SBIC), and finally, the Hannan-Quinn Information Criterion (HQIC).

Throughout section 6.1, consider the following VAR(p) model:

$$X_t = \phi + \Phi_1 x_{t-1} + ... + \Phi_p x_{t-p} + \varepsilon_t, \qquad t = 0, \pm 1, \pm 2, ..., \pm T \tag{6.1}$$

where $x_t = (x_{1t}, ..., x_{kt})'$ is a $(k*1)$ random vector, $\phi = (\phi_1, ..., \phi_k)'$ is a fixed $(k*1)$ vector of intercept terms that allows for the probability of a nonzero mean $E(x_t)$, and the Φ_i are fixed $(k*k)$ coefficient matrices (Lütkepohl (2005)). At last, $\varepsilon_t = (\varepsilon_{1t}, ..., \varepsilon_{kt})'$ is a k dimensional innovation process where $E(\varepsilon_t) = 0$, while $E(\varepsilon_t \varepsilon_t') = \sum_\varepsilon$, and $E(\varepsilon_t \varepsilon_s') = 0$ for every $s \neq t$.

The Log Likelihood procedure illustrates how much more likely the data is under a certain model in comparison to another. Hamilton (1994), expresses the Log Likelihood of Equation 6.1 as:

$$LL = \left(\frac{T}{2}\right)\left\{\ln\left(|\hat{\sum}^{-1}|\right) - k\ln(2\pi) - k\right\} \tag{6.2}$$

with T is the number of observations and k the number of equations. $\hat{\sum}$ is the maximum likelihood estimate of $E[\varepsilon_t \varepsilon_t']$ where ε_t is a $k*1$ dimensional vector of disturbance.

Knowing that $\ln\left(|\hat{\sum}^{-1}|\right) = \ln\left(|\hat{\sum}|\right)$, Equation 6.2 can be rewritten as:

$$LL = -\left(\frac{T}{2}\right)\left\{\ln\left(|\hat{\sum}|\right) + k\ln(2\pi) + k\right\} \tag{6.3}$$

The Likelihood Ratio (LR) measure is a special case of the Log Likelihood procedure augmented in order to be compared to a chosen set of critical values. The Likelihood Ratio is derived from the value of the Log Likelihood procedure with j lags (Stata Corporation (2013)):

$$LR = 2\{LL(j) - LL(j-1)\} \tag{6.4}$$

The Akaike Final Prediction Error (FPE) criterion relies on simulations in which the model is run on a different data set (Akaike (1969, 1970)). Lütkepohl (2005) presents the formula for the Final Prediction Error criterion as:

$$FPE = |\sum_\varepsilon| \left(\frac{T + kp + 1}{T - kp - 1}\right)^k \tag{6.5}$$

Equation 6.5 assumes that there is a constant in the model and that no variables are dropped because of collinearity issues. To tackle these restrictions, Akaikes' Final Prediction Error criterion is implemented as:

$$FPE = |\sum_\varepsilon| \left(\frac{T + \bar{m}}{T - \bar{m}}\right)^k \tag{6.6}$$

with $\bar{m}$ being the average number of parameters across the k equations, therefore accounting for variables dropped because of collinearity.

6.1.1 Akaike Information Criterion

The Akaike Information Criterion (AIC) measures the relative quality of a model for a given dataset by offering an estimate of the information lost in a certain model. Similar to the Likelihood Ratio test, the Akaike Information Criterion relies on the Log Likelihood procedure by rewarding the goodness of fit of a model while penalising possible overfitting of the model in the light that increasing the amount of parameters in a model almost always benefits the calculated goodness of fit of that given model.

The Akaike Information Criterion is defined as (Akaike (1974)):

$$AIC = -2\left(\frac{LL}{T}\right) + \frac{2t_p}{T} \tag{6.7}$$

where t_p represents the total amount of parameters in the model and LL is the Log Likehood.

6.1.2 Schwarz Bayesian Information Criterion

Philosophically, the Akaike Information Criterion selects the best approximation of the truth in the light that none of the models are true (Burnham and Anderson (2004)). On the contrary, the Schwarz Bayesian Information Criterion (SBIC) will select the true model if it is amongst the candidate models considered (Vrieze (2012)).

Mathematically, Schwarz (1978) assumes that the data distribution is in an exponential family (as proposed by Darmois (1935) and Koopman (1936)) and therefore points towards asymptotical issues around the Akaike Information Criterion in that it will not perform well for models with large numbers of observations. The author therefore proposes to multiply the dimension of Akaikes' model (Akaike (1974)) by *half the natural logarithm of the number of observations*:

$$SBIC = -2\left(\frac{LL}{T}\right) + \frac{\ln(T)}{T}t_p \tag{6.8}$$

where t_p represents the total amount of parameters in the model and LL is the Log Likehood.

Theoretically, the SBIC should perform better in low-dimensional model, while the AIC shouldn't be used for models with a large number of observations (Schwarz (1978)). In practice however, there is an ongoing debate about which of the two model selection criteria performs better under what circumstances. A good comparison of the two can be found in Yang (2005) and Aho et al. (2014) amongst other.

6.1.3 Hannan-Quinn Information Criterion

In the light of the two selection criteria proposed by Akaike (1974) and Schwarz (1978), the Hannan-Quinn Information Criterion (HQIC) reconciles the two approaches and proposes a middle ground between a consistent criterion and an asymptotically efficient criterion (Hannan and Quinn (1979)):

$$HQIC = -2\left(\frac{LL}{T}\right) + \frac{2\ln\{\ln(T)\}}{T} t_p \tag{6.9}$$

where t_p represents the total amount of parameters in the model and LL is the Log Likehood. Equation 6.9 suggests that consistency is maintained through a penalty term relying on the law of the iterated logarithms (Khintchine (1924)) while asymptotic efficiency is assured through the very slow growth of the term $\ln(\ln(T))$.

While certain researchers argue for the superiority of the Hannan-Quinn Information Criterion against other model selection criteria (Griffin and Stulz (2001)), the HQIC is not very prominent in comparison to the AIC and the SBIC.

6.2 Order of Integration

The order of integration of a time series reports the number of differences required to obtain a stationary process. Mathematically, the time series x with lag operator L and first difference $1-L$ is integrated of order d if $(1-L)^d x_t$ is a stationary process.

6.3 Unit Root Testing

Dickey and Fuller (1979) propose a procedure to detect the existence of a unit root in time series. Consider a basic model where:

$$x_t = \alpha + x_{t-1} + e_t \tag{6.10}$$

Note that e_t is a sequence of independent normal random variables with variance σ^2 and mean zero (Dickey and Fuller (1979)). The value taken by α specifies the model, in other words, when $\alpha = 0$, equation 6.10 is a random walk without drift.

Following Dickey and Fuller (1979), the model 6.10 can be fitted by Ordinary Least Squares (OLS):

$$x_t = \alpha + px_{t-1} + \delta_t + e_t \tag{6.11}$$

where p is a real number. In the case of a random walk without drift, where $\alpha = 0$ and $\delta = 0$, the time series x_t converges to a stationary series if $|p| < 1$ with $t \to \infty$ (Dickey and Fuller (1979)). In case $|p| > 1$, the time series x_t is not stationary and its variance grows exponentially as t increases. In this case, regression 6.11 is likely to be afflicted by serial correlation. The Augmented version of the Dickey-Fuller test controls for that by fitting the following model:

$$\Delta x_t = \alpha + px_{t-1} + \delta t + \zeta_1 \Delta x_{t-1} + \zeta_2 \Delta x_{t-2} + ... + \zeta_k \Delta x_{t-k} + \varepsilon_t \tag{6.12}$$

where k specifies the amount of lags and ζ_k are the coefficients of the zero-mean stationary regressors Δx_{t-k} (Hamilton (1994)). Four cases are specified by Dickey and Fuller (1979) and Dickey and Fuller (1981). Case one is a random walk without drift, where $\alpha = 0$ and $\delta = 0$. Case two includes a constant α in the regression, in other words: $\alpha \neq 0$ and $\delta = 0$. Case three includes a drift and allows for a constant (i.e. $\alpha \neq 0$), however, no time trend is included (i.e. $\delta = 0$). The fourth and final case is a random walk with a time trend, where $\delta \neq 0$ and $\alpha \neq 0$. A description and discussion of the four different cases can be found in Hamilton (1994).

The null hypothesis $H_0 : p = 1$ that the time series has a unit root, specified under the test statistic $Z_t = \hat{p}/\hat{\sigma}_p$ where $\hat{\sigma}_p$ is the standard error of $\hat{p}$, is tested against the alternative $H_1 : p < 1$ by means of the t-statistic that only follows a normal distribution in case three (MacKinnon (1994)). Critical values of the testing statistic can be found in Fuller (1996).

The Dickey-Fuller test, or a deviation of it, has found a wide field of application in financial research since its implementation. Examples can be found in Berck and Roberts (1996) on natural resource prices, in Bierens (1997) on the US price level, in Enders and Granger (1998) on interest rates, in Liew et al. (2004) on Asian real exchanges rates, and more recently, in Escobari and Jafarinejad (2016) on Real Estate Investment Trust (REIT) indices.

6.4 Cointegration of Time Series Variables

The concept of cointegration was first defined by Granger (1981) and Granger and Weiss (1983). Formally, for two variables to be cointegrated, both series must have an order of integration of one while a linear combination of the series is integrated of order zero. Engle and Granger (1987) take the matter further and propose a two step model to test for cointegration amongst two stationary series x_t and y_t for which a linear combination z_t must also be stationary. Mathematically:

$$x_t - \beta y_t = z_t \tag{6.13}$$

Since the value of z_t is unknown, the first step of the model is to estimate it through an OLS regression and check the estimated $\hat{z}_t$ series for stationarity. In a second step, Engle and Granger (1987) run regressions on the first differenced variables of equation 6.13 while including the lagged residuals $\hat{z}_{t-1}$ as a regressor.

Phillips and Ouliaris (1990) question this model and believe that the residual-based unit root tests applied to the estimated cointegrating residuals do not follow the Dickey and Fuller (1981) distribution suggested by Engle and Granger (1987) under the null hypothesis of no cointegration. Phillips and Ouliaris (1990) argue that due to the spurious regression phenomenon under the null hypothesis, the distribution of the residual based unit root tests depends on the number of deterministic trend terms and the amount of variables used when testing for cointegration. Phillips and Ouliaris (1990) therefore provide the researcher with upgraded $\hat{Z}_\alpha$ and $\hat{Z}_t$ or $\hat{P}_u$ and $\hat{P}_z$ distributions, depending on the relative size of the computed value of the statistic in comparison to the appropriate critical value, and conclude by saying that the $\hat{Z}_\alpha$ test has superior power properties when working with large samples.

6.4.1 Estimation of Cointegration Vectors in a Vector Autoregression Model

Unlike the method from Engle and Granger (1987), Johansen (1988a,b, 1991, 1995) proposes a procedure allowing for more than only one cointegrating relationship. However, this test is subject to asymptotic properties and is hence best suited for large samples because it might otherwise not deliver reliable results (Kitamura (1998)).

Johansen's approach merges the technique of *reduced rank reduction* (discussed by Anderson (1951), Velu et al. (1986), Ahn and Reinsel (1990), and Reinsel and Ahn (1992)) and the notion of *canonical analysis* considered in Box and Tiao (1977), Tso (1981), Pena and Box (1987), and Velu et al. (1987).

Following Johansen (1991, 1995), given a VAR model of I(1) X's

$$X_t = \Phi_1 X_{t-1} + ... + \Phi_p X_{t-p} + \varepsilon_t, \qquad t = 1, ..., T \tag{6.14}$$

there always exists an error correction representation of the former

$$\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \Pi X_{t-1} - \gamma_0 - \gamma_1 t + \varepsilon_t, \quad \varepsilon_t \sim N_k(0, \Omega) \quad t = 1, ..., T \tag{6.15}$$

where X_t is a $k * 1$ vector of the variables observed at time t. Ω and Φ_j are $k * k$ matrices with $j = 1, ..., p-1$. Furthermore, γ_0 and γ_1 are both the respective $k * 1$ vectors of the VECM's intercepts and linear trend coefficients. Finally, ε_t is a k dimensional white noise process.

Johansen (1995) tests for a long-run relationship using full information maximum likelihood cointegration analysis; if $\Pi = 0$, the variables are not cointegrated, but if $Rank(\Pi) = r, 0 < r < k$, there is evidence for cointegration.

In the latter case, one can decompose $\Pi = \alpha\beta'$ and hence rewrite equation 6.15 as:

$$\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \alpha(\beta' X_{t-1} - \beta_0 - \beta_1 t) - \gamma_0 - \gamma_1 t + \varepsilon_t, \tag{6.16}$$

where α is a $k * r$ matrix of coefficients, with r representing the cointegrating rank of the system; and β is a $k * r$ matrix of coefficients defining the r cointegrating vectors in the system. Being both $r * 1$ vectors, β_0 is a vector of intercepts for the cointegrating vectors, and β_1 is a vector of coefficients allowing for linear deterministic trends in the cointegrating vectors.

Johansen tests for cointegration using two likelihood ratio tests: the trace test and the maximum eigenvalue test. The tests are defined as:

$$J_{Trace} = -T \sum_{j=r+1}^{k} ln(1-\hat{\lambda}_j) \tag{6.17}$$

$$J_{Max.} = -T ln(1-\hat{\lambda}_{r+1}) \tag{6.18}$$

where T is the sample size, $\hat{\lambda}_j$ is the j^{th} largest canonical correlation and the following hypotheses are set up:

$$H_0\, Trace\, Test = r\, cointegrating\, vectors\, in\, the\, model$$
$$H_1\, Trace\, Test = k\, cointegrating\, vectors\, in\, the\, model$$
$$H_0\, Maximum\, Eigenvalue\, Test = r\, cointegrating\, vectors\, in\, the\, model$$
$$H_1\, Maximum\, Eigenvalue\, Test = r+1\, cointegrating\, vectors\, in\, the\, model$$

The asymptotic critical values can be found in Johansen and Juselius (1990), in general, the test statistics of neither of the two testing procedures follows a χ^2 distribution. Elliott (1998) points out a drawback of Johansen's procedure: the critical values used for the likelihood ratio tests are based on a pure unit-root assumption, so in case the variables in the system are near-unit-root processes, the critical values considered will not be correct any longer. However, this problem can be tackled with a Bonferroni type bounds procedure such as proposed in Cavanagh et al. (1995) for inference on the cointegrating vector and by Hjalmarsson and Österholm (2007) for residual-based tests of cointegration.

Lütkepohl et al. (2001) focus on the properties of the two likelihood ratio tests and find that especially in small sample scenarios, a Monte Carlo comparison provides evidence for a better performance of the trace test in comparison to the maximum likelihood ratio test. The trace test also shows evidence for superior performance in cases in which the process has two or more cointegrating relations than the amount specified under the null hypothesis. Lütkepohl et al. (2001) conclude by advising the researcher to execute both tests simultaneously or even to apply the trace test exclusively.

Johansen's procedure is very widely recognised and used in finance and economics. Examples can be found in Kasa (1992) looking at trends in stock markets, in Sephton and Larsen (1991) testing the market efficiency hypothesis on US Dollar exchange rates, in Masih and Masih (1996) on energy consumption, in Gilmore and

McManus (2002) looking at portfolio diversification, in Katircioglu (2009) on the effect of tourism on economic growth in Turkey, and finally, in Ferruz and Lample (2016) on the effect of excess mortgages on housing prices.

6.4.2 Autoregressive Distributed Lags

As mentioned earlier, a major drawback of Johansen's approach is the unreliability of results in small sample scenarios. Pesaran and Shin (1999) therefore propose the Auto Regressive Distributed Lags (ARDL) model in which $\{X_t\}_{t=1}^{\infty}$ stands for a $(k+1)$ vector random process, and the data-generating process for $\{X_t\}_{t=1}^{\infty}$ is a VAR model of order p (Pesaran et al. (2001)):

$$\Psi(L)(x_t - \mu - \gamma_t) = \varepsilon_t, \qquad t = 1, 2, ... \tag{6.19}$$

here, both μ and ε are unknown $(k+1)$ vectors of intercept and trend coefficients and Z is the lag operator. $\Psi(L) = I_{k+1} - \sum_{i=1}^{p} \Psi_i L^i$ is the lag polynomial of the $(k+1,\, k+1)$ matrix with $(\Psi_i)_{i=1}^{p}(k+1,\, k+1)$ matrices of unknown coefficient (see Harbo et al. (1998) and Pesaran et al. (2000)). Pesaran et al. (2001) re-expresses $\Psi(L)$ as $\Psi(L) \equiv -\Pi L + \Gamma(L)(1-L)$, a vector equilibrium correction model in which $\Pi \equiv -(I_{k+1} - \sum_{i=1}^{p} \Psi_i)$ defines the long-run multiplier matrix and $\Gamma(L) \equiv I_{k+1} - \sum_{i=1}^{p-1} \Gamma_i L^i$, $\Gamma_i = -\sum_{j=i+1} \Psi_j$, $i = 1, ..., p-1$ is defined as the short-run response matrix lag polynomial. In vector equilibrium correction model form, equation 6.19 can be rewritten as:

$$\Delta x_t = a_0 + a_1 t + \Pi x_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta x_{t-1} + \varepsilon_t, \qquad t = 1, 2, ... \tag{6.20}$$

where $\Delta \equiv 1 - L$ is the difference operator and

$$\begin{aligned} a_0 &\equiv -\Pi\mu + (\Gamma + \Pi)\gamma \\ a_1 &\equiv -\Pi\gamma \end{aligned} \tag{6.21}$$

The sum of the short-run coefficient matrices is defined by $\Gamma \equiv I_m - \sum_{i=1}^{p-1} \Gamma_i = -\Pi + \sum_{i=1}^{p} i\Psi_i$. Pesaran et al. (2000) prove that if $\gamma \neq 0$, then the resultant a_0 constraint on a_1 in Equation 6.20 assures that the deterministic trending behaviour of the level process $\{X_t\}_{t=1}^{\infty}$ is invariant to the cointegrating rank of Π; similar results hold for the intercept of $\{X_t\}_{t=1}^{\infty}$ when $\mu \neq 0$ and $\gamma = 0$ (Pesaran et al. (2000)). Pesaran et al. (2001) assume that the long-run multiplier matrix Π has rank r with $0 \leq r \leq k$ and test their model with the Wald test statistic and the F-statistic within a generalised Dickey-Fuller type regression (more information about the test statistics can be found in Kanioura and Turner (2005) and Cook (2006)). Nielsen and Rahbek (2000) show that the critical regions of the Wald test statistic and the F-statistic used are asymptotically *similar*.

A major advantage of testing for cointegration between variables in levels by transforming a conventional ARDL test is that it can be applied irrespectively of the order of integration of the underlying regressors (Pesaran et al. (2001)). ARDL models have therefore enjoyed wide applicability in different fields. Examples can be found in Anari and Kolari (2002) investigating the relationship between house prices and inflation, in Narayan and Narayan (2005) on income and price elasticities of imports for Fiji, in Tang (2007) evaluating money demand of Southeast Asian countries, in Wong and Tang (2008) about the effects that exchange rate variability has on Malaysia's electrical exports, in Nikolaidou (2008) on demand for military expenditure from EU countries, in Wang (2009) about the impact of crisis events and macroeconomic activity on tourism in Taiwan, in Odhiambo (2009) on the relationship between energy consumption and economic growth in Tanzania, and finally, in Jalil and Mahmud (2009) on the long-run relationship between carbon emissions and energy consumption, income and foreign trade in China between 1975 and 2005.

6.4.3 Time-Varying Cointegration

Bierens and Martins (2010) introduce a time varying Vector Error Correction Model (VECM) in which the cointegrating vectors are smooth functions of time. Following their approach for the previous $k*1$ vector time series X_t (equation 6.15), it can be presumed that for some t there are fixed $r<k$ linearly independent columns of the time-varying $k*r$ matrix $\beta_t=(\beta_{1t},...,\beta_{rt})$ of cointegrating vector; where the β_t matrices can be modelled using Chebyshev time polynomials. The resulting columns form the time-varying space of cointegrating vectors: $S_t^c = span(\beta_{1t},\beta_{2t},...,\beta_{rt})\subset \mathbb{R}^k$ with $t=1,2,...$ and the remaining $k-r$ orthogonal vectors can be expressed by a $k*(k-r)$ matrix $\beta_{t\perp}$ such that $\beta'_{t\perp}X_{t-1}$ doesn't represent a cointegration relationship.

Bierens and Martins (2010) build upon a time-varying VECM of order p with Gaussian error and free of intercepts and time trends:

(6.22) $$\Delta X_t = \sum_{j=1}^{p-1}\Phi_j\Delta_{t-j} + \Pi'_t X_{t-1} + \varepsilon_t, \quad t=1,...,T$$

where $X_t \in \mathbb{R}^k$ and $\varepsilon_t \sim N_k(0,\Omega)$. Also, Ω and Φ_j are $k*k$ matrices and T is the number of observations. The following hypotheses are set up:

$$H_0\, Time\, Invariant\, Cointegration: \Pi_t' = \Pi' = \alpha\beta'$$
$$H_1\, Time\, Varying\, Cointegration: \Pi_t' = \alpha\beta_t'$$

α is a fixed $k*r$ matrix (with r representing the cointegrating rank of the system), and β is a time-varying $k*r$ matrix with constant rank r.

Assuming standard smoothness and orthonormality conditions, Bierens and Martins (2010) Lemma 1 proves that the parameters of the time-varying cointegrating vector β_t can be approximated for some fixed m by a finite sum of Chebyshev time polynomials $P_{1,T}(t)$ of decreasing smoothness:

$$\beta_t = \beta_m(t/T) = \sum_{i=0}^{m} \xi_{i,T} P_{i,T}(t), \qquad t = 1, ..., T \tag{6.23}$$

where $1 \leq m < T-1$ and $\xi_{i,T} = \frac{1}{T}\sum_{t=1}^{T} \beta_T P_{i,T}(t)$ for $i = 0,...,T-1$ are unknown $k*r$ matrices.

Chebyshev time polynomials are defined by

$$P_{0,T}(t) = 1, P_{i,T}(t) = \sqrt{2}cos(\frac{i\pi(t-0.5}{T})$$
$$t = 1, 2, ..., T \qquad i = 1, 2, 3, ...$$

and are orthonormal, so for all couples of integers i, j, following property holds: $\frac{1}{T}\sum_{t=1}^{T} P_{i,T}(t)P_{j,T}(t) = 1(i=j)$. However, p-values become zero for any m above four, suggesting only to consider results for $m \leq 4$ (Bampinas and Panagiotidis (2015)).

More formally, following hypotheses are set up when testing for time-varying cointegration:

$$H_0\, Time\, Invariant\, Cointegration:\ \xi_{i,T} = O_{k*r}\ for\ i = 1,...,m\ and\ \xi_i = O_{k*r}\ for\ i > m$$
$$H_1\, Time\, Varying\, Cointegration:\ \lim_{T\to\infty} \neq O_{k*r}\ for\ some\ i = 1,...,m\ and \xi_i = O_{k*r}\ for\ i > m$$

With $\Pi' = \alpha\beta'$ and if 6.23 is substituted in 6.22, one gets: $\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \alpha(\sum_{i=0}^{m} \xi_i P_{i,T}(t))' X_{t-1} + \varepsilon_t$, which can be rewritten as

$$\Delta X_t = \sum_{j=1}^{p-1} \Phi_j \Delta X_{t-j} + \alpha\xi' X_{t-1}^{(m)} + \varepsilon_t \tag{6.24}$$

where $\xi' = (\xi'_0, \xi'_1, ..., \xi'_m)$ is an $r*(m+1)k$ matrix of rank r. Further, $X^{(m)}_{t-1}$ is defined by

$$X^{(m)}_{t-1} = (X'_{t-1}, P_{1,T}(t)X'_{t-1}, P_{2,T}(t)X'_{t-1}, ..., P_{m,T}(t)X'_{t-1})' \tag{6.25}$$

The null hypothesis of time-invariant cointegration corresponds to $\xi' = (\beta', O_{r,k.m})$, so that $\xi' X^{(m)}_{t-1} = \beta' X^{(m)}_{t-1}$, with $X^{(0)}_{t-1} = X_{t-1}$. The null hypothesis an be tested with a likelihood ratio test, where

$$LR^{tvc}_T = -2[\hat{l}_T(r,0) - \hat{l}_T(r,m)]$$

The above equation differentiates between two cases: in the time-invariant of $m = 0$ and the time-varying case where $m > 0$. In the time-invariant case, $\hat{l}_T(r,0)$ is the log-likelihood of the VECM of order p (equation 6.24), so that $X^{(m)}_{t-1} = X_{t-1}$. In the time-varying case $\hat{l}_T(r,m)$ is the log-likelihood of the VECM of order p (equation 6.24), but $X^{(m)}_{t-1}$ is given by equation 6.25. In both cases, r is the cointegration rank, and the LR^{tvc}_T statistic is asymptotically distributed as a χ^2 distribution with $r*m*k$ degrees of freedom (Bampinas and Panagiotidis (2015)).

Since its publication, the methodology proposed by Bierens and Martins (2010) has been widely applied in finance and economics. Examples can be found in Neto (2012) looking at Swiss gasoline demand, in Park and Park (2013) on exchange-rate predictability, in Kavussanos et al. (2014) on economic spillovers between the freight and commodity derivatives markets, in Bampinas and Panagiotidis (2015) on the long-run inflation hedging potential of gold and silver in the US and the UK, and finally, in Aye et al. (2016) on gold's inflation hedging potential in the United States between 1833 and 2013.

6.5 Structural Breaks

Considering how to deal with deterministic components, the method proposed by Johansen (1991, 1995) focuses on polynomial trends. However, Perron (1989) points towards the importance of broken trends in nonstationary time series analysis. Different procedures have been proposed so far to detect the occurrence of structural breaks in the cointegration relationship amongst time series.

6.5.1 Residual-based Tests with Regime and Trend Shifts

Gregory and Hansen (1996a) demonstrate that if regime shifts are maintained under the null, the results of residual-based cointegration tests can change severely. Popular tests for cointegration such as Engle and Granger (1987) (and Johansen (1991)), test the null hypothesis of no cointegration against the alternative of cointegration; supposing for the existence of a stationary distribution in a given linear combination of the integrated variables. Aware of this problem, Gregory and Hansen (1996a) derive a battery of tests allowing the cointegrating vector to change at a single unknown time during the period considered. Four models are formulated: a standard approach, an equation taking into account level shift in the cointegrating relationship, another one allowing for a time trend in the level shift, and finally, a model that allows both the slope vector and the level to shift in the cointegrating relationship. Gregory and Hansen (1996b) offer an alternative method specifying a break in the constant, the slope and the trend, along with their respective critical values; an extension of Perron (1989).

The Regime Shift model of Gregory and Hansen (1996a) allows the intercept, the equilibrium equation, and the slope vector to shift. It is defined as:

$$y_{1t} = \mu_1 + \mu_2 \varphi_{1\tau} + \alpha_1^T y_{2t} + \alpha_2^T y_{2t} \varphi_{1\tau} + \varepsilon_t, \qquad t = 1, ..., n \tag{6.26}$$

where $y_t = (y_{1t}, y_{2t})$ is the observed data while y_{1t} is real-valued and y_{2t} is an m-vector. μ_1 represents the intercept before the shift, while μ_2 represents the change in the intercept at the time of the shift. Also, α_1 stands for the cointegrating slope coefficient before the regime shift and α_2 denotes the change in the slope coefficients.

Many cointegration testing procedures presume that the cointegrating vector is time-invariant. An advantage of the method proposed by Gregory and Hansen (1996a) is that it does not require information in regard to timing or occurrence of a break. The testing procedures are augmentations of the Z_α and Z_t unit root tests proposed by Phillips (1987) and the Augmented Dickey-Fuller (ADF) test recommended by Engle and Granger (1987).

Since its introduction, the Gregory and Hansen (1996a) test has been widely used in economic research. Examples can be found in Hamori and Matsubayashi (2001) on Japanese imports, in Lucey and Voronkova (2008) on Russian equity markets, in Valadkhani and Chancharat (2008) on the dynamic linkages between Thai and international stock markets, in Esso (2010) on the relationship between energy use and economic growth in different African countries, in Shahbaz et al. (2012) on energy consumption and economic growth in Pakistan, and finally, in Le and Chang (2013) on oil price shocks.

6.5.2 Multiple Breakpoint Testing

Different procedures have been proposed to identify multiple breakpoints of time series simultaneously (applications can be found in Lumsdaine and Papell (1997), Cooper (1998) and Burdekin and Siklos (1999) amongst others), but the procedure proposed by Bai and Perron (2003a) stands out by estimating the breaks one by one (Bai (1997a)). Proposed initially for a simple model with mean shifts in a linear process, the procedure was augmented to identify change points in multiple regressions (Bai (1997b)) and in more general linear models (Bai and Perron (1998)).

The Bai and Perron (2003a) procedure examines a multiple linear regression with m breaks and $m+1$ regimes:

$$y_t = x_t'\beta + z_t'\delta_j + u_t \quad (6.27)$$

with $t = T_{j-1}+1, ..., T_j$. In Equation 6.27, y_t is the observed dependent variable at time t, where $T_0 = 0$ and $T_{m+1} = T$ for $j = 1, ..., m+1$. The indices $(T_1, ..., T_m)$ uncover unknown break points and are treated as unknown, assuming that $T_0 = 0$ and $T_{m+1} = T$. Furthermore, $x_t(p*1)$ and $z_t(p*1)$ are vectors of covariate with their corresponding vectors of coefficients β and $\delta_j(j = 1, ..., m+1)$ (Bai and Perron (2003b)). It should be noted that u_t stands for the disturbance term at time t and its variance doesn't need to be constant. Finally, the parameter vector β is estimated using the entire sample and is not subject to shifts, Equation 6.27 is therefore a partial structural change model. In case $p = 0$, the result would be a pure structural change model in which all coefficients are subject to change; therefore, breaks in the variance of u_t are only permitted if these breaks occur at the same time as the breaks in the parameters of of the regression (Bai and Perron (2003b)).

The purpose of the Bai and Perron (2003a) procedure is to estimate the unknown regression coefficients along with the break points, given that T observations on (y_t, x_t, z_t) are available (Bai and Perron (2003b)). The method of estimation applied is based on the least-squares principles by reformulating Equation 6.27 in a matrix form:

$$Y = X\beta + \bar{Z}\delta + U \quad (6.28)$$

where $Y = (y_1, ..., y_T)'$, $X = (x_1, ..., x_T)'$, $U = (u_1, ..., u_T)'$ and $\delta = (\delta'_1, \delta'_2, ..., \delta'_{m+1})'$. $\bar{Z}$ is the matrix which diagonally partitions$Z$ at $(T_1, ..., T_m)$, in other words: $\bar{Z} = diag(Z_1, ...Z_{m+1})$ with $Z_i = (z_T)$ (Bai and Perron (2003b).

So for each m-partition $(T_1, ..., T_m)$, the associated least-squares estimates of β and δ_j are obtained by minimising the sum of squared residual (Bai and Perron (2003b)):

$$(Y - X\beta - \bar{Z}\delta)'(Y - X\beta - \bar{Z}\delta) = \sum_{i=1}^{m+1} \sum_{t=T_{i-1}+1}^{T_i} [y_t - x'_t\beta - z'_t\delta_i]^2 \quad (6.29)$$

where restrictions are imposed on the possible break dates which must be asymptotically distinct and bounded from the boundaries of the sample (Bai and Perron (2003b)). Three different testing alternatives are proposed by Bai and Perron (2003a): first, a sup$F$-type test with a fixed number of breaks ($m = k$) against the alternative of no structural break ($m = 0$), second, a binary maximum test looking at an unknown number of breaks against the null hypothesis (Goktas and Disbudak (2014)), and finally, a sup$F_t(l+1|l)$ test examining the l break null hypothesis against the $l+1$ hypothesis of a single change (Bai and Perron (2003a)).

The Bai and Perron (2003a) procedure has been widely applied throughout different fields, such as the predictability of stock returns (Pesaran and Timmermann (2002)), or for the detection of structural breaks in the mean real interest rates of industrialised countries (Rapach and Wohar (2005)), the effects of the September 11 attacks on international terrorism (Enders and Sandler (2005)), structural stability testing of predictive regression models for US equity (Rapach and Wohar (2006)), and more recently, on the effects of tourism on economic growth in Sri Lanka (Stauvermann et al. (2016)).

6.6 Autoregressive Integrated Moving Average Model

An Autoregressive Integrated Moving Average (ARIMA) model is the generalised form of an Autoregressive Moving Average (ARMA) model that can help in predicting future points of the time series it is applied to.

The Autoregressive (AR) prefix indicates that the variable of interest y_t is regressed on its own lagged value, the Integrated (I) specification allows the model to be run on non-stationary data, and the Moving Average (MA) specifies the regression error as a linear combination of the error terms.

Considering the following first-order autoregressive moving-average process:

$$y_t = x_t\beta + \mu_t \tag{6.30}$$

in which the disturbance term is defined as:

$$\mu_t = p\mu_{t-1} + \theta\epsilon_{t-1} + \epsilon_t \tag{6.31}$$

where p is the first-order autocorrelation parameter, θ is the first-order moving-average parameter and ϵ_t is a white-noise disturbance term; an ARIMA procedure would fit Equation 6.31 in Equation 6.30 and yield the following model:

$$y_t = x_t\beta + \sum_{i+1}^{p} p_i(y_{t-i} - x_{t-i}\beta) + \sum_{j=1}^{q} \theta_j\varepsilon_{t-j} + \varepsilon_t \tag{6.32}$$

Models fitted with an ARIMA procedure can produce dynamic forecast results by using the Kalman filter approach (Kalman (1960)) allowing to forecast the time series for far longer future time steps than through a classical regression model. By way of illustration, the following model is considered (Stata Corporation (2013)):

$$y_t = \beta_0 + p y_{t-1} + \varepsilon_t \tag{6.33}$$

for $t = 1, ..., T$ and forecasted values want to be generated starting at time f. A simple regression would yield to the following one-step-ahead forecasts:

$$\hat{y}_f = \hat{\beta}_0 + \hat{p} y_{f-1} \tag{6.34}$$

in which the actual values of y will be used in period $f-1$ to predict the value in time f. So given that values of y are only available up to time T, no forecast can be made beyond time step $f = T+1$. Within an ARIMA procedure, the value for $\hat{y}_t$ is computed as suggested in Equation 6.34, but any value beyond that will be computed as such:

$$\hat{y}_{f+1} = \hat{\beta}_0 + \hat{p}\hat{y}_{f+1} \tag{6.35}$$

therefore relying on previously forecasted values.

Different applications of ARIMA modeling procedures can be found in Contreras et al. (2003) forecasting electricity prices, in Williams and Hoel (2003) forecasting vehicle traffic flow, in Pai and Lin (2005) forecasting stock price movements, or in Reikard (2009) forecasting solar radiation.

6.7 Variable Selection of Linear Regression Models

Computational advances of the last years have allowed researchers to look away from classical linear regression models and to consider *multimodeling* approaches, that consist in generating results by processing numerous models simultaneously (Fisher and Getis (2010)). Several procedures exist to test for model uncertainty and select the optimal subset of variables from a large amount of doubtful variables, prominent examples of Bayesian model averaging methods can be found in Clyde and George (2004), while other methods suggest a Bayesian Averaging of Classical Estimates (Sala-I-Martin et al. (2004)) or random forecasts based on tree predictors (Breiman (2001)). However, two methods stand out due to their relative simplicity and their simple interpretation of results, making them very attractive choices to provide understandable and graspable econometric results: the Extreme Bounds Analysis and the General-to-Specific Modeling Algorithm.

6.7.1 Extreme Bounds Global Sensitivity Analysis

The Extreme Bounds Analysis (EBA) proposed by Leamer (1983) and Leamer (1985) can help in understanding whether or not small changes in the variables identified by the model can substantially change the conclusion of the empirical results (Kennedy (2003)). Furthermore, given a large number of possible variables, an Extreme Bounds Analysis allows to understand the extent to which each variable impacts y across a wide variety of possible specifications. Considering a wide set of variables $\mathbf{X}$, it is of interest to know which variables are robustly associated with the dependent variable y. An Extreme Bound Analysis implies running a large number of different regression models each consisting of a subset of explanatory variables $\mathbf{F}$ fixed in every regression model and an additional unique subset $\mathbf{D}$ of doubtful variables. Finally, a subset v of the set of doubtful variables $\mathbf{X}$ can be declared to be *focus* variables if they are of particular interest to the researcher. If the regression coefficient of a doubtful variable retains statistical significance over a large proportion of estimated models, the variable is declared to be *robust*, while the relationship with the dependent variable y can otherwise be declared to be *fragile*.

Formally, to find out if a *focus* variable $v \in \mathbf{X}$ is robustly correlated with the dependent variable y, the following regression model is estimated numerous times (Hlavac (2016)):

$$y = \alpha_j + \beta_j v + \gamma_j \mathbf{F} + \delta_j \mathbf{D}_j + \varepsilon \tag{6.36}$$

where j indexes the regression models, $\mathbf{D}_j$ is a vector of k variables taken from the set of variables $\mathbf{X}$ and ε is the error term. Conventionally, $\mathbf{D}_j$ is limited to include a maximum of three doubtful variables per model (Levine and Renelt (1992) and Achen (2005)) but the amount can of course be set subjectively, while this comes at cost of a much more complex computation and running time.

Equation 6.36 is estimated in an Ordinary Least Squares (OLS) framework for each M possible combination of $\mathbf{D}_j \subset \mathbf{X}$ and the regression coefficients $\hat{\beta}_j$ on focus variable v, along with the corresponding standard errors $\hat{\sigma}_j$ are collected and stored for two different testing procedures proposed by Leamer (1985) and Sala-I-Martin (1997).

6.7.1.1 Testing the Extreme Bounds of the Regression Coefficients

Leamer (1985) proposes testing whether a variable is *robust* or *fragile* by looking only at the extreme bounds of the regression coefficients that represent the minimum and maximum value. For any *focus* variable v across the M estimated regression models, the lower and the upper extreme bounds are defined as:

$$\hat{\beta}_j \pm \tau \hat{\sigma}_j \tag{6.37}$$

where τ is the critical value for the requested confidence level (Leamer (1985)). If both the upper and the lower extreme bounds have the same sign, the *focus* variable v is determined as *robust*, otherwise as *fragile*.

6.7.1.2 Testing the Distribution of the Extreme Bounds of the Regression Coefficients

A severe drawback of the testing procedure proposed by Leamer (1985) is that a single regression model out of several millions is enough to classify a variable as *fragile*. Indeed, many studies using the Extreme Bounds Analysis following Leamer (1985) conclude that most variables are *fragile* (see Levine and Renelt (1992) or Levine and Zervos (1993) for examples).

Sala-I-Martin (1997) therefore proposes a method focusing on the entire distribution of the regression coefficients, providing the researcher with a level of confidence to the robustness of the variables. More specifically, Sala-I-Martin (1997) considers the value of $CDF(0)$ and the amount of the variable's cumulative distribution that lies on each side of zero (Hlavac (2016)) and which are fitted in one model believed to follow a normal distribution and in a more generic model that doesn't assume any particular distribution of the regression coefficients.

In a first step, Sala-I-Martin (1997) calculates the weighted mean of the regression coefficients $\bar{\beta} = \sum_{j=1}^{M} w_j \hat{\beta}_j$ and of the variances $\bar{\sigma}^2 = \sum_{j=1}^{M} w_j \hat{\sigma}_j^2$ where w_j represents weights that are applied to results from each estimated regression model, giving more weight to regressions that are more likely to be the true model (Sala-I-Martin (1997)). The weighting is done proportionally to the integrated likelihood, where:

$$w_j = \frac{L_j}{\sum_{i=1}^{M}} L_i \tag{6.38}$$

While cumulative density function in the model assuming a normal distribution is given as $\beta = \mathcal{N}(\bar{\beta}, \bar{\sigma}_j^2)$, the cumulative distribution function in the generic model is produced by estimating the cumulative density function from each regression separately and pooling them into an aggregate cumulative density function of the form:

$$\Phi(0) = \sum_{j=1}^{M} w_j \phi_j (0|\hat{\beta}_j, \hat{\sigma}_j^2) \tag{6.39}$$

where individual cumulative density functions from each regression coefficient $\hat{\beta}_j$ are denoted as $\phi_j(0|\hat{\beta}_j, \hat{\sigma}_j^2)$.

The Extreme Bounds Analysis approach has found wide application across many fields, such as on the determinants of long-term economic growth rates (Sturm and Haan (2005)), the determinants of regional growth rates (Reed (2009)), the determinants of foreign direct investment (Moosa and Cardak (2006)) and investment into research and development (Wang (2010)) amongst many other examples.

6.7.2 General-to-Specific Model Algorithm

Pioneered by Sargan (1964), the General-to-Specific (GenSpec) approach consists of starting with a General Unrestricted Model (GUM) and reducing the GUM in order to obtain a more parsimonious and specific model. The complication therefore lies in how to select the variables to delete out of the model and is done relying on the t-test and the F-test, corresponding to a likelihood-based evaluation of a given model y, where the likelihood function of the model is given by the density:

$$L_y(\theta_y) = \begin{cases} f_y(X;\tilde{\theta}_y) \\ -\infty \end{cases} \quad \text{if} \quad min(\hat{\eta}_y(X;\tilde{\theta}_y) - \eta)\left\{ \begin{array}{c} \geq \\ < \end{array} \right\} 0 \tag{6.40}$$

where $f_y(X;\theta_y)$ is the Probability Density Function (PDF) associated with model y at the parameter vector θ_y for the sample X (Krolzig and Hendry (2001)). η denotes the significance level for the misspecification tests with $\hat{\eta}$ their corresponding p-values. The vector of p-values, $\hat{\eta}_y(X;\tilde{\theta}_y)$, is evaluated at the maximum likelihood estimate $\tilde{\theta}_y$ under model y and mapped into marginal rejection probabilities, assuring that the PDF of model y is only accepted as the likelihood function in case the sample information is coherent with the underlying assumptions of the model itself (Krolzig and Hendry (2001)).

In a Monte Carlo framework, the significance level of the misspecification tests can be set endogenously, so that if a test of the Data Generating Process (DGP) reveals a significant diagnostic outcome, the significance level is adjusted accordingly. Also, if the GUM fails a misspecification test at a desired significance level $\bar{\eta}''$, a more binding critical value is used; and if the GUM also fails at a reduced significance level $\bar{\eta}' < \bar{\eta}''$, the test statistic is excluded from the test battery for the following search (Krolzig and Hendry (2001)). Econometrically, for the kth test:

$$\theta_k = \left\{ \begin{array}{c} \bar{\eta}'' \\ \bar{\eta}' \\ 0 \end{array} \right\} \quad \text{if} \quad \hat{\eta}_{k,GUM}(X,\tilde{\theta}_{GUM}) \in \left\{ \begin{array}{cc} [\bar{\eta}'',1] & \text{desired significance level} \\ [\bar{\eta}',\bar{\eta}'') & \text{reduced significance level} \\ [0,\bar{\eta}') & \text{test excluded} \end{array} \right\}$$

where $0 < \bar{\eta}' < \bar{\eta}'' < 1$.

Additional information, discussions and application examples of the General-to-Specific model algorithm can be found in Hoover and Perez (1999), Song and Witt (2003), Hendry and Krolzig (2003) and Clarke (2014). An excellent discussion on econometric and philosophical issues around the GenSpec procedure can be found in Campos et al. (2005).

6.8 Testing Procedures for Linear Regressions

Several assumptions concerning the disturbance term are implied in classical linear regression models of the form $y = \alpha + \beta x_t + u_t$ (Brooks (2014)):

The first assumption, is that the errors have zero mean, or using econometric notation: $E(u_t) = 0$.

The second assumption states that the variance of the errors is both constant and finite over all values of x_t; econometrically: $var(u_t) = \sigma^2 < \infty$.

A third assumption is that the errors are linearly independent of one another, so that: $cov(u_i, u_j) = 0$.

Fourthly, it is assumed that no relationship exists between the error and the corresponding x variate; mathematically: $cov(u_t, x_t) = 0$.

The fifth and final assumption is a reformulation of the fourth assumption and states that u_t is normally distributed, or $u_t\ N(0, \sigma^2)$.

If the assumptions presented above hold, the estimators $\hat{\alpha}$ and $\hat{\beta}$ derived by an Ordinary Least Squares procedure can be considered to be Best Linear Unbiased Estimators (BLUE).

Here, *Best* means that estimator $\hat{\beta}$ has minimum variance amongst the class of linear unbiased estimators.

Linear states that $\hat{\alpha}$ and $\hat{\beta}$ are linear combinations of the random variable y.

On average, the true value of $\hat{\alpha}$ and $\hat{\beta}$ will be equal to their true value and therefore *Unbiased*.

Finally, $\hat{\alpha}$ and $\hat{\beta}$ are *Estimators* of the true values of α and β.

The section below is presenting a set of testing procedure used throughout this thesis in dealing with Classical Linear Regression Models (CLRM) and their deviations.

6.8.1 Identifying Heteroscedasticity through Residuals

A major assumption of linear regression procedures is that the variance of the error terms u is constant, an assumption known as the *assumption of homoscedasticity* (Brooks (2014)). Breusch and Pagan (1979) propose a testing procedure to detect the presence of possible heteroscedasticity in linear regression models by building upon a classical regression model of the form:

$$y = \beta_0 + \beta_1 x + u \tag{6.41}$$

where a set of residuals $\hat{u}$ can be obtained, while an Ordinary Least Squares procedure would constrain their mean value to be 0. In the case that this assumption might fail, the variance of the residuals might be linearly related to independent variables and the model could be examined by regressing the squared residuals on the independent variables (Brooks (2014)):

$$\hat{u}^2 = \alpha_0 + \alpha_1 x + v \tag{6.42}$$

Breusch and Pagan (1979) model the variances of the error term σ_t^2 as:

$$\sigma_t^2 = h(z_t'\alpha) \tag{6.43}$$

where the function $h(\cdot)$, not indexed by t, is assumed to possess both a first and a second order derivative. Furthermore, α is a $(p * 1)$ vector of unrestricted parameters unrelated to the β coefficients in Equation 6.41, while the first element in z is unity (Breusch and Pagan (1979)).

Specifications in Equation 6.43 allow to test for the Null Hypothesis of homoscedasticity using:

$$H_0 : \alpha_2 = ... = \alpha_p = 0 \tag{6.44}$$

and therefore $z_t'\alpha = \alpha_1$ so that $\sigma_t^2 = h(\alpha_1) = \sigma^2$ is constant.

A Lagrange Multiplier (LM) statistic is used to test the null hypothesis represented by parametric constraints $\phi(\theta) = 0$ (Rao (1973)):

$$LM = \hat{d}'\hat{\Psi}^{-1}\hat{d} \tag{6.45}$$

with the hat indicating that the quantities are evaluated with $\hat{\theta}$, the restricted maximum likelihood estimate which satisfies $\phi(\hat{\theta}) = 0$ (Breusch and Pagan (1979)). It should also be noted that $d = \frac{\partial l}{\partial \theta}$ the first derivative vector in regard to parameters θ and $\Psi = -E(\frac{\partial^2 l}{\partial \theta \partial \theta'})$ is the information matrix.

Due to its' wide field of applicability, examples of the Breusch and Pagan (1979) procedure can be found in studies on the drivers of consumption in Australia (Hoque (1992)), on the determinants of the international travel and tourism service trade between the European, Asian and North American markets from 2000 to 2005 (Chang and Lai (2011)), in medicine (Cantinotti et al. (2014) and Liu et al. (2014)), and finally, on public sector efficiency (Mateus et al. (2015)).

6.8.2 Evaluating Estimator Consistency

Hausman (1978) proposes a test that evaluates the known consistency of an estimator $\hat{\theta}_1$ with another estimator $\hat{\theta}_2$ efficient under the assumption being tested.

Theoretically, the procedure is based on the expectation that for a standard regression of the type:

$$y = x\theta + \varepsilon \tag{6.46}$$

two assumptions are made: first, that the conditional expectations of ε given x is zero and that ε have a spherical covariance matrix. More specifically, in econometric terms:

$$E(\varepsilon|x) = 0 \tag{6.47}$$

and

$$V(\varepsilon|x) = \sigma^2 I \tag{6.48}$$

While quite some attention is paid to testing the assumption presented in Equation 6.48, Hausman (1978) proposes a unified approach to test the assumption made in Equation 6.47. The basic null hypothesis is that $\hat{\theta}_2$ is both an efficient and consistent estimator of the true parameters. So if a comparison of the estimates from estimator $\hat{\theta}_2$ with the efficient estimator $\hat{\theta}_1$ assumed in Equation 6.47 can be made, and noting that their differences is uncorrelated with estimator $\hat{\theta}_1$ under the null hypothesis, Equation 6.46 can be reformulated as:

$$y = x\theta + \tilde{x}\alpha + v \tag{6.49}$$

where $\tilde{x}$ is a suitably transformed version of x (Hausman (1978)). The test statistic is distributed as χ^2 with a number of degrees of freedom equal to the rank of the difference in the variance matrices and computed as follows (Stata Corporation (2013)):

$$H = (\beta_c - \beta_e)'(V_c - V_e)^{-1}(\beta_c - \beta_e) \tag{6.50}$$

where β_c is the coefficient vector from the consistent estimator $\hat{\theta}_1$ and β_e is the coefficient vector from the efficient estimator $\hat{\theta}_2$. Furthermore, V_c is the covariance matrix of the consistent estimator $\hat{\theta}_1$ and V_e is the covariance matrix of the efficient estimator $\hat{\theta}_2$.

Application example of the Hausman (1978) procedure and variations thereof can be found in Ham (1982) on labour supply, in Cornwell et al. (1990) on production frontiers, in Arendt (2005) on the link between education level and health, in Huang and Tauchen (2005) on stock market prices, and finally, in Lee and Park (2009) on hospitality management.

6.8.3 Determining Serial Correlation in the Idiosyncratic Error Term

Serial correlation in panel data leads to biased standard errors and to less efficient results; Wooldridge (2002) therefore proposes a testing procedure that identifies serial correlation in the idiosyncratic error term in both random- and fixed-effects models. Assume the following model:

$$y_{it} = \alpha + \mathbf{X}_{it}\beta_1 + \mathbf{Z}_i\beta_2 + \mu_i + \epsilon_{it} \qquad i \in \{1,2,...,N\} \qquad t \in \{1,2,...,T_i\} \tag{6.51}$$

where y_{it} is the dependent variable and α, β_1, and β_2 are $1+K_1+K_2$ parameters (Drukker (2003)). $\mathbf{X}_{it}$ is a $(1*K_1)$ vector of time-varying covariates and $\mathbf{Z}_i$ is a $(1*K_2)$ vector of time-invariant covariates, while μ_i is the individual level effect and ϵ_{it} is the idiosyncratic error.

In the case that the μ_i are correlated with the $\mathbf{X}_{it}$ or the $\mathbf{Z}_i$, then the coefficients on the time-varying covariates $\mathbf{X}_{it}$ can be consistently estimated by a regression on either the within-transformed data or the first-differenced data.

In the case that the μ_i are uncorrelated with the $\mathbf{X}_{it}$ and the $\mathbf{Z}_i$, the coefficients on both time-varying and time-invariant covariates can be estimated consistently and efficiently using the feasible generalised least squares method known as random-effects regression (Drukker (2003)). A discussion on the estimators of the coefficients of the covariates $\mathbf{X}_{it}$ and $\mathbf{Z}_i$ can be found in Wooldridge (2002) and Baltagi (2013).

Assuming that there is no serial correlation in the idiosyncratic errors, or assuming that $E[\epsilon_{it}\epsilon_{is}] = 0$ for all $s \neq t$, Wooldridge (2002) relies on the residuals obtained from a regression in first-differences of the form:

$$\begin{aligned} y_{it} - y_{it-1} &= (\mathbf{X}_{it} - \mathbf{X}_{it-1})\beta_1 + \epsilon_{it} - \epsilon_{it-1} \\ \Delta y_{it} &= \Delta\mathbf{X}_{it}\beta_1 + \Delta\epsilon_{it} \end{aligned} \tag{6.52}$$

where Δ is the first-difference operator (Drukker (2003)). The Wooldridge (2002) procedure estimates the parameters β_1 by regressing Δy_{it} on $\Delta\mathbf{X}_{it}$ and obtains the residuals $\hat{e}_{it}$. In case the ϵ_{it} are not serially correlated, then $Corr(\Delta\epsilon_{it}, \Delta\epsilon_{it-1}) = -0.5$ (Drukker (2003)). Wooldridge (2002) therefore regresses the residuals $\hat{e}_{it}$ on their lags and tests that the coefficient on the lagged residuals is equal to -0.5 while accounting for within-panel correlation in the regression of $\hat{e}_{it}$ on $\hat{e}_{it-1}$ by adjusting the variance-covariance matrix for clustering at the panel level (Drukker (2003)).

While different procedures exist to test for serial correlation (Baltagi (2013)), the major advantage of the procedure proposed by Wooldridge (2002) is that it requires relatively few assumptions and is easy to implement. Application examples and further implications can be found in Khediri and Ben-Khedhiri (2011), in Mendolia and Walker (2015) and in Born and Breitung (2016) amongst others.

6.9 Linear Panel Data Models

Assuming a model of the following form:

$$y_i = \alpha + \beta x_i + \varepsilon_i \tag{6.53}$$

an important task is to derive an optimal equation for the straight line $y = \alpha + \beta x$. Mathematically, the *best fit* is expressed by the following minimisation problem:

$$\min_{\alpha\beta} Q(\alpha,\beta)$$
$$Q(\alpha,\beta) = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (y_i - \alpha - \beta x_i)^2$$

so that the estimators $\hat{\alpha}$ and $\hat{\beta}$ are defined as:

$$\begin{aligned} \hat{\alpha} &= \bar{y} - \hat{\beta}\bar{x} \\ \hat{\beta} &= \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = \frac{Cov[x,y]}{Var[x]} \end{aligned} \tag{6.54}$$

where $\bar{x}$ and $\bar{y}$ indicate the average value of x and y respectively (Brooks (2014)).

6.9.1 A Linear Regression Model allowing for Fixed and Random Effects Estimators

It is also possible to fit regression models to panel data in regard to both fixed effects and random effects estimators, but is surprisingly complex to model econometrically.

Building upon a basic model of the form:

$$y_{it} = \alpha + x_{it}\beta + v_i + \varepsilon_{it} \tag{6.55}$$

where ε_{it} is the error term of the system and v_i the panel-specific error term, the question of interest that remains is the estimation of β. So in the light that v_i differs between units but is constant within the unit, the following must hold:

$$\bar{y}_i = \alpha + \bar{x}_i\beta + v_i + \bar{\varepsilon}_i \tag{6.56}$$

where $\bar{y}_i$ is defined as $\sum_t \frac{y_{it}}{T_i}$, while $\bar{x}_i$ is calculated by $\sum_t \frac{x_{it}}{T_i}$. In this sense, it follows that $\bar{\varepsilon}_i$ is obtained through $\sum_t \frac{\varepsilon_{it}}{T_i}$. So subtracting Equation 6.56 from Equation 6.55 yields:

$$(y_{it} - \bar{y}_i) = (x_{it} - \bar{x}_i)\beta + (\varepsilon_{it} - \bar{\varepsilon}_i) \tag{6.57}$$

Determining the coefficients in Equation 6.55 through a fixed effect model basically implies using Ordinary Least Squares to perform the estimation of Equation 6.57. Using a random effect model in determining the coefficients of Equation 6.55 implies relying on a matrix weighted average of the estimates produced by the between and within estimators (Stata Corporation (2013)). More specifically, the random effect model relies on the following estimation:

$$(y_{it} - \theta\bar{y}_i) = (1-\theta)\alpha + (x_{it} - \theta\bar{x}_i)\beta + \{(1-\theta)v_i + (\varepsilon_{it} - \theta\bar{\varepsilon}_i)\} \tag{6.58}$$

where θ is a function of σ_v^2 and σ_ε^2 so that $\hat{\theta} = 1 - \sqrt{\frac{\hat{\sigma}_\varepsilon^2}{T_i\hat{\sigma}_u^2\hat{\sigma}_\varepsilon^2}}$ (Stata Corporation (2013)). It should be noted that in case $\sigma_v^2 = 0$, implying that v_i is always 0, it follows that $\theta = 0$ and that Equation 6.55 can be directly estimated by an Ordinary Least Squares procedures.

The popular R^2 procedure can be used to evaluate goodness of fit of the model, where the *classical* measure is predicted on:

$$\hat{y}_{it} = \hat{\alpha} + x_{it}\hat{\beta} \tag{6.59}$$

while the goodness of fit statistic for the fixed effect specification in Equation 6.57 is predicted on:

$$\hat{\hat{y}}_{it} = (\hat{y}_{it} - \hat{\bar{y}}_i) = (x_{it} - \bar{x}_i)\hat{\beta} \tag{6.60}$$

and finally, the R^2 statistic of the random effect specification in Equation 6.58 is predicted on:

$$\hat{\hat{y}}_{it} = (\hat{y}_{it} - \hat{\theta}\hat{\bar{y}}_i) = (x_{it} - \theta\bar{x}_i)\hat{\beta} \tag{6.61}$$

Comprehensive application examples of panel data models can be found in Nauges and Thomas (2003) on water consumption, in Glaser and Weber (2009) on the effect of past stock price return on trading volume, in Christoffersen et al. (2010) on volatility dynamics for the S&P500, in Asiedu and Lien (2011) on the impact of democracy on foreign direct investments, and finally, in Aisen and Veiga (2013) on the determinants of economic growth.

6.10 Dynamic Panel Data Models

In the light of unobserved fixed or random panel-specific effects, linear dynamic panel-data models include p lags of the dependent variable y as covariates. However, this might lead to an inconsistency of standard estimators, given that the unobserved panel-level effects are correlated with the values of the lagged variable y (Stata Corporation (2013)). In order to tackle this problem, the following section highlights four different panel-data estimation models building upon previously presented formal testing procedures for linear regressions.

Throughout the section, the following *classical* linear dynamic panel-data model shall be considered (Stata Corporation (2013)):

$$y_{it} = \sum_{j=1}^{p} \alpha_j y_{i,t-j} + x_{it}\beta_1 + w_{it}\beta_2 + v_i + \epsilon_{it} \qquad i+=1.....N \qquad t=1,...,T_i \tag{6.62}$$

with N the sample of individual time series and T the observation periods. x_{it} is a $1*k_1$ vector of strictly exogenous covariates and w_{it} is a $1*k_2$ vector of predetermined and exogenous covariates. β_1 and β_2 are respective k_1*1 and k_2*1 vectors of parameters to be estimated, while v_i are panel-level effects and ϵ_{it} independent and identically distributed over the entire sample with variance σ_ϵ^2. The independence of v_i and ϵ_{it} is assumed for each i over all t.

6.10.1 Linear Dynamic Panel Data Modeling

Based upon the works of Anderson and Hsiao (1981, 1982) on dynamic models, and of Holtz-Eakin et al. (1988) on vector autoregression coefficients in panel-data, Arellano and Bond (1991) build their methodology upon the Generalised Method of Moments (GMM) and propose a procedure designed for datasets with many panels but few observation periods, with the only requirement that no autocorrelation is present in the idiosyncratic errors.

The GMM estimator $\hat{\alpha}$ is based on the sample moments $N^{-1}\sum_{i=1}^{N} Z_i'\bar{v}_t = N^{-1}Z'\bar{v}$ so that:

$$\hat{\alpha} = argmin_\alpha(\bar{v}'Z)A_N(Z'\bar{v}) = \frac{\bar{y}_{-1}'ZA_NZ'\bar{y}}{\bar{y}_{-1}'ZA_NZ'\bar{y}_{-1}} \tag{6.63}$$

where $\bar{v} = \bar{y} - \alpha\bar{y}_{-1} = (\bar{v}_1', ..., \bar{v}_N')'$ is a $N(T-2)*1$ vector and $Z = (Z_1', ..., Z_N')'$ is a $N(T-2)*m$ matrix (Arellano and Bond (1991)). A_N needs to be set to $A_N = (N^{-1}\sum_i Z_i'HZ_i)^{-1}$ where H is a $(T-2)$ square matrix in order to obtain the one-step estimator $\hat{\alpha}_1$ while the two-step estimator $\hat{\alpha}_2$ is obtained by setting $A_N = \hat{V}_N^{-1}$ (Hansen (1982)).

Regarding the GMM estimator $\hat{\beta}$, it can be obtained by:

$$\hat{\beta} = (\bar{X}'ZA_NZ'\bar{X})^{-1}\bar{X}'ZA_NZ'\bar{y} \tag{6.64}$$

where $\bar{X}$ is a stacked $(T-2)N * k$ matrix of observations on $\bar{x}_{it}$ and the alternative choices of A_N will produce one-step and two-step estimators.

The procedure proposed by Arellano and Bond (1991) assures estimator consistency by removing panel-level effects through first-differentiation and by forming moment conditions derived from the first-difference errors of Equation 6.62.

Due to its availability in different economic and statistical software packages, the procedure proposed by Arellano and Bond (1991) has been widely applied in financial research. Examples can be found in Podrecca and Carmeci (2001) on economic growth, in Castells and Solé-Ollé (2005) on regional allocation of infrastructure investment, in Liu (2006) on financial structure, corporate finance and growth of manufacturing firms in Taiwan, in Naudé and Krugell (2007) on determinants of foreign direct investment in Africa, and finally, in Chang et al. (2011) on the relationship between military expenditure and economic growth.

6.10.2 Linear Dynamic Panel Data Modeling with Additional Moment Conditions

In the light of possible model limitations highlighted by Arellano and Bover (1995), Blundell and Bond (1998) propose a related estimator to Arellano and Bond (1991) using additional moment conditions in assuring estimator consistency under the only additional condition that $E = [v_i \Delta y_{i2}] = 0$ holds for all i in Equation 6.62. Building upon a *classical* dynamic panel-data model as presented in Equation 6.62, Blundell and Bond (1998) argue that the lagged-level instrument in the Arellano and Bond (1991) estimator becomes weak in two cases: first, if the autoregressive process becomes too persistent, and second, if the ratio of the variance of the panel-effects v_i to the variance of the idiosyncratic error ϵ_{it} becomes too large (Stata Corporation (2013)).

Building upon the work of Arellano and Bover (1995), Blundell and Bond (1998) propose to use moments conditions that use lagged differences as instruments for the level equation in addition to the moment conditions of lagged levels as instruments for the differenced equations - hence resulting in an additional moment estimator. Econometrically, their procedure results in a GMM estimator $\hat{\alpha}$ of the following form:

$$\hat{\alpha} = \hat{\alpha}_{dif} = (\bar{y}'_{-1} Z A_N Z' \bar{y}_{-1})^{-1} \bar{y}'_{-1} Z A_N Z' \bar{y} \tag{6.65}$$

where $\bar{y}'_i$ is the $(T-2)$ vector $(\Delta y_{i3}, \Delta y_{i4}, ..., \Delta y_{iT})$ and $\bar{y}'_{i,-1}$ is the $(T-2)$ vector $(\Delta y_{i2}, \Delta y_{i3}, ..., \Delta y_{i,T-1})$ (Blundell and Bond (1998)).

In the same fashion as Arellano and Bond (1991), the definition of the matrix A_N is essential in determining $\hat{\alpha}$. Blundell and Bond (1998) define the optimal weights of A_N as:

$$A_N = (N^{-1} \sum_{i=1}^{N} Z'_i \hat{u}_i \hat{u}'_i Z_i)^{-1} \tag{6.66}$$

with $\hat{\hat{u}}_i$ the residuals of an initial consistent estimator and $u_{it} \equiv v_i + \epsilon_{it}$ the decomposition of the error term.

The Blundell and Bond (1998) procedure had received increased attention across different fields in recent times; examples and applications of the procedure can be found in Lemma and Negash (2013) on the adjustment speed of debt maturity structures, in Lee and Mukoyama (2015) on productivity and employment dynamics of US manufacturing plants, in Gásquez and Royuela (2016) on the determinants of international football success. and finally, in Da Silva and Cerqueira (2017) on household electricity prices in the EU.

6.10.3 A Linear Dynamic Panel Data Model allowing for Autocorrelation in the Idiosyncratic Errors

As mentioned above, Arellano and Bond (1991) propose one-step and two-step GMM estimator using moment conditions relying on lagged levels of the dependent and predetermined variables. This procedure is augmented by Blundell and Bond (1998) who show that the lagged-level instruments in the Arellano and Bond (1991) estimator become weak in two cases: either as the autoregressive process becomes too persistent or if the ratio of the panel-level effect variance v_t to the variance of the idiosyncratic error ϵ_{it} becomes too large.

Both procedures require that there be no autocorrelation in the idiosyncratic errors, hence limiting there field of application. A linear dynamic panel data procedure can however be respecified as such, that the correlation in the idiosyncratic errors follows a low-order Moving-Average (MA) process, hence tackling the restriction imposed by Arellano and Bond (1991) and Blundell and Bond (1998).

Mathematically, a panel-data model like that in Equation 6.62 can be considered, where x and w might contain both lagged independent variables and time dummies. Define $\mathbf{X}_{it}^{L} = (y_{i,t-1}, y_{i,t-2}, ..., y_{i,t-p}, x_{it}, w_{it})$ as the $1 * K$ vector of covariates for i at time t where $K = p + k_1 + k_2$ and define p as the number of lags included, k_1 as the number of strictly exogenous variables in x_{it}, and k_2 as the number of predermined variables in w_{it} in order to rewrite Equation 6.62 as a set of T_i equations for each individual (Stata Corporation (2013)):

$$y_i^L = \mathbf{X}_i^L \delta + v_i \iota_i + \epsilon_i \tag{6.67}$$

where L stands for levels and T_i is the number of observations available for individual i. y_i, ι_i and ϵ_i are all $T_1 * 1$ while $\mathbf{X}_i$ is $T_i * K$.

Given a value of i, stacking the transformed and untransformed matrices of the covariates yields:

$$\mathbf{X}_i = \begin{pmatrix} \mathbf{X}_i^* \\ \mathbf{X}_i^L \end{pmatrix} \tag{6.68}$$

while we need also define a matrix of instruments $\mathbf{Z}_i$ of the following form (Stata Corporation (2013)):

$$\mathbf{Z}_i = \begin{pmatrix} \mathbf{Z}_{di} & 0 & \mathbf{D}_i & 0 & \mathbf{I}_i^d \\ 0 & \mathbf{Z}_{Li} & 0 & \mathbf{L}_i & \mathbf{I}_i^L \end{pmatrix} \tag{6.69}$$

where $\mathbf{Z}_{di}$ is the matrix of the GMM-type instrument for the difference equation and $\mathbf{Z}_{Li}$ is the matrix of the GMM-type instruments for the level equation. $\mathbf{D}_i$ is the matrix of standard instruments for the difference equation, while $\mathbf{L}_i$ is the matrix of standard instruments for the level equation. Finally, $\mathbf{I}_i^d$ is the matrix of standard instruments from the difference and level equations for the differenced errors, while $\mathbf{I}_i^L$ is the matrix of standard instruments from the difference and level equations for the level errors.

Now, the one-step estimator $\hat{\beta}_1$ can be defined as:

$$\hat{\beta}_1 = \mathbf{W}_1^{-1} \mathbf{Q}_{xz} \mathbf{A}_1 \mathbf{Q}_{zy} \tag{6.70}$$

where $\mathbf{Q}_{xz} = \sum_i \mathbf{X}_i' \mathbf{Z}_i$ and $\mathbf{Q}_{zy} = \sum_i \mathbf{Z}_i' y_i$ (Stata Corporation (2013)). Furthermore, $\mathbf{W}_1 = \mathbf{Q}_{xz} \mathbf{A}_1 \mathbf{Q}_{xz}'$ and $\mathbf{A}_1 = (\sum_i \mathbf{Z}_i' \mathbf{H}_{1i} \mathbf{Z}_i)^{-1}$ where H_{1i} is a diagonal matrix product of its first-difference transformation and the identity matrix.

Likewise, the two-step estimator $\hat{\beta}_2$ can be defined as:

$$\hat{\beta}_2 = \mathbf{W}_2^{-1}\mathbf{Q}_{xz}\mathbf{A}_2\mathbf{Q}_{zy} \tag{6.71}$$

with $\mathbf{W}_2 = \mathbf{Q}_{xy}\mathbf{A}_2\mathbf{Q}'_{xz}$ and $\mathbf{A}_2 = (\sum_i \mathbf{Z}'_i\mathbf{H}_{2i}\mathbf{Z}_i)^{-1}$, where $\mathbf{H}_{2i}$ is a product of the one-step residuals.

More information about the procedure, as well as an excellent mathematical derivation of the bias-corrected estimator for the robust standard errors of two-step GMM estimators can be found in Windmeijer (2005).

6.10.4 A Bias Corrected Least-Squares Dummy Variable Dynamic Panel Data Estimator

A final renowned panel-data estimation procedure is the bias-corrected Least-Squares Dummy Variable (LSDV) procedure initially proposed by Nickell (1981) and that assures consistency of the estimates in a scenario in which the amount of panels rises towards infinity.

Formally, an LSDV procedure transforms Equation 6.62 into a matrix format:

$$y = D\eta + W\delta + \epsilon \tag{6.72}$$

where y and $W = (y_{t-1} \vdots X)$ are $(NT * 1)$ and $(NT * k)$ matrices of stacked observations respectively (Bruno (2005b)). Furthermore, $D = I_N \otimes \iota_T$ is the $(NT * N)$ matrix of individual dummies with ι_T the $(T * 1)$ vector of all unity elements. Finally, η is the $(N * 1)$ vector of individual effects, while ϵ is the $(NT * 1)$ vector of disturbances and $\delta = (\alpha \vdots \beta')$ is the $(k * 1)$ vector of coefficients.

Building upon the exogenous selection procedure of Bun and Kiviet (2003) applied to unbalanced panels, Bruno (2005a) proposes a more general approximation procedure for the coefficients in Equation 6.62 valid for the observation interval $[0, T]$. Bruno (2005a) defines a selection indicator r_{it} such that $r_{it} = 1$ if (y_{it}, x_{it}) is observed, and $r_{it} = 0$ otherwise in order to define a dynamic selection rule $s(r_{it}, r_{i,t-1})$ that only includes observations for which both the current value and the lagged value are observable. Formally:

$$s_{it} = \left\{ \begin{array}{ll} 1 & \text{if } (r_{i,t}, r_{i,t-1} = (1,1) \\ 0 & \text{otherwise} \end{array} \right\} \quad i = 1, ..., N \text{ and } t = 1, ..., T \tag{6.73}$$

so that for any i, the number of usable observations is given by $T_i = \sum_{t=1}^{T} s_{it}$ while the total number of usable observations is given by $n = \sum_{i=1}^{N} T_i$ and $\bar{T} = \frac{n}{N}$

denotes the average group size. For every i, Bruno (2005b) defines a $(T*1)$ vector $s_i = [s_{i1},...,s_{iT}]'$, a $(T*T)$ diagonal matrix S_i that has the vector s_i on its diagonal, and a $(NT*NT)$ block-diagonal matrix $S = \text{diag}(S_i)$ so that Equation 6.72 can be rewritten:

$$Sy = SD\eta + SW\delta + S\epsilon \tag{6.74}$$

The LSDV estimator is defined as:

$$\delta_{\text{LSDV}} = (W'M_sW)^{-1}W'M_sy \tag{6.75}$$

where $M_s = S\{I - D(D'SD)^{-1}D'\}S$ is the symmetric and idempotent $(NT*NT)$ matrix deleting individual means and selecting usable observations (Bruno (2005b)).

Further discussions on the Least-Squares Dummy Variable procedure can be found in Kiviet (1995), in Kao (1999), and finally, in Bun and Carree (2005).

CHAPTER 7

An Investigation Into the Relationships Between Precious Metals and Inflation

Based on a Bierens and Martins (2010) formal test for time variation, this chapter examines the relationship between gold and silver, and inflation. Considering forty years of data for the United States of America, the United Kingdom of Great Britain and Northern Ireland, and Japan, time varying cointegration relationships are extracted and breaks in the relationship between inflation and the two precious metals identified.

Evidence points to a break in the relationship(s) of gold and official inflation in the mid 1990s in the USA but to less clear results for the UK and Japan. However, gold seems to have offered a protection against an increase in money supply throughout nearly the entire past 40 year period in the US and the UK but failed to do so in Japan. Supporting previous findings we find evidence for a time-varying relationship in cointegration between gold and both predicted and realised inflation in nearly all cases.

Regarding silver, short-run cointegration relationships with US inflation measures are uncovered. While silver acts as a short-run hedge against the CPI in the United States of America during crises periods, it isn't able to do so in regard to the PPI and money supply. In the United Kingdom, silver is found to be a better hedge against nominal consumer price inflation than gold, while the hedging ability is found to be limited against the PPI. Indeed, regarding the relationship with both the PPI an British money supply, silver was only a short-run hedge during the late 1970s and throughout the 1980s and mid 1990s respectively. In Japan, silver isn't a good inflation hedge due to the disruptive effect of the Hunt brother's cornering of the silver market in 1980, while a break in the silver-PPI relationship only occurred later, around 1989. Interestingly however, silver is found to be a better hedge than gold against money supply in the Asian economy, uncovering the inflation hedging superiority of the white precious metal in comparison to gold.

7.1 Gold

In contrary to silver, gold has an *alleged* property to be used as an inflation hedge. This section identifies the truthfulness of this belief by examining the relationship between gold and nominal inflation, predicted inflation, and inflation surprise in the United States, the United Kingdom and Japan.

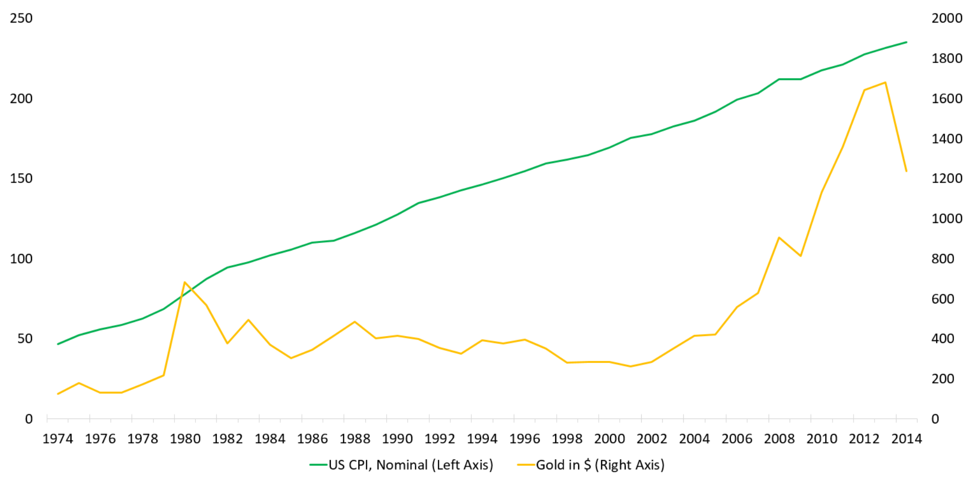
7.1.1 United States of America

The United States play an important role on the gold market. Not only because of the considerable size of their gold holdings, but mainly because the official price of gold is quoted in US Dollars; leading to a quite obvious relationship between the price of gold and the strength of the US Dollar as a currency.

7.1.1.1 Consumer Price Index

When considering a plot of the nominal US CPI against the price of gold, an obvious trend can immediately be uncovered for both series (Figure 7.1).

Figure 7.1: The Nominal US CPI and Gold in $ between 1974 and 2014



However, even though the nominal consumer price inflation index increased steadily over the past 40 years, the price of gold stagnated throughout the 1990s and really only increased from 2002 onward. Since mid 2012 however, the price of gold started to drop again and fell back to the level of 2010.

7.1.1.1.1 Gold in $ and the Nominal Consumer Price Index

A first step when looking at the relationship between gold and the nominal US CPI is to identify the optimal lag length to use in the model; the Schwarz Bayesian Information Criterion (Schwarz (1978)) points towards an optimal lag length of three months.

The Augmented Dickey Fuller test (Dickey and Fuller (1979, 1981)) indicates that both series are non-stationary and possess a unit root (Table 7.1).

Table 7.1: Augmented Dickey Fuller Test - Gold & the US CPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-1.988	-3.443	-2.871	-2.570
D.Gold	-4.636	-2.335	-1.648	-1.283
USCPI	-2.690	-3.981	-3.421	-3.130
D.USCPI	-4.380	-2.335	-1.648	-1.283

The Dickey Fuller test results indicate that levels values can be used to proceed to the next step: identifying a possible long-run cointegration relationship between the two series by means of the methodology proposed by Johansen (1991, 1995). The results in table 7.2 show evidence for a long-run cointegration relationship between the price of gold and the index for consumer price inflation in the United States of America.

Table 7.2: Johansen Test for Cointegration - Gold & the US CPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	8	-2656.9807	.	64.2346	12.53
1	11	-2625.1941	0.12453	0.6615*	3.84
2	12	-2624.8634	0.00138		

In other words, considering the overall time window between January 1974 and January 2014, gold was cointegrated with the nominal US CPI on the long-run. However, an essential question is to understand if the identified relationship was varying through time, which can be done by means of the Bierens and Martins (2010) test (Table 7.3).

Table 7.3: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the US CPI, Nominal

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	6.44	4.61	5.99	0.03991
m = 2	13.12	7.78	9.49	0.01069
m = 3	16.13	10.64	12.59	0.01307
m = 4	17.28	13.36	15.51	0.02735

The test results indicate significant and robust evidence for time-variation in the cointegration relationship of the two series. So even though gold is cointegrated with nominal US consumer price inflation on the long-run, this cointegration relationship did not persevere during the entirety of the time-window considered.

The Gregory and Hansen test is used to identify regime shifts in the cointegration relationship between two series (Table 7.4).

Table 7.4: Gregory and Hansen Test - Gold & the US CPI, Nominal

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-3.07	310	Oct. 1999	-5.47	-4.95	-4.68
Z_t	-3.05	308	Aug. 1999	-5.47	-4.95	-4.68
Z_α	-20.09	308	Aug. 1999	-57.17	-47.04	-41.85

The results indicate a clear break in the relationship about late 1999. The final test to run is the Bai and Perron test allowing to identify multiple breaks in the cointegration relationship (Table 7.5).

Table 7.5: Bai and Perron Multiple Break Test - Gold & the US CPI, Nominal

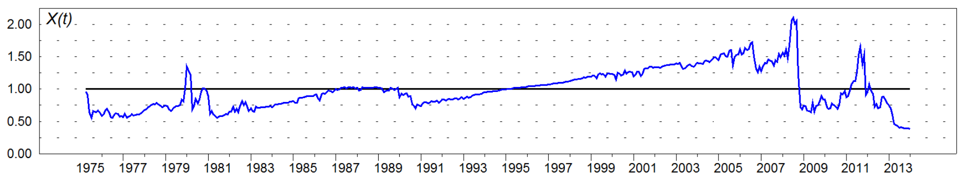
	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	2.576	0.047	54.223	0
2	DZ(1,2)	4.346	0.109	39.714	0
3	DZ(1,3)	6.558	0.086	76.452	0

Breakpoint	Lower 95%	-	Upper 95%
Sep-07	Jun-07	to	Jul-09
Apr-10	Oct-09	to	Jun-10

From all the test results above, the following can be concluded about the relationship between the price of gold and the nominal US CPI. A long-run cointegration relationship existed between both series over the entire time-window between January 1974 and January 2014. However, this relationship was unstable through time; during certain periods, gold and the nominal US CPI were indeed not cointegrated. Formal testing procedures point towards the breaks in the long-run cointegration relationship. The Gregory and Hansen (1996a) procedure points towards a regime shift around late 1999, while the Bai and Perron (2003a) procedure indicates major breaking points in September 2007 and in April 2010.

A visualisation of the changing relationship between the two time series can be obtained by plotting the Johansen Test Trace Statistic, where cointegration exists if the blue line is below the horizontal black line (Figure 7.2).

Figure 7.2: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal US CPI (Scaled by the 5% Critical Value) - All Parameters



The result are all very revealing. There is evidence that since around the mid 1990s, gold stops to be cointegrated with consumer price inflation in the USA, results reflecting the decrease of the gold price during this period against an increase of the rate of inflation (Figure 7.1). The Gregory and Hansen (1996a) test results indicate a break in late 1999 (Table 7.4), when the price of gold was around it's lowest point in the past forty years. On the other hand, the Bai and Perron (2003a) test outlines time windows drawn by financial crises (Table 7.5). The first breaking point in September 2007, occurring within the time interval between June 2007 and July 2009 clearly reflects the Global Crisis of 2008. Figure 7.2 suggests that the troublesome events of 2008 pushed the two time series back to a cointegration relationship with the blue line dropping below the horizontal scale. The second time window outlined by the Bai and Perron (2003a) procedure occurs between October 2009 and June 2010 and a breakpoint in April 2010 (Table 7.5). It seems to suggest that the growing complication to finance European Governments and the weakness of the US Dollar around that time pushed gold away from a cointegration relationship with the US CPI. The cointegration relationship observed in the early

1980s is in line with Batten et al. (2014) who come to the same conclusion. Baur and Lucey (2010) and Baur and McDermott (2010) find evidence for gold's capacity to act as a hedge during market turmoil, evidence from the Financial Crisis and the return to a cointegration relationship in 2012 are observations in favour of the authors findings. The regime shift occurring in 1999 (Table 7.4) is also identified by Beckmann and Czudaj (2013) who also point towards regime shifts in 2006 and 2009, results somehow similar to the Bai and Perron (2003a) multiple break test (Table 7.5). A possible discussion occurs when one considers the shift back to cointegration between gold and the nominal US CPI in 2008 (Figure 7.2). Here, an explanation can be found in gold's safe haven capacities during market turmoils (Baur and Lucey (2010)), but also in the fact, that the year of 2008 is one of the rare deflationary episodes of the US CPI (Hoang et al. (2016)).

In conclusion, the findings assert that gold was a hedge against nominal consumer price inflation in the USA except for a rather long time window during the 1990s. Market turmoils tend to assure a cointegration relationship between both time series due to the alleged safe haven qualities of gold as a financial asset. The combination between a stormy financial climate and a deflationary episode in 2008 led to a drastic return to cointegration between gold and the US CPI. Except for a short interruption in 2010 linked to a weak US Dollar, gold is again, since 2012, a comfortable hedge against the Consumer Price Index in the USA.

7.1.1.1.2 Gold in $ and the Predicted Consumer Price Index

Predicted inflation was derived using an ARIMA(1,1,3) model, more information about the model in question can be found in Appendix A.

The Schwarz Bayesian Information Criterion (Schwarz (1978)) suggests an optimal lag length of one month and unanimity amongst the time series is assured by using their natural logarithm. The Dickey Fuller test results indicate that both series have the same order of integration (Table 7.6), enabling a continuation of the testing procedures.

Following the methodology applied on the nominal series, the Johansen test for cointegration is used to identify the nature of the long-run relationship between gold and the predicted US CPI (Table 7.7).

Table 7.6: Augmented Dickey Fuller Test - Gold & the US CPI, Predicted

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ln_gold	-1.336	-3.443	-2.871	-2.570
D.ln_gold	-4.677	-2.335	-1.648	-1.283
pred_USCPI	-2.527	-3.981	-3.421	-3.130
D.pred_USCPI	-2.401	-2.335	-1.648	-1.283

Table 7.7: Johansen Test for Cointegration - Gold & the US CPI, Predicted

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	0	2489.9897	.	239.1182	12.53
1	3	2608.5342	0.39041	2.0292*	3.84
2	4	2609.5488	0.00423		

Results indicate a long-run cointegration relationship between gold and the predicted US CPI from January 1974 to January 2014. This long-run relationship is, however, time-varying as indicated by the Bierens and Martins (2010) test results (Table 7.8).

Table 7.8: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the US CPI, Predicted

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	15.31	4.61	5.99	0.00047
m = 2	20.96	7.78	9.49	0.00032
m = 3	22.04	10.64	12.59	0.00119
m = 4	26.60	13.36	15.51	0.00083

According to the Gregory and Hansen (1996a) procedure, a major shift in the cointegration relationship occurs in early 1998 (Table 7.9) and therefore about one and a half years earlier than between gold and the nominal US CPI (Table 7.4), a results indicating the quicker adaptation of the market to anticipated changes in inflation.

Table 7.9: Gregory and Hansen Test - Gold & the US CPI, Predicted

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-3.16	289	Feb. 1998	-5.47	-4.95	-4.68
Z_t	-3.21	288	Jan. 1998	-5.47	-4.95	-4.68
Z_α	-20.44	288	Jan. 1998	-57.17	-47.04	-41.85

Somewhat different results however are obtained through the Bai and Perron (2003a) procedure (Table 7.10).

Table 7.10: Bai and Perron Multiple Break Test - Gold & the US CPI, Predicted

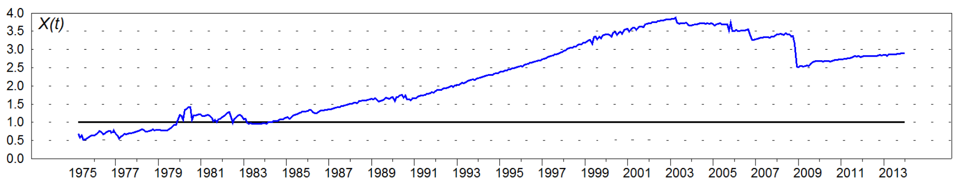
	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	1.283	0.004	323.280	0
2	DZ(1,2)	1.154	0.003	345.511	0
3	DZ(1,3)	1.315	0.005	251.006	0

Breakpoint	Lower 95%	-	Upper 95%
Apr-90	Aug-89	to	Sep-91
Sep-07	May-07	to	Mar-08

Even though the breakpoint of September 2007 is still identified (Table 7.5), a new window between August 1989 and September 1991 seems to be relevant in the cointegration relationship between gold and the predicted US CPI. A finding likely to be explained by the observed start of a dropping gold price in the early 1990s (Figure 7.1).

A visualisation of the relationship between gold and predicted inflation is obtained based on the Trace Statistic of the Johansen Test where a cointegration relationship does indeed exist if the blue line is below the horizontal scale (Figure 7.3).

Figure 7.3: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted US CPI (Scaled by the 5% Critical Value) - All Parameters



In contrast to the results derived from nominal consumer price inflation in the USA (Figure 7.2), it seems that gold was only an efficient hedge against predicted inflation during the late 1970s; since 1985, gold is no longer cointegrated with the predicted US CPI. A challenge to the finding for nominal inflation: concerning predicted consumer price inflation in the United States of America, it can be asserted that gold is not an effective hedging instrument.

Similar patterns are however observed (Figures 7.2 and 7.3). One such pattern is the cointegration relationship between both series in the late 1970s, broken again at the time of the Second Oil Crisis and the quick increase and decrease of the gold price linked to it. The effect of the recent Global Financial Crisis can also be observed for both respective time series, with the difference that gold was cointegrated with nominal inflation between 2008 and 2011 (Figure 7.2). A major difference of the results obtained from nominal and predicted inflation is that gold did not recently returned to a situation of cointegration with predicted inflation; gold is however a hedge against nominal US consumer price inflation since 2012.

7.1.1.1.3 Gold in $ and Consumer Price Inflation Surprise

Inflation surprise is the difference between nominal inflation and predicted inflation. Not surprisingly, inflation surprise is an I(0) series and needs to be considered against changes in the gold price (Table 7.11) using an optimal lag length of zero months (Schwarz (1978)).

Table 7.11: Augmented Dickey Fuller Test - Gold & the US CPI, Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
D.ln_gold	-4.677	-2.335	-1.648	-1.283
surprise_USCPI	-4.897	-2.335	-1.648	-1.283

The two I(0) series can be fit into an ARDL model in order to test their long-run relationship. The results in Table 7.12 suggest that the series indeed share a long-run relationship.

Table 7.12: ARDL Test - Gold & the US CPI, Surprise

F-Statistic	**1% Critical Value**	**2.5% Critical Value**	**5% Critical Value**	**10% Critical Value**
272.63	6.84	5.77	4.94	4.04

t-Statistic	**1% Critical Value**	**2.5% Critical Value**	**5% Critical Value**	**10% Critical Value**
-23.154	-3.43	-3.13	-2.86	-2.57

Indexing the changes in the price of gold as well as the changes in inflation surprise allows both time series to become I(1) integrated (Table 7.13). The Schwarz (1978) procedure suggests using an optimal lag length of one month in the system.

Table 7.13: Augmented Dickey Fuller Test - Gold & the US CPI, Indexed Surprise

Variable Considered	**Test Statistic**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
gold_index	-1.409	-3.443	-2.871	-2.570
D.gold_index	-4.648	-2.335	-1.648	-1.283
USCPI_sur.ind	-1.181	-3.443	-2.871	-2.570
D.USCPI_sur.ind	-4.592	-2.335	-1.648	-1.283

In contrast to the results for nominal and predicted consumer price inflation in the USA, gold is not cointegrated with inflation surprise in the long-run as the Johansen test results suggest (Table 7.14). When no cointegration vector is detected by Johansen's procedure, it is impossible to proceed in running a Bierens and Martins (2010) test for time-varying cointegration.

Table 7.14: Johansen Test for Cointegration - Gold & the US CPI, Indexed Surprise

Maximum Rank	**Parms**	**LL**	**Eigenvalue**	**Trace Statistic**	**5% Critical Value**
0	0	16.243884	.	4.5956*	12.53
1	3	18.133206	0.00787	0.8170	3.84
2	4	18.541704	0.00171		

The Gregory and Hansen (1996a) procedure is used to detect regime shifts in the long-run relationship between both time series (Table 7.15).

Table 7.15: Gregory and Hansen Test - Gold & the US CPI, Indexed Surprise

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-3.92	285	Nov. 1997	-5.47	-4.95	-4.68
Z_t	-3.99	285	Nov. 1997	-5.47	-4.95	-4.68
Z_α	-28.88	285	Nov. 1997	-57.17	-47.04	-41.85

All three tests indicate that the major shift in the long-run relationship between gold and inflation surprise occurs in November 1997, and therefore a few months earlier than what is observed for gold and predicted inflation (Table 7.9). In line with the previous Gregory and Hansen (1996a) test results, it can be robustly asserted that a shift in the relationship between gold and the US CPI occured in the late 1990s, towards the end of a weak gold price phase (Figure 7.1).

Table 7.16: Bai and Perron Multiple Break Test - Gold & the US CPI, Indexed Surprise

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	0.997	0.005	179.607	0
2	DZ(1,2)	1.165	0.002	486.103	0
3	DZ(1,3)	1.394	0.005	290.424	0

Breakpoint	Lower 95%	-	Upper 95%
Apr-79	Nov-78	to	Jun-79
Jan-07	Aug-06	to	Apr-07

The Bai and Perron (2003a) multiple break procedure points toward two different time windows (Table 7.16). The first around 1979 and the second around 2007; results different to the Gregory and Hansen (1996a) results (Table 7.15).

Figure 7.4: US CPI Surprise Index and Gold between 1974 and 2014

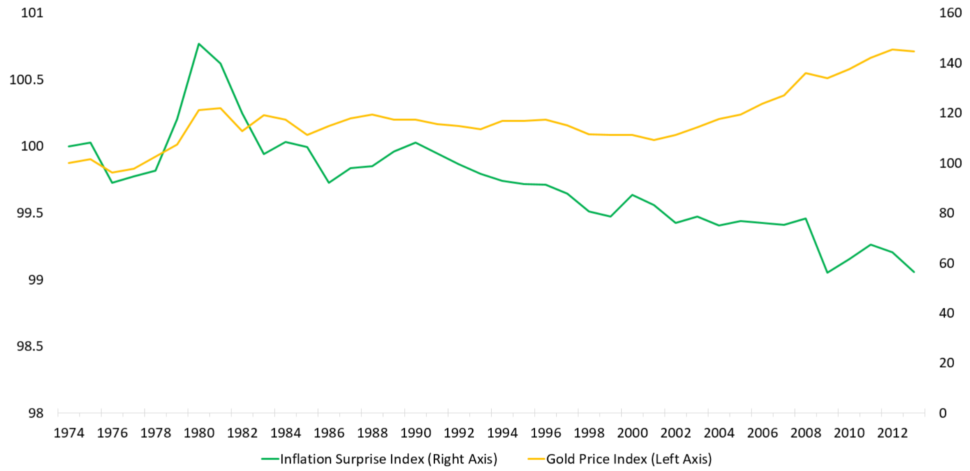


Figure 7.4 nicely illustrates the findings of the analysis conducted. It can clearly be observed, that the two time series start to veer apart from the late 1970s, early 1980s, a break point indicated by the Bai and Perron (2003a) procedure. The second time window outlined in Table 7.16, between August 2006 and April 2007 indicates the drop in the inflation surprise index (occurring during short deflationary period in the US (Hoang et al. (2016))) against a continuing increase of the price of gold. The results of the Gregory and Hansen (1996a) procedure (Table 7.15) are an early indication for the peak in inflation surprise around the late 1990s, occurring, like the findings for nominal and predicted inflation, around a time drawn by international financial crises.

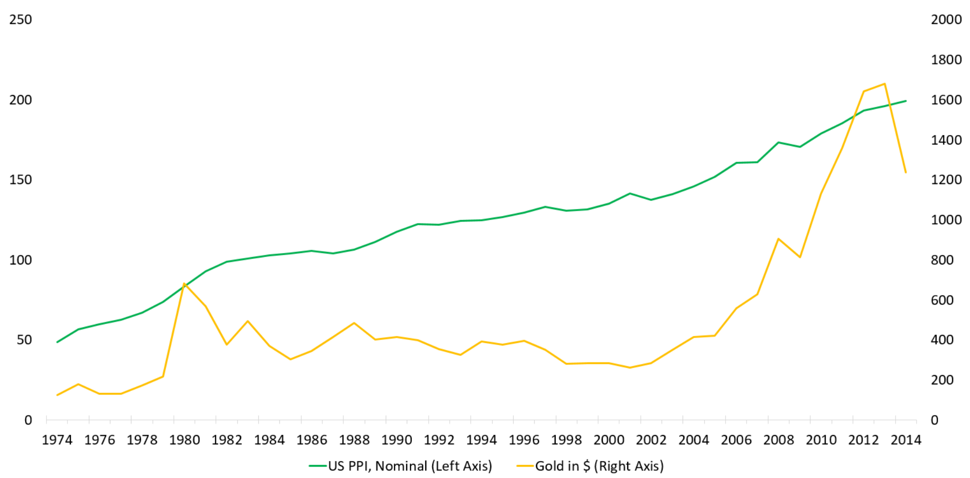
7.1.1.1.4 Concluding Remarks

Considering all the results obtained for the US CPI, it can be asserted that except for a time-window between the mid 1990s and 2008, gold was indeed cointegrated with nominal inflation (Figure 7.2). In light of the finding that gold returned to a cointegration relationship during the Global Financial Crisis of 2008, previous academic findings about the hedging and safe haven capacity of gold are extended (Baur and Lucey (2010) and Baur and McDermott (2010)). Furthermore, as discussed above, the different episodes of cointegration between the series outlined by the model correspond to the findings of previous papers on the topic (Beckmann and Czudaj (2013), Batten et al. (2014) and Hoang et al. (2016)). However, results obtained from all different inflation measures challenge the conclusion that gold is a hedge against inflation during economic crises. Considering all inflation measures derived, nominal, predicted and surprise inflation, many indicators reveal that the late 1990s are a crucial time window in the relationship between gold and the US CPI, leading to a break in the relationship (Figure 7.2, Tables 7.4, 7.9 and 7.15). Even though the late 1990s are drawn by the Asian Financial Crisis, the Russian Financial Crisis, the Dot-com Bubble and the early days of the 2000s recession, gold is not a hedge against any of the three considered US CPI measures during that time period. The abrupt return to a cointegration relationship between gold and inflation in 2008 is therefore to be explained by a period of deflation in the United States of America (Hoang et al. (2016)) and should not be used as an argument in favour of gold's empirical ability to protect investors from inflation in crisis periods.

7.1.1.2 Producer Price Index

The Producer Price Index reflects the inflationary pressure for inputs from producers in the United States of America. Considering both time series in Figure 7.5, a pattern similar to the CPI can be observed (Figure 7.1). A difference remains in the level of the PPI, that does not reach the high values of the equivalent measure for consumer price inflation.

Figure 7.5: The nominal US PPI and Gold in $ between 1974 and 2014



The nominal PPI and the price of gold start to veer apart in the early 1980s. While the PPI is drawn by a steady increase with short deflation periods around 2000 and 2008, the price of gold is steadily falling during the 1990s to record a steep price increase starting in the early 2000s.

7.1.1.2.1 Gold in $ and the Nominal Producer Price Index

An optimal lag length of two months is recommended in a model consisting of the price of gold and the nominal US PPI (Schwarz (1978)) and the Augmented Dickey Fuller test (Dickey and Fuller (1979, 1981)) indicates non-stationarity for both time series (Table 7.17).

Table 7.17: Augmented Dickey Fuller Test - Gold & the US PPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-1.988	-3.443	-2.871	-2.570
D.Gold	-4.636	-2.335	-1.648	-1.283
USPPI	-1.583	-3.981	-3.421	-3.130
D.USPPI	-5.248	-2.335	-1.648	-1.283

In the next step, both I(1) series are fitted into a Johansen (1991, 1995) test for cointegration (Table 7.18).

Table 7.18: Johansen Test for Cointegration - Gold & the US PPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	4	-2971.4890	.	33.6891	12.53
1	7	-2955.1882	0.06580	1.0874*	3.84
2	8	-2954.6444	0.00227		

The results indicate a cointegration relationship over the long-run between gold and the US Producer Price Index. The stability of this relationship can be analysed via the Bierens and Martins (2010) test for time-varying cointegration (Table 7.19).

Table 7.19: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the US PPI, Nominal

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	8.44	4.61	5.99	0.01470
m = 2	10.61	7.78	9.49	0.03128
m = 3	10.88	10.64	12.59	0.09227
m = 4	13.15	13.36	15.51	0.10675

So far, the results observed for the US PPI are quite similar to the results of the US CPI: gold was cointegrated with the nominal inflation index between

January 1974 and 2014, but the Bierens and Martins (2010) test indicates that this relationship was not stable over time. The next step therefore consists of identifying the points in time at which the relationship between gold and the nominal PPI shifts.

Table 7.20: Gregory and Hansen Test - Gold & the US PPI, Nominal

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-3.11	296	Aug. 1998	-5.47	-4.95	-4.68
Z_t	-3.24	308	Aug. 1999	-5.47	-4.95	-4.68
Z_α	-24.19	308	Aug. 1999	-57.17	-47.04	-41.85

The Gregory and Hansen (1996a) procedure (Table 7.20) indicates very similar breakpoints as identified for the nominal US CPI (Table 7.4): evidence for a regime shift in the late 1990s. It is remarkable, that both, the Z_t and the Z_a unit root test point towards a break in August 1999 for both the CPI and the PPI, reinforcing our earlier comments and explanations on the importance of the late 1990s for the relationship between gold and inflation in the USA.

Table 7.21: Bai and Perron Multiple Break Test - Gold & the US PPI, Nominal

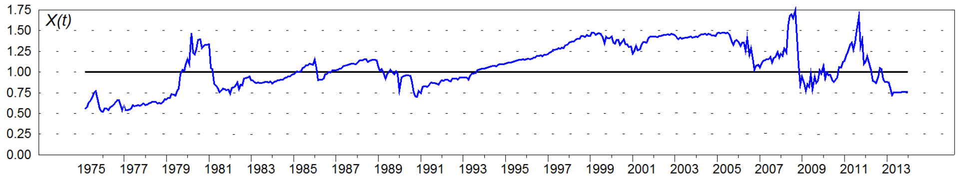
	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	3.065	0.048	64.000	0
2	DZ(1,2)	5.300	0.114	46.562	0
3	DZ(1,3)	7.789	0.088	88.926	0

Breakpoint	Lower 95%	-	Upper 95%
Aug-07	Apr-07	to	Oct-08
Apr-10	Sep-09	to	Jul-10

Regarding the Bai and Perron (2003a) test results (Table 7.21), the time windows indicated are again very similar to those outlined for the US CPI (Table 7.5). A difference however is that the first time window, corresponding to the Global Financial Crisis of 2008, occurs earlier than that indicated for the US CPI. Conciliating both breakpoints procedures in Tables 7.20 and 7.21, the results indicate the importance that international financial crises events have on the cointegration relationship between gold and nominal producer price inflation in the USA.

Visualising the change in the relationship by plotting the Johansen Test Trace Statistic enables an easier understanding of when the two time series in question are cointegrated (Figure 7.6).

Figure 7.6: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal US PPI (Scaled by the 5% Critical Value) - All Parameters



The results for the nominal US PPI are very similar to those of the nominal US CPI (Figure 7.2) with the same windows of cointegration observable for the two different inflation series. Gold was cointegrated with the US PPI throughout the 1970s with a break occuring around 1980, very similar to the findings for the nominal CPI (Figure 7.2). For the PPI however, it seems that the break in cointegration starting in 1980 is longer than it was for the nominal US CPI. So even though gold quickly returned to becoming a hedging instrument for consumer prices, it took more time to return to a cointegration relationship with the PPI. During the early 1980s, gold and the PPI were cointegrated though this relationship started to change around 1985, about a year earlier than what is observed for gold and the nominal US CPI. Since around the mid 1990s, gold is not cointegrated with producer price inflation until the deflationary period of 2008 (Figures 7.6 and 7.5). The change in trend around late 1999, where the Trace Statistic starts to drop (Figure 7.6) is also indicated by the Gregory and Hansen (1996a) procedure (Table 7.20) and supported by the findings of Beckmann and Czudaj (2013). The first time window identified by the Bai and Perron (2003a) multiple break test (Table 7.21), between April 2007 and October 2008 indicates the fallback towards a cointegration relationship of gold and the PPI - where the blue line drops below the horizontal scale (Figure 7.6). The Financial Crisis of 2008 and the deflationary period accompanying the events led the two series to be cointegrated again until 2011, with the exception of a short time window indicated by the Bai and Perron (2003a) procedure (Table 7.21). International turmoil on the global financial markets in the late 1990s and early 2000s also played a role on pushing back the two series towards cointegration, even though the Trace Statistic started increasing again around 2001 (Figure 7.6) and a cointegration relationship was therefore never reached between the two series towards the very end of the second millennium. Finally, since 2012, gold and the PPI were again cointegrated.

In conclusion, gold and the Producer Price Index in the USA were cointegrated over the long-run between January 1974 and January 2014. However this long-run relationship broke between 1995 and 2008. Financial turmoils act in favour of gold's role as a hedging instrument (see Baur and Lucey (2010) and Baur and McDermott (2010)) though the deflationary episode of 2008 played a major role in pushing gold and the PPI towards cointegration. In more recent times, since 2012, gold and the PPI are again cointegrated, a finding of importance to producers who like to use an investment in gold as a protection against rising input prices.

7.1.1.2.2 Gold in $ and the Predicted Producer Price Index

Details about the selection of the appropriate ARIMA(2,1,1) model to derive predicted PPI values can be found in Appendix B.

The Schwarz Bayesian Information Criterion (Schwarz (1978)) points towards an optimal lag length of one month to use in the model and the Augmented Dickey Fuller test indicates that both series are integrated of order one (Table 7.22).

Table 7.22: Augmented Dickey Fuller Test - Gold & the US PPI, Predicted

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ln_gold	-1.336	-3.443	-2.871	-2.570
D.ln_gold	-4.677	-2.335	-1.648	-1.283
pred_USPPI	-2.795	-3.981	-3.421	-3.130
D.pred_USPPI	-3.560	-2.335	-1.648	-1.283

The Johansen procedure is used to detect a possible long-run relationship between the two I(1) time series (Table 7.23).

Table 7.23: Johansen Test for Cointegration - Gold & the US PPI, Predicted

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	0	2318.4536	.	78.1714	12.53
1	3	2356.2769	0.14609	2.5249*	3.84
2	4	2357.5393	0.00526		

The Johansen test results indicate that gold and the predicted producer price index were cointegrated between 1974 and 2014, but that the relationship varied through time as indicated by the Bierens and Martins (2010) test results (Table 7.24).

Table 7.24: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the US PPI, Predicted

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	24.71	4.61	5.99	0.00000
m = 2	28.15	7.78	9.49	0.00001
m = 3	29.27	10.64	12.59	0.00005
m = 4	36.54	13.36	15.51	0.00001

The results so far are similar to those observed for the nominal US Producer Price Index (Tables 7.18 and 7.19): the inflation series is cointegrated with the price of gold but this relationship varied over the past 40 years. The Gregory and Hansen (1996a) procedure indicated shifts in the cointegration relationship between gold and the nominal PPI around August 1998 and August 1999, regarding the results for the predicted PPI, these shifts are clustered around early 1998 (Table 7.25).

Table 7.25: Gregory and Hansen Test - Gold & the US PPI, Predicted

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-3.36	289	Feb. 1998	-5.47	-4.95	-4.68
Z_t	-3.40	288	Jan. 1998	-5.47	-4.95	-4.68
Z_α	-23.96	288	Jan. 1998	-57.17	-47.04	-41.85

A considerable difference to the nominal PPI is found considering the Bai and Perron (2003a) results.

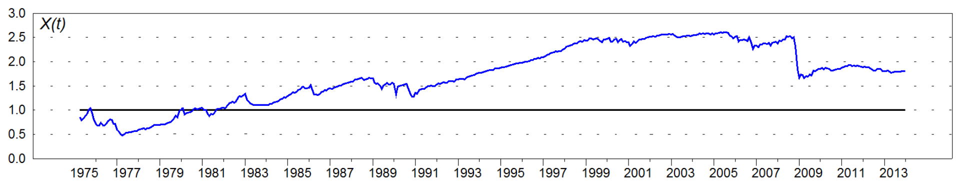
Table 7.26: Bai and Perron Multiple Break Test - Gold & the US PPI, Predicted

	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	1.279	0.004	356.064	0
2	DZ(1,2)	1.200	0.003	369.784	0
3	DZ(1,3)	1.361	0.005	274.255	0

Breakpoint	Lower 95%	-	Upper 95%
Sep-90	May-89	to	Nov-93
Aug-07	Apr-07	to	Jan-08

The time window between 2009 and 2010 observed for the nominal PPI (Table 7.21) is not indicated in the case of the predicted PPI, but seems to have been exchanged for the time window between May 1989 and November 1993 (Table 7.26).

Figure 7.7: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted US PPI (Scaled by the 5% Critical Value) - All Parameters



A visualisation of the cointegration relationship between gold and the predicted Producer Price Index in the USA shows that a cointegration relationship between the two series only existed in the late 1970s, up until approximately 1982 (Figure 7.7). The Gregory and Hansen (1996a) results indicate a shift in the cointegration relationship around early 1998 (Table 7.25), a time around which the Trace Statistic reaches a local maximum after a steady increase since 1977; a local maximum around 1998 is also observed for the relationship between gold and the nominal PPI (Figure 7.6). The first time window indicated by the Bai and Perron (2003a) procedure (Table 7.26), between May 1989 and November 1993, indicates the attempted change in trend between the two series, where the blue line starts to fall back towards the horizontal scale, however failing to reach a relationship of cointegration (Figure 7.7). An early indication of the effect of the Global Financial Crisis of 2008 is given by the second time window of the Bai and Perron (2003a) procedure: between April 2007 and January 2008 (Table 7.26). The early indication of a changing relationship due to the Financial Crisis is also observed for the results obtained for the predicted Consumer Price Index (Table 7.10 and Figure 7.3). Even though the pattern in Figure 7.7 somewhat resembles the observations for the nominal US PPI (Figure 7.6), a big resemblance is found with the predicted CPI (Figure 7.3). Except for the late 1970s, gold is not cointegrated with expected inflation in the United States of America. It seems as though the Bai and Perron (2003a) procedure indicates changes in the relationship proactively, pointing towards the anticipation of market actors when looking at expected inflation rather than nominal values. Even though gold was an on-and-off hedge against the nominal PPI between 1974 and 2014 (Figure 7.6), it can be said that gold is not an effective hedge against predicted PPI values except for the late 1970s, a period that drives the long-run relationship of both series (Figure 7.7 and Table 7.23).

7.1.1.2.3 Gold in $ and Producer Price Inflation Surprise

Producer Price inflation surprise and the monthly changes in the price of gold are both I(0) series as suggested by the Augmented Dickey Fuller test (Table 7.27).

Table 7.27: Augmented Dickey Fuller Test - Gold & the US PPI, Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
D.ln_gold	-4.677	-2.335	-1.648	-1.283
surprise_USPPI	-6.611	-2.335	-1.648	-1.283

The I(0) series can be fitted into an ARDL model with an optimal lag length of zero months (Schwarz (1978)) to test their long-run relationship (Table 7.28).

Table 7.28: ARDL Test - Gold & the US PPI, Surprise

F-Statistic	1% Critical Value	2.5% Critical Value	5% Critical Value	10% Critical Value
272.682	6.84	5.77	4.94	4.04

t-Statistic	1% Critical Value	2.5% Critical Value	5% Critical Value	10% Critical Value
-23.197	-3.43	-3.13	-2.86	-2.57

The ARDL test results suggest a levels relationship between the two time-series. The next step consists of indexing the two time series in order to transform them into I(1) integrated series. The Schwarz (1978) procedure suggests using an optimal lag length of one month in the system. The Dickey Fuller test results confirm that the suprise PPI index and the gold change index are both I(1) series (Table 7.29).

Table 7.29: Augmented Dickey Fuller Test - Gold & the US PPI, Indexed Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
gold_index	-1.409	-3.443	-2.871	-2.570
D.gold_index	-4.648	-2.335	-1.648	-1.283
USPPI_sur.ind	-0.791	-3.443	-2.871	-2.570
D.USPPI_sur.ind	-6.245	-2.335	-1.648	-1.283

In contrast to a relationship in levels of the two time series suggested by the ARDL test (Table 7.28), the Johansen procedure suggests no long-run cointegration relationship between the two indexed series (Table 7.30). A failure of cointegration between two series makes it impossible to run the Bierens and Martins (2010) procedure to detect time-varying cointegration.

Table 7.30: Johansen Test for Cointegration - Gold & the US PPI, Indexed Surprise

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	0	-376.33797	.	3.8555*	12.53
1	3	-374.70194	0.00682	0.5834	3.84
2	4	-374.41023	0.00122		

Regime shifts in the relationship between the two time series are detected via the Gregory and Hansen (1996a) procedure (Table 7.31).

Table 7.31: Gregory and Hansen Test - Gold & the US PPI, Indexed Surprise

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-3.03	390	Aug. 2006	-5.47	-4.95	-4.68
Z_t	-3.07	390	Aug. 2006	-5.47	-4.95	-4.68
Z_α	-16.39	390	Aug. 2006	-57.17	-47.04	-41.85

Similar to what is observed for the US CPI surprise index (Table 7.15) the Gregory and Hansen (1996a) test results are very clear, with all three tests pointing towards the same break point: August 2006. The break indicated by the Gregory and Hansen test is set at the beginning of an exponential increase of the gold price lasting for about 6 years (Figure 7.5). The time window in which the gold price exponentially increases, set around the recent Global Financial Crisis, is also detected by the Bai and Perron (2003a) multiple break procedure (Table 7.32).

Table 7.32: Bai and Perron Multiple Break Test - Gold & the US PPI, Indexed Surprise

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	0.993	0.005	184.779	0
2	DZ(1,2)	1.163	0.002	494.750	0
3	DZ(1,3)	1.400	0.005	295.965	0

Breakpoint	Lower 95%	-	Upper 95%
May-79	Jan-79	to	Jul-79
Jan-07	Aug-06	to	Mar-07

The results in Table 7.32 are quite similar to the results observed for the indexed CPI surprise factor (Table 7.16). The first time window, between January 1979 and July 1979 points towards the start of a 30 year period during which the two series diverge from one another (Figure 7.8), while the second time window, between January 2007 and March 2007 points towards the start of a very sharp increase of the gold price (Figure 7.5).

Figure 7.8: US PPI Surprise Index and Gold between 1974 and 2014

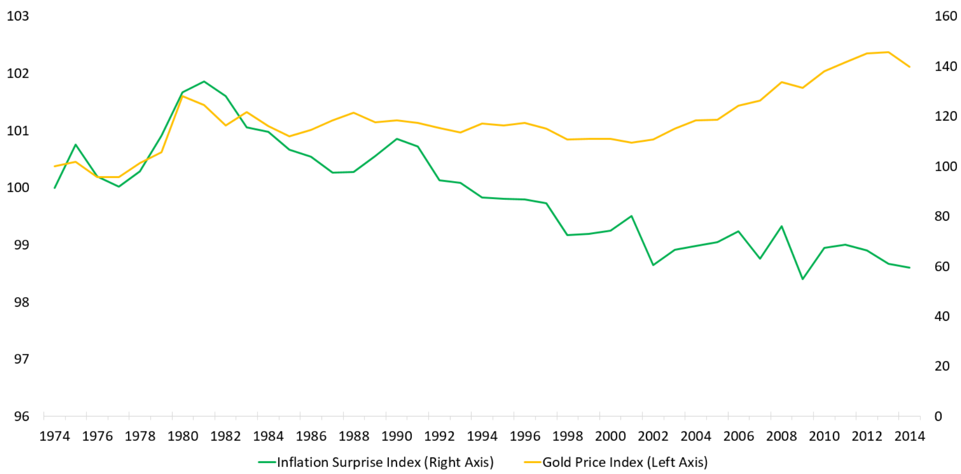


Figure 7.8 summarises the analysis conducted for the two indexed series. Gold was not cointegrated with US PPI inflation surprise over the past 40 years but the two series did evolve close to one another in the late 1970s, early 1980s. Looking at the nominal CPI, Batten et al. (2014) finds this time window to be the driver of the cointegration relationship between gold and American inflation. The time window between 2006 and 2007 is in line with the findings of Hoang et al. (2016) who contrast a deflationary period against a steadily rising price of gold. The falling inflation surprise index can be considered as an indication of a more pessimistic market environment, in which the realised inflation rates tend to be below the predicted inflation values.

7.1.1.2.4 Concluding Remarks

In conclusion, it can be said that gold was cointegrated with the nominal and the predicted US PPI between January 1974 and January 2014 but wasn't cointegrated with PPI surprise over that time window. Strong evidence of cointegartion between gold and the nominal and predicted US PPI is observed in the late 1970s, early 1980s - results similar to those found by Batten et al. (2014) considering the US CPI over a similar time window. The deflationary period around 2008 linked with a rising price of gold pushed back the nominal series to a cointegration relationship with gold (Figure 7.6). A similar effect can be observed for the relationship between gold and the predicted PPI (Figure 7.7) and again support the importance that deflationary episodes have on the long-run relationship with gold (Hoang et al. (2016)). Breaks in the relationship between the nominal PPI series and the price of gold outlined by the Gregory and Hansen (1996a) procedure occurring during the late 1990s (Table 7.20) underline the findings of Beckmann and Czudaj (2013). The regime shifts observed by the authors around the late 2000s are outlined by the Bai and Perron (2003a) procedure (Table 7.21) and can all, amongst other regime shifts observed by Beckmann and Czudaj (2013), be observed in Figure 7.6. Similar to what is observed for the US CPI measures, the belief that gold is an effective hedge against inflation during economic troubles must be challenged. The late 1990s, though drawn by economic turmoil, did not lead to a cointegration relationship between gold and any of the three PPI measures considered in the analysis. The partial return to a cointegration relationship between gold and producer price inflation in the USA around 2008 should therefore be accounted to deflation more than to the financial crisis event as such.

7.1.1.3 Money Zero Maturity

As suggested by the term itself, Money Zero Maturity (MZM) is an aggregation of all monetary instruments with zero maturity (Poole (1991)) that can be converted into transaction balances without penalty or capital loss (Carlson and Keen (1996)). In their work focused on the considered monetary aggregate, Carlson and Keen (1996) argue that the major bulk of MZM variation reflects a systematic effect of interest rates. Studying the relationship between MZM and gold therefore allows for an opening of the analysis towards another very important underlying variable in the context of inflation: interest rates. However, in contrary to the previously considered CPI and PPI measures, the relationship between gold and MZM should be viewed from a different angle. Instead of viewing MZM as a variable anticipated by market actors to influence the price of gold, this part takes a more distant approach and looks only at the relationship between gold and the nominal amount of liquid money in circulation in the US economy. A focus on predicted money supply and its surprise element is not necessary. Indeed, market actors react to announcements in money supply, rather than anticipating them; so estimating predicted changes would make little sense.

7.1.1.3.1 Gold in $ and Money Zero Maturity

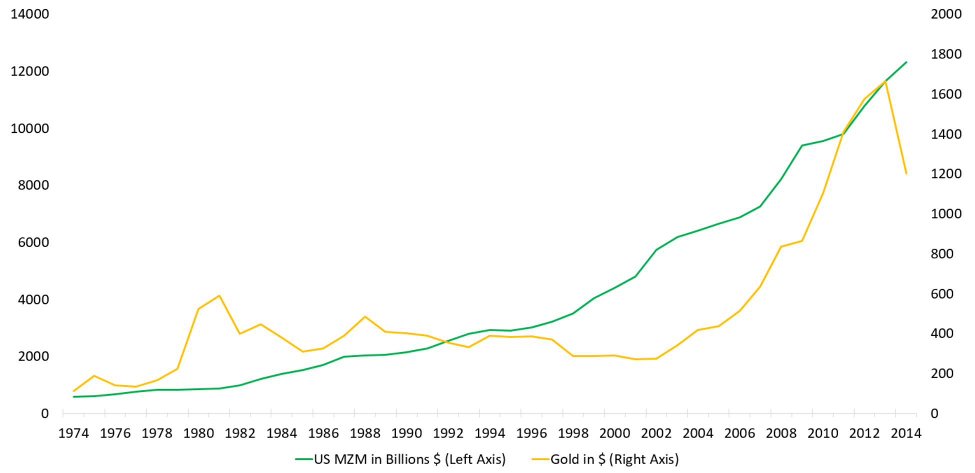
Over the period considered, the two time series don't seem to veer apart as much as gold and the nominal US CPI (Figure 7.1) and gold and the nominal US PPI (Figure 7.5). While MZM was steadily increasing between 1974 and 2014, the price of gold trended down between 1982 and 2002 (Figure 7.9). A sharp increase of both measures can be observed between 2002 and 2012, around the time where the price of gold starts to fall off again while money supply continues to increase.

An optimal lag length of 14 months is suggested by the Schwarz Bayesian Information Criterion and the Augmented Dickey Fuller test indicated non-stationarity for both time series (Table 7.33).

Table 7.33: Augmented Dickey Fuller Test - Gold & US MZM

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-1.473	-3.443	-2.871	-2.570
D.Gold	-3.981	-2.335	-1.648	-1.283
MZM	1.009	-3.982	-3.422	-3.130
D.MZM	-3.192	-2.335	-1.648	-1.283

Figure 7.9: Money Zero Maturity and Gold in $ between 1974 and 2014



The Johansen test for cointegration indicates a cointegration relationship between gold and US Money Zero Maturity (Table 7.34).

Table 7.34: Johansen Test for Cointegration - Gold & US MZM

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	52	-4515.3721	.	26.9240	12.53
1	55	-4505.0392	0.04329	6.2581	3.84
2	56	-4501.9102	0.01331		

Building upon the cointegration relationship observed in Table 7.34, the Bierens and Martins (2010) procedure is used to detect time-variation in the cointegration relationship between gold and US Money Zero Maturity.

Table 7.35: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & US MZM

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	2.08	4.61	5.99	0.35278
m = 2	4.08	7.78	9.49	0.39498
m = 3	7.81	10.64	12.59	0.25252
m = 4	16.11	13.36	15.51	0.04078

The results in Table 7.35 must be interpreted considering the p-value. Robust results are only delivered with a Chebyshev order of 4 and a p-value of 0.04078.

In the latter case, there is indeed evidence for time-variation in the relationship between gold and US money supply as the test statistic is greater than the respective critical values. Even though the results for Chebyshev time polynomials less than 4 suggest that the cointegration relationship between the two time series is time-invariant, the according p-values are not robust and a certainty of the suggested results can't be comfortably asserted.

Considering the suggested evidence for time-variation in the relationship between gold and US Money Zero Maturity, the Gregory and Hansen (1996a) test points towards breaks in the relationship amongst the two series in September 1999 and in October 2007 (Table 7.36).

Table 7.36: Gregory and Hansen Test - Gold & US MZM

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-4.67	406	Oct. 2007	-5.47	-4.95	-4.68
Z_t	-2.46	309	Sep. 1999	-5.47	-4.95	-4.68
Z_α	-15.78	309	Sep. 1999	-57.17	-47.04	-41.85

Finally, the Bai and Perron (2003a) procedure is run to allow for a different methodology to identify breaks in the long-run relationship between gold and US money supply.

Table 7.37: Bai and Perron Multiple Break Test - Gold & US MZM

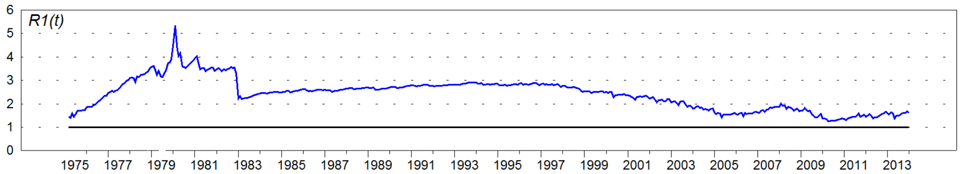
	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	0.235	0.007	33.454	0
2	DZ(1,2)	0.083	0.002	48.027	0
3	DZ(1,3)	0.136	0.002	73.147	0

Breakpoint	Lower 95%	-	Upper 95%
Feb-91	Dec-90	to	Sep-92
Oct-09	Mar-09	to	Dec-10

Different breaks are identified by the Bai and Perron (2003a) procedure: one in the early 1990s, and another one in the late 2000s (Table 7.37).

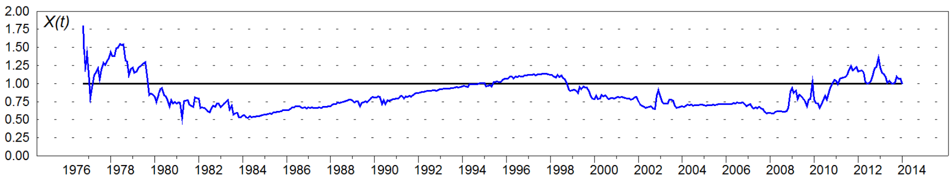
Plotting the Johansen Test Trace Statistic of the long-run parameters only suggests that the cointegration vector in the gold-money relationship is time-invariant (Figure 7.10).

Figure 7.10: Recursive Plot of Johansen's Trace Statistic for Gold and US Money Zero Maturity (Scaled by the 5% Critical Value) - Long-Run Parameters



Furthermore, plotting the Trace Statistic of all parameters allows to recognise the breaks identified by the Gregory and Hansen (1996a) test and the Bai and Perron (2003a) procedure. Especially the break around 1999 (Table 7.36) and around the recent Financial Crisis (Table 7.37) can be well observed in Figure 7.11.

Figure 7.11: Recursive Plot of Johansen's Trace Statistic for Gold and US Money Zero Maturity (Scaled by the 5% Critical Value) - All Parameters



7.1.1.3.2 Concluding Remarks

Gold and US Money Zero Maturity were cointegrated between 1980 and 1995, shifted back towards a cointegration relationship between 1999 and 2011, but seem not to be cointegrated in recent years. The break point in September 1999, identified by the Z_T and Z_α unit root tests of the Gregory and Hansen (1996a) procedure (Table 7.36) can clearly be observed in Figure 7.11, where the two series shift back to a cointegration relationship for more than 10 years; up until late 2010, a break identified by the Bai and Perron (2003a) procedure (Table 7.37). Considering the first time window pointed out by the Bai and Perron (2003a) procedure, between December 1990 and September 1992 (Table 7.37), it reflects the years of a falling gold price against a growing money supply in the US (Figure 7.9). During that time window, the blue line in Figure 7.11 is indeed shifting up towards an end of the cointegration relationship between gold and US MZM. The break identified by the

Gregory and Hansen (1996a) procedure occurring in October 2007 is a reflection of the very sharp increase of the price of gold during that time (Figure 7.9) and led to a decrease of the Trace Statistic in Figure 7.11 ensuring more secured cointegration between the two time series. Finally, the results for US MZM indicate the ability of gold to act as a short-run rather than as a long-run hedge.

The results are quite different to what is observed for the nominal US CPI (Figure 7.2) and the nominal US PPI (Figure 7.6). While for both inflation series, evidence pointed towards a cointegration relationship with gold during the early 1980s (results in line with Beckmann and Czudaj (2013) and Batten et al. (2014)), gold and money supply were indeed not cointegrated during that time period. However, while previous argumentation suggested that gold might not be an effective hedge against inflation during financial turmoils building upon the observations in Figure 7.2 and Figure 7.6 where it can be observed that gold was not cointegrated with the CPI/PPI during the late 1990s despite the great financial troubles, it seems that gold was indeed a protection against an increase in the money supply (Figure 7.11).

The findings for the United States of America initially questioned gold's ability to be used as an inflation hedge in troublesome times, however, considering the results for money supply, and based on the argumentation that money supply is the very root of inflation, it can be argued that gold does indeed offer protection against inflation in the USA during financial turmoils, but that this hedging potential is reflected in the country's money supply more than in the nominal published inflation indices, supporting the argumentation of biased inflation indices published by National Governments.

A display of the Johansen Trace Statistic and the different inflation measures can be found in Appendix C.

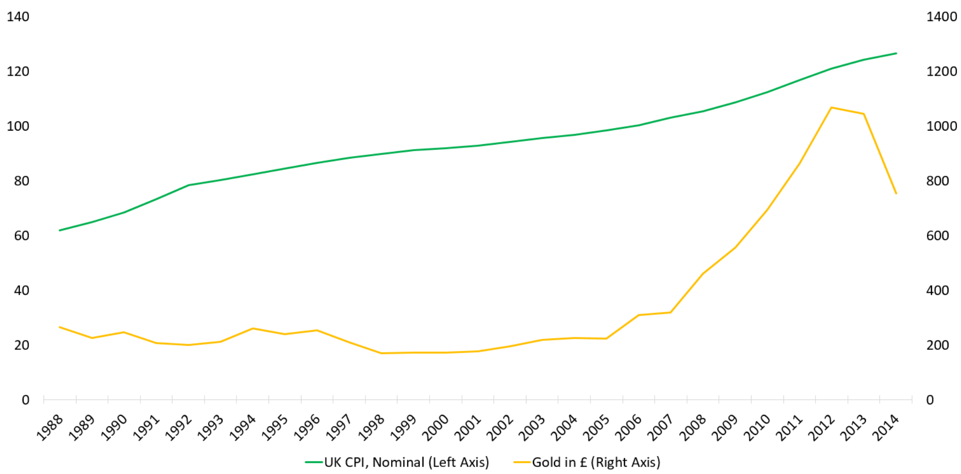
7.1.2 The United Kingdom of Great Britain and Northern Ireland

The United Kingdom plays a non-trivial role on the gold market. The London Bullion Market Association (LBMA) is the largest spot gold market in the World (Hoang et al. (2016)) and sets the official global gold price since 1919. Despite the geographical importance the UK has on the price of gold, it is also a leading global economy. The results provided in this section are therefore of value to a substantial amount of researchers, regulators, investors, and decision makers.

7.1.2.1 Consumer Price Index

In order to assure unanimity with the CPI measures of the USA and Japan, the inflation series considered is the CPI rate lasting from January 1988 to January 2014 replacing the discontinued Retail Price Index (RPI). An upward trend in British inflation is quite obvious as can be seen in Figure 7.12.

Figure 7.12: The nominal UK CPI and Gold in £ between 1988 and 2014



The price of gold in £ went through a period of stagnation between 1988 and 2005 against a steadily increasing CPI rate. A vary sharp increase of the gold price is noticed from 2005 onwards and starts falling back from around 2012 to reach the same level as in 2010 towards the end of the observation period.

7.1.2.1.1 Gold in £ and the Nominal Consumer Price Index

The Augmented Dickey Fuller test (Dickey and Fuller (1979, 1981)) indicates that the two series are of the same order of integration (Table 7.38), therefore allowing running the relevant battery of tests proposed in the methodology section.

The Schwarz Bayesian Information Criterion (Schwarz (1978)) advises to consider a lag of one month in the system.

Table 7.38: Augmented Dickey Fuller Test - Gold & the UK CPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-1.437	-3.456	-2.878	-2.570
D.Gold	-2.767	-2.339	-1.650	-1.285
UKCPI	-1.330	-3.988	-3.428	-3.130
D.UKCPI	-2.371	-2.340	-1.650	-1.285

In a next step, a Johansen test of cointegration is used to detect the nature of a possible long-run relationship between the two time series.

Table 7.39: Johansen Test for Cointegration - Gold & the UK CPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	0	-1605.3804	.	81.1470	12.53
1	3	-1565.0662	0.22773	0.5185*	3.84
2	4	-1564.8069	0.00166		

The evidence in Table 7.39 suggests there was indeed a long-run cointegration relationship between the price of gold and the UK CPI between January 1988 and January 2014. In order to formally derive if this relationship was stable through time, a Bierens and Martins (2010) procedure for time-varying cointegration is applied (Table 7.40).

Table 7.40: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the UK CPI, Nominal

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	2.46	4.61	5.99	0.29253
m = 2	13.79	7.78	9.49	0.00801
m = 3	18.76	10.64	12.59	0.00459
m = 4	33.52	13.36	15.51	0.00005

Concidering p-values, reliable results are obtained with a Chebyshev order of 2. This leads to the conclusion that the relationship between gold and consumer price inflation in the United Kingdom was not stable through time. The Gregory and Hansen (1996a) procedure identifies regime shifts in the cointegration between the two time series.

Table 7.41: Gregory and Hansen Test - Gold & the UK CPI, Nominal

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-3.09	256	Apr. 2009	-5.47	-4.95	-4.68
Z_t	-3.39	256	Apr. 2009	-5.47	-4.95	-4.68
Z_α	-22.83	256	Apr. 2009	-57.17	-47.04	-41.85

All three testing procedures point towards a shift occurring in April 2009 (Table 7.41). Results somehow supported by the Bai and Perron (2003a) procedure that points towards very similar time intervals and breaking points (Table 7.42).

Table 7.42: Bai and Perron Multiple Break Test - Gold & the UK CPI, Nominal

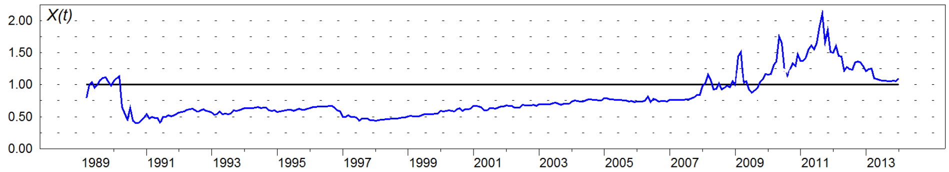
	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	2.575	0.048	53.957	0
2	DZ(1,2)	5.060	0.117	43.321	0
3	DZ(1,3)	7.729	0.079	98.235	0

Breakpoint	Lower 95%	-	Upper 95%
Dec-07	Aug-07	to	Apr-08
Feb-10	Aug-09	to	May-10

The analysis so far suggests that gold and the UK CPI were cointegrated in the long-run between January 1988 and January 2014. However, the Bierens and Martins (2010) procedure indicated that this relationship was not stable through time (Table 7.40). Both, the Gregory and Hansen (1996a) procedure (Table 7.41) as well as the Bai and Perron (2003a) multiple break test (Table 7.42) indicate a break in the relationship around the recent Financial Crisis.

A visualisation of the relationship between the price of gold in £ and the consumer price index for the United Kingdom (Figure 7.13) supports the findings of the formal testing procedures.

Figure 7.13: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal UK CPI (Scaled by the 5% Critical Value) - All Parameters



In conclusion, it can be said, that until 2009, holding gold was an effective hedging strategy against inflation for an investor exposed to British consumer price inflation. Hoang et al. (2016) consider a longer time span of UK inflation data and come to the conclusion that gold is not a hedge against inflation in the long-run, but is indeed a hedge in the short-run. This conclusion is also supported by our findings, where an explanation of the non-existing long-run relationship can be found in the recent time-window between 2009 and 2014. Using a Markov-Switching Vector Error Correction Model (MS-VECM), Beckmann and Czudaj (2013) find evidence for a regime switch around 2009, findings supported by results in Tables 7.41 and 7.42 and in Figure 7.13. The results for the UK CPI are supporting what is observed for the relationship between gold and the US CPI (Figure 7.2). Global Financial turmoils are harmful to the cointegration relation between the two time series. Even though, during the late 1990s, gold and the UK CPI were cointegrated, the blue line shifts back up henceforth, suggesting a weakening cointegration relationship (Figure 7.13). More recently, gold is not a hedge against the UK CPI, an important finding for investors who should reconsider hedging strategies against British consumer price inflation.

7.1.2.1.2 Gold in £ and the Predicted Consumer Price Index

An ARIMA(12,1,6) model is used to derive predicted CPI values for the United Kingdom; more information about the model can be found in Appendix E.

The Schwarz Bayesian Information Criterion (Schwarz (1978)) indicates an optimal lag length of one month to use in the model and the Dickey Fuller test indicates that both, the predicted UK CPI and the natural logarithm of gold in £ are I(1) integrated series (Table 7.43).

Table 7.43: Augmented Dickey Fuller Test - Gold & the UK CPI, Predicted

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ln_gold	0.307	-3.455	-2.878	-2.570
D.ln_gold	-13.155	-2.339	-1.650	-1.284
pred_UKCPI	-3.383	-3.988	-3.428	-3.130
D.pred_UKCPI	-2.234	-2.340	-1.650	-1.285

However, the thoroughness of the Dickey and Fuller (1979, 1981) procedure is not as strong as it is for the nominal UK CPI values considering the confidence interval. It can however be concluded with decent certainty, that the predicted values of UK consumer price inflation are integrated of order 1.

A Johansen test for cointegration is used to detect the possible existence of a long-run relationship between the two series (Table 7.44).

Table 7.44: Johansen Test for Cointegration - Gold & the UK CPI, Predicted

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	0	1712.6213	.	81.7089	12.53
1	3	1753.1457	0.22942	0.6600*	3.84
2	4	1753.4757	0.00212		

The Johansen test indicates a long-run cointegration relationship between gold and the predicted UK CPI. In other words, gold was a hedge against predicted consumer price inflation in the United Kingdom between January 1988 and January 2014. The Bierens and Martins (2010) procedure is applied to test whether this cointegration relationship is static or evolved over time (Table 7.45).

Table 7.45: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the UK CPI, Predicted

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	2.83	4.61	5.99	0.24280
m = 2	6.45	7.78	9.49	0.16793
m = 3	13.57	10.64	12.59	0.03477
m = 4	28.61	13.36	15.51	0.00037

Results in Table 7.45 indicate that the relationship between gold and the predicted CPI in the United Kingdom was not stable through time. In light of the p-values, results for Chebyshev values of order 1 and 2 should be rejected and the results for $m = 3$ accepted instead.

Table 7.46: Gregory and Hansen Test - Gold & the UK CPI, Predicted

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-3.03	243	Apr. 2008	-5.47	-4.95	-4.68
Z_t	-3.32	115	Aug. 1997	-5.47	-4.95	-4.68
Z_α	-25.04	115	Aug. 1997	-57.17	-47.04	-41.85

The Gregory and Hansen (1996a) test indicates two shifts around August 1997 and April 2008. The results are therefore quite different to the Gregory and Hansen (1996a) results for the nominal UK CPI (Table 7.41) where only one shift was found in April 2009. The first shift indicated by the Gregory and Hansen (1996a) procedure for the predicted UK CPI (Table 7.46) occurs one year earlier than the shift for the nominal series. However, both breakpoints, in August 1997 and in April 2008 are supported by evidence from the Bai and Perron (2003a) test (Table 7.47).

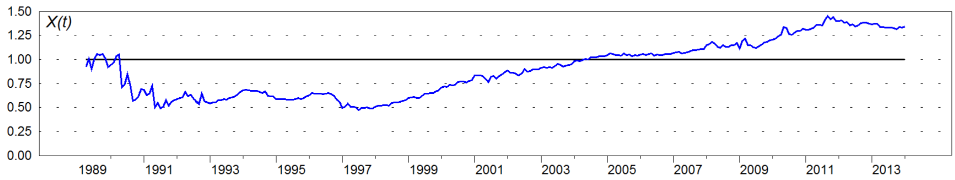
Table 7.47: Bai and Perron Multiple Break Test - Gold & the UK CPI, Predicted

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	1.250	0.041	297.667	0
2	DZ(1,2)	1.182	0.003	333.991	0
3	DZ(1,3)	1.396	0.005	303.691	0

Breakpoint	Lower 95%	-	Upper 95%
Oct-96	Dec-94	to	Feb-98
Dec-07	Sep-07	to	Mar-08

A visualisation of the changing relationship between gold and the predicted UK consumer price index is offered in Figure 7.14.

Figure 7.14: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted UK CPI (Scaled by the 5% Critical Value) - All Parameters



The breaks point in August 1997 outlined by the Gregory and Hansen (1996a) test (Table 7.46) and also pointed out by the Bai and Perron (2003a) procedure (Table 7.47) can be observed in Figure 7.14, where the blue line reaches a minimum value. From August 1997 onwards, the cointegration relationship between gold and the predicted UK CPI gets weaker and the two values stop to be cointegrated around 2004. The second time window outlined by the Bai and Perron (2003a) procedure in Table 7.47 is set during the recent Global Financial Crisis and is linked to the very sharp increase of the price of gold during that period (Figure 7.13). In contrast to the results observed for the nominal UK CPI rate (Figure 7.13), it seems that gold and predicted inflation were cointegrated over a shorter time window. Furthermore, global financial turmoils don't seem to have such an important effect on the price of gold in comparison to what can be observed for the nominal UK CPI rate. Just like what can be observed for the nominal UK CPI rate, it can be said that in more recent periods, gold is not a hedge against predicted consumer price inflation in the United Kingdom, urging investors to reconsider their exposure to the precious metal as a protection against a depreciation of the purchasing power of the pound sterling.

7.1.2.1.3 Gold in £ and Consumer Price Inflation Surprise

Subtracting the predicted UK CPI values from the nominal UK CPI values generates the inflation surprise values. While the Schwarz Bayesian Information Criterion (Schwarz (1978)) suggests not considering a lag in the system, the Augmented Dickey Fuller test indicates that both series are I(0) integrated (Table 7.48).

Table 7.48: Augmented Dickey Fuller Test - Gold & the UK CPI, Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
D.ln_gold	-13.241	-2.339	-1.650	-1.284
surprise_UKCPI	-17.662	-2.338	-1.650	-1.284

An ARDL model is then fitted to test the long-run relationship between the two series (Table 7.49).

Table 7.49: ARDL Test - Gold & the UK CPI, Surprise

F-Statistic	1% Critical Value	2.5% Critical Value	5% Critical Value	10% Critical Value
188.881	6.84	5.77	4.94	4.04

t-Statistic	1% Critical Value	2.5% Critical Value	5% Critical Value	10% Critical Value
-19.343	-3.43	-3.13	-2.86	-2.57

The ARDL test results indeed suggest a positive levels relationship between changes in the natural logarithm of the gold price and UK consumer price inflation surprise between 1988 and 2014.

In a next step, an index of gold price changes and the UK CPI surprise element is created. The Schwarz (1978) criterion recommends using a lag length of one month in the model and the Augmented Dickey Fuller test indicates that the two time series are of the same order of integration (Table 7.50).

Table 7.50: Augmented Dickey Fuller Test - Gold & the UK CPI, Indexed Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
gold_index	0.307	-3.455	-2.878	-2.570
D.gold_index	-13.155	-2.339	-1.650	-1.284
UKCPI_sur.ind	-1.187	-3.455	-2.878	-2.570
D.UKCPI_sur.ind	-17.657	-2.339	-1.650	-1.284

Fitting both series into the Johansen model allows to detect the existence of a possible long-run relationship between them. The Johansen test results (Table 7.51) indicate that the two series were not cointegrated between 1988 and 2014. In other words: gold is not a hedge against inflation surprise in the long-run.

Table 7.51: Johansen Test for Cointegration - Gold & the UK CPI, Indexed Surprise

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	0	28.793182	.	1.8722*	12.53
1	3	29.659764	0.00556	0.1391	3.84
2	4	29.729302	0.00045		

The Gregory and Hansen (1996a) procedure indicates uniform results of all three procedures pointing towards a shift in July 2008. Gregory and Hansen (1996a) results for the nominal UK CPI (Table 7.41) and the predicted UK CPI (Table 7.46) support evidence for an importance of the recent financial crisis in the gold inflation relationship.

Table 7.52: Gregory and Hansen Test - Gold & the UK CPI, Indexed Surprise

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-3.97	246	Jul. 2008	-5.47	-4.95	-4.68
Z_t	-4.21	246	Jul. 2008	-5.47	-4.95	-4.68
Z_α	-32.87	246	Jul. 2008	-57.17	-47.04	-41.85

The Bai and Perron (2003a) procedure supports the evidence that the early days of the recent Global Financial Crisis had an important effect on the relationship between gold and inflation surprise in the United Kingdom by pointing out the time window between October 2008 and March 2009 (Table 7.53).

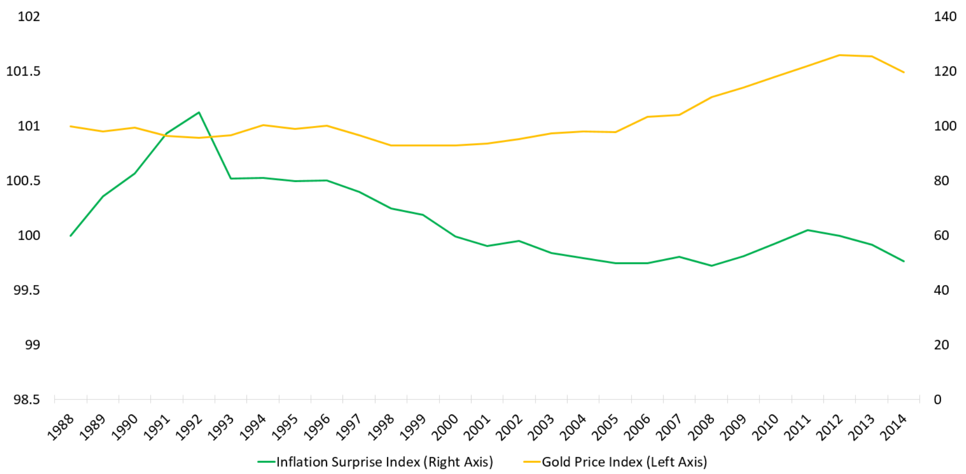
Table 7.53: Bai and Perron Multiple Break Test - Gold & the UK CPI, Indexed Surprise

	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	0.966	0.002	521.014	0
2	DZ(1,2)	1.072	0.004	242.699	0
3	DZ(1,3)	1.219	0.003	347.058	0

Breakpoint	Lower 95%	-	Upper 95%
Nov-05	Jul-05	to	Mar-06
Jan-09	Oct-08	to	Mar-09

It can be seen on Figure 7.15 that from 1993 onward, the two indices start to veer apart.

Figure 7.15: UK CPI Surprise Index and Gold between 1988 and 2014



A sharp increase of the gold index is observed around 2008, reflecting the sharp price increase around that same time (Figure 7.12). Inflation surprise seems to have picked up as well during that time window and starts falling again from 2012 onward (Figure 7.15). The Financial Crisis of 2008 is pointed out as a breakpoint in the relationship between the two series by both the Gregory and Hansen (1996a) procedure (Table 7.52) and the Bai and Perron (2003a) procedure (Table 7.53), where a probable explanation is the common increase of both series during that period. Even though over the entire time period considered, the two series tend to evolve away from one another, the Financial Crisis pushes the two series upwards, pointing to the hedging potential of gold against consumer price inflation surprise in the UK during that period of time. The first time window indicated by the Bai and Perron (2003a) procedure, between July 2005 and March 2006, could be considered an early indication of the change in relationship to come around with the financial turmoils of the Financial Crisis. It can therefore be concluded, that expect for certain short time windows, gold was not a hedge against inflation surprise in the UK (Table 7.51) between 1988 and 2014.

7.1.2.1.4 Concluding Remarks

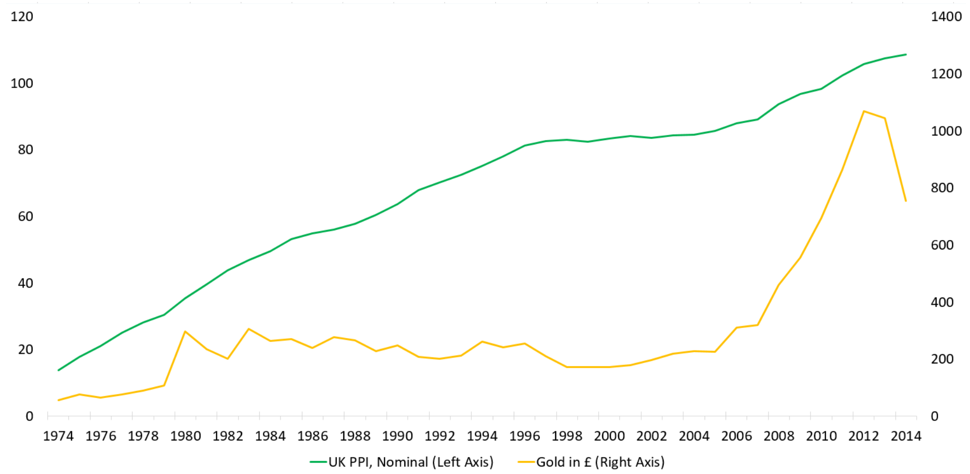
The above section analysed three different measures of the consumer price index in the United Kingdom: nominal, predicted and surprise inflation. In conclusion, it can be said that gold was a hedge against nominal and predicted inflation on the long-run, but not against inflation surprise. However, this relationship was not stable through time, in line with Beckmann and Czudaj (2013) it is found that the Financial Crisis of 2008 lead to a break in the cointegration relationship between gold and nominal inflation (Figure 7.13), while this break occurred even earlier for predicted inflation (Figure 7.14). These results however have to be handled with care since the price of gold in pound sterling increased sharply between 2005 and 2012 (Figure 7.12). While the results support Hoang et al. (2016) in finding that the relationship between gold and UK inflation is not static, jumping to the conclusion that gold is not a long-run hedge against the UK CPI might be erroneous. The correct answer should rather be that only recently, when the gold price started a sharp decent around 2012 (Figure 7.12), gold is not a hedge against consumer price inflation in the UK. The early indication of a break in the cointegartion relationship by Figures 7.13 and 7.14 point towards the exceptional increase in volatility of the gold price that harmed the traditional long-run *golden constant* effect of the yellow metal. Concerning the United Kingdom, a conclusion should therefore much more emphasise the harm that speculative activities have on the gold-inflation relationship: heavy gold price movements deteriorate the hedging abilities of gold against inflation. In the light of the safe haven and hedge argumentation of Baur and Lucey (2010), results seem to point towards safe haven abilities of gold rather than long-run hedging potential against inflation, though a formal analysis would be required. These results are of particular interest to investors and regulators, who should reconsider their portfolio position in gold in the light of the recent speculative element the metal has obtained.

7.1.2.2 Producer Price Index

In the United Kingdom, the Producer Price Index (PPI) is calculated by the Office for National Statistics (ONS) and reflects the changes in the prices of goods bought and sold by UK manufacturers. The PPI series for the UK have a longer history and the time span between January 1974 and January 2014 is therefore considered.

Even though an upward trend of the UK PPI can be observed between January 1974 and January 2014, it seems that the increase was quite linear between 1974 and 1996 and between 2006 and 2014 (Figure 7.16). Between 1998 and 2006 however, it seems that the PPI went through a period of stagnation with short deflationary episodes. A stagnation of the price of gold during the same time period is observable, as well as a striking surge of the gold price between 2008 and 2012.

Figure 7.16: The nominal UK PPI and Gold in £ between 1974 and 2014



7.1.2.2.1 Gold in £ and the Nominal Producer Price Index

When analysing the relationship between the price of gold in £ and the nominal UK PPI, the Schwarz Bayesian Information Criterion (Schwarz (1978)) recommends using a lag length of two months.

The Augmented Dickey Fuller Test indicates that both series are integrated of order one (Table 7.54).

Table 7.54: Augmented Dickey Fuller Test - Gold & the UK PPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-3.031	-3.443	-2.871	-2.570
D.Gold	-2.123	-2.335	-1.648	-1.283
UKPPI	-2.027	-3.981	-3.421	-3.130
D.UKPPI	-4.393	-2.335	-1.648	-1.283

Results of the Dickey and Fuller (1979, 1981) procedure in Table 7.54 are significant at the 5% critical value level. The results are therefore not as significant as the Augmented Dickey Fuller test results for the nominal UK CPI (Table 7.38), but a significance level of 95% is powerful enough to proceed and apply the Johasen test for cointegration (Table 7.55).

Table 7.55: Johansen Test for Cointegration - Gold & the UK PPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	4	-2141.3357	.	39.8912	12.53
1	7	-2121.7015	0.07871	0.6228*	3.84
2	8	-2121.3901	0.00130		

.

The evidence in Table 7.55 suggests a long-run cointegration relationship between the nominal UK PPI and the price of gold in pound sterling between January 1974 and January 2014. Possible time-variation in the relationship can be derived through the procedure proposed by Bierens and Martins (2010).

Table 7.56: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the UK PPI, Nominal

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	0.88	4.61	5.99	0.64464
m = 2	4.33	7.78	9.49	0.36339
m = 3	17.12	10.64	12.59	0.00885
m = 4	18.27	13.36	15.51	0.01929

Considering the p-values, reliable results are only obtained with a Chebyshev factor of 3 and 4, in which case the cointegration relationship between the nominal UK PPI and gold is found to vary through time (Table 7.56). The Gregory and Hansen (1996a) procedure is used to identify regime shifts in the cointegration relationship between the two series.

Table 7.57: Gregory and Hansen Test - Gold & the UK PPI, Nominal

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-3.16	260	Aug. 1995	-5.47	-4.95	-4.68
Z_t	-3.08	262	Oct. 1995	-5.47	-4.95	-4.68
Z_α	-22.96	262	Oct. 1995	-57.17	-47.04	-41.85

Two shifts towards late 1995 are identified by the Gregory and Hansen (1996a) procedure (Table 7.57) but results are somehow different for the Bai and Perron (2003a) procedure.

Table 7.58: Bai and Perron Multiple Break Test - Gold & the UK PPI, Nominal

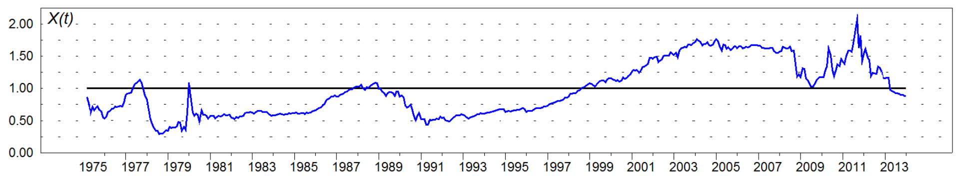
	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	4.807	0.126	38.018	0
2	DZ(1,2)	2.985	0.056	52.864	0
3	DZ(1,3)	8.398	0.088	95.709	0

Breakpoint	Lower 95%	-	Upper 95%
Nov-88	Jun-87	to	Sep-89
Dec-08	Aug-08	to	Feb-09

The results in Table 7.58 point towards two major breaks. The first around the late 1980s and the second around the recent Financial Crisis of 2008.

The two breaks indicated by the Bai and Perron (2003a) procedure (Table 7.58) can clearly be seen in the visualisation of the Johansen Trace Statistic, where a value below 1 indicates cointegration while a value above 1 indicates that gold is not cointegrated with the nominal UK Producer Price Index (Table 7.17).

Figure 7.17: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal UK PPI (Scaled by the 5% Critical Value) - All Parameters



The results for the UK PPI are quite different to those found for the UK CPI (Figure 7.13). On the one hand, both the UK CPI and the UK PPI are cointegrated with gold (Tables 7.39 and 7.55) and this relationship evolved over time (Tables 7.40 and 7.56), but the break in cointegration between gold and the UK PPI seem to occur much earlier, around the late 1990s (Figure 7.17). The breaks in the relationship between gold and the UK CPI identified occurred around the Financial Crisis of 2008 (Tables 7.41 and 7.42), the results for the UK PPI indicate a shift around late 1996 (Table 7.57) and a break in the cointegration relationship around late 1988 (Table 7.58). Only one time window indicated by the Bai and Perron (2003a) procedure is in line with the recent financial turmoils: the second time window between August 2008 and February 2009 (Table 7.58). It is only a recent phenomenon that gold is no longer cointegrated with producer price inflation in the United Kingdom, more specifically, gold was indeed a hedge against price increases affecting UK manufacturers up until 1999. A short break in cointegration occurred during the late 1980s (Figure 7.17), observations in line with the Bai and Perron (2003a) test results indicating a break window between August 2008 and February 2009. A possible explanation for the short break occurring in the late 1980s could be the found in the sharp increase of the UK interest rate from 7.5% in May 1988 to 15% in October 1989, akin to the importance of interest rates on the price of gold. O'Connor et al. (2015) indeed argue, that interest rates can be considered the opportunity costs of holding gold because they are the benefit an investor would have earned if he purchased a bond instead. Recently, Baur (2011) argued for the existence of a negative relationship between long-term interest rates and the price of gold, findings supported by Erb and Harvey (2013) who observed this relationship for the UK specifically. The late 1990s and early 2000s are drawn by global financial turmoils. Here, it seems that international financial unrest harmed the inflation hedging potential of gold, while indeed, gold and the nominal UK PPI are not cointegrated any longer since around 1999. On the other hand, the more recent crisis of 2008 seems to have been beneficial to the gold/inflation relationship in the United Kingdom. The magnitude of the recent crisis however led to a much greater increase of the price of gold than during the early 2000s (Figure 7.16) and furthermore was not important enough to push back the two time series to a cointegration relationship (Figure 7.17). The results obtained from this analysis are in line with Beckmann and Czudaj (2013), indicating regime shifts in the late 1980s and around the recent financial crisis. In conclusion, it can be said that gold is not per se an effective hedge against nominal producer price inflation in the United Kingdom as the relationship changed in the late 1990s, urging manufacturers to reconsider their inflation hedging strategy.

7.1.2.2.2 Gold in £ and the Predicted Producer Price Index

Predicted values of the UK PPI were derived through an ARIMA(2,1,2) procedure, more information about the model can be found in Appendix F. The Dickey Fuller unit root testing procedure indicates that the predicted UK PPI series derived from the natural logarithm of the nominal UK PPI series is integrated of order 0 (Table 7.59).

Table 7.59: Augmented Dickey Fuller Test - Gold & the UK PPI, Prediction Based on Natural Logarithm

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ln_gold	-1.462	-3.443	-2.872	-2.570
D.ln_gold	-4.273	-2.335	-1.648	-1.283
pred_UKPPI	-4.435	-3.981	-3.421	-3.130

In order to work with two aligned I(1) series, the exponential of the two series is considered, ensuring that both the price of gold and the predicted UK PPI index are of the same order of integration (Table 7.60).

Table 7.60: Augmented Dickey Fuller Test - Gold & the UK PPI, Prediction Based on Exponential

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-3.028	-3.443	-2.872	-2.570
D.Gold	-2.120	-2.335	-1.648	-1.283
pred_UKPPI	-2.010	-3.981	-3.421	-3.130
D.pred_UKPPI	-4.486	-2.335	-1.648	-1.283

It should be noted, that gold fails at the 1% confidence level, but the 5% confidence level is considered convincing enough to carry on with the testing procedure and proceed with the Johansen test for cointegration using a lag length of two months in the model (Schwarz (1978)).

Table 7.61: Johansen Test for Cointegration - Gold & the UK PPI, Predicted

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	4	-2241.5019	.	41.5030	12.53
1	7	-2221.0520	0.08201	0.6033*	3.84
2	8	-2220.7504	0.00126		

A long-run relationship between gold and predicted producer price inflation is detected in the United Kingdom (Table 7.61). In a next step, a Bierens and Martins (2010) procedure is used to detect possible time-invariancy in the cointegration relationship between the two time series (Table 7.62).

Table 7.62: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the UK PPI, Predicted

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	1.31	4.61	5.99	0.51977
m = 2	5.87	7.78	9.49	0.20939
m = 3	16.09	10.64	12.59	0.01329
m = 4	17.69	13.36	15.51	0.02367

Similar to the Bierens and Martins (2010) test results for the nominal UK PPI (Table 7.56), increased attention should be given to the p-values of the respective Chebyshev time polynomials. More specifically, only the results provided with Chebyshev time polynomials of order 2 and 3 can be considered statistically significant. Indeed, these results indicate that the relationship between gold and the predicted Producer Price Index in the United Kingdom was varying over time (Table 7.62).

Table 7.63: Gregory and Hansen Test - Gold & the UK PPI, Predicted

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-3.55	260	Sep. 1995	-5.47	-4.95	-4.68
Z_t	-3.26	261	Oct. 1995	-5.47	-4.95	-4.68
Z_α	-25.42	261	Oct. 1995	-57.17	-47.04	-41.85

The Gregory and Hansen (1996a) test results (Table 7.63) are very similar to those observed for the nominal UK PPI (Table 7.57), with an evidence for a shift in cointegration between the two series around late 1995. The Bai and Perron (2003a) procedure is used to detect multiple breaks in the long-run relationship and to identify the time windows during which the relationship between gold and predicted producer price inflation in the United Kingdom changed (Table 7.64).

Table 7.64: Bai and Perron Multiple Break Test - Gold & the UK PPI, Predicted

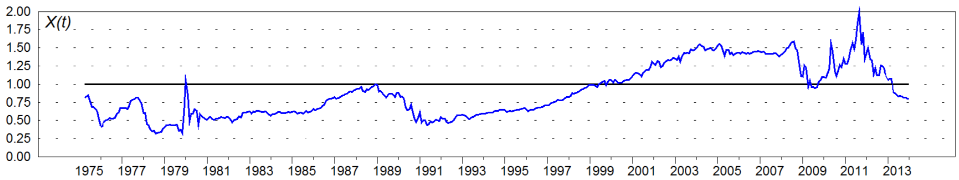
	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	4.803	0.126	37.972	0
2	DZ(1,2)	2.985	0.056	52.814	0
3	DZ(1,3)	8.396	0.088	95.625	0

Breakpoint	Lower 95%	-	Upper 95%
Nov-88	Jun-87	to	Sep-89
Dec-08	Aug-08	to	Feb-09

The time windows identified by the Bai and Perron (2003a) procedure (Table 7.64) are very similar to those identified for nominal producer price inflation in the UK (Table 7.58), with two major breaks detected: the first during the late 1980s and the second during the recent Global Financial Crisis of 2008.

The evolving cointgeration relationship between the price of gold in £ and the predicted UK PPI is visualised by plotting the Johansen Trace Statistic and scaling it by the 5% critical value (Figure 7.18).

Figure 7.18: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted UK PPI (Scaled by the 5% Critical Value) - All Parameters



The results observed for the predicted UK PPI are very similar to those observed for the nominal UK PPI. Gold was cointegrated with predicted producer price inflation between January 1974 and January 2014 (Table 7.61), but the relationship was evolving over time (7.62). The break identified in the late 1980s by the Bai and Perron (2003a) procedure (Table 7.64) can be seen in Figure 7.18, a period during which the cointegration relationship between gold and predicted inflation nearly breaks. Similar to earlier argumentation, a likely explanation is to be found in the sharp increase of UK interest rates around that period of time. The second time window identified by the Bai and Perron (2003a) test occurred between August 2008 and February 2009 (Table 7.64). Indeed, it seems that the recent heavy global financial turmoils were beneficial for the relationship between gold and predicted producer price inflation in the United Kingdom, especially since the two series converged back to a relationship of cointegration around mid 2009. The trend in the relationship between gold and the predicted UK PPI is very similar to the results observed for the nominal UK PPI (Figure 7.17): since 1999, the two series are not cointegrated any longer. For both cases, the Gregory and Hansen (1996a) test suggest that the shift in the relationship occurred around late 1995 (Tables 7.57 and 7.63), pointing towards the rather long lag of time that passed between an announced shift in cointegration and the actual shift itself. However, it needs to be pointed out, that towards the end of the observation sample, gold and predicted inflation converged back to cointegration - weakening the earlier advice given, that producers should reconsider their holdings in gold as a hedge against price fluctuations affecting UK manufacturers.

7.1.2.2.3 Gold in £ and Producer Price Inflation Surprise

Producer price inflation surprise in the United Kingdom is obtained by subtracting the predicted values from the nominal values. Following Schwarz (1978), no lag is included in the system and the Augmented Dickey Fuller test indicates that the two series are integrated of order 0 (Table 7.65).

Table 7.65: Augmented Dickey Fuller Test - Gold & the UK PPI, Surprise

Variable Considered	**Test Statistic**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
D.ln_gold	-4.275	-2.335	-1.648	-1.283
surprise_UKPPI	-24.616	-2.334	-1.648	-1.283

Both series being stationary, an ARDL test can be run to detect the existence of a potential long-run relationship between the two series (Table 7.66).

Table 7.66: ARDL Test - Gold & the UK PPI, Surprise

F-Statistic	**1% Critical Value**	**2.5% Critical Value**	**5% Critical Value**	**10% Critical Value**
262.356	6.84	5.77	4.94	4.04

t-Statistic	**1% Critical Value**	**2.5% Critical Value**	**5% Critical Value**	**10% Critical Value**
-22.815	-3.43	-3.13	-2.86	-2.57

The ARDL results indeed suggest a long-run relationship between the two series. In order to understand if a cointegration relationship between the price of gold in pound sterling and PPI inflation surprise exists in the United Kingdom, the two series are indexed in order to be fitted into a Johansen model.

Table 7.67: Augmented Dickey Fuller Test - Gold & the UK PPI, Indexed Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
gold_index	-1.462	-3.443	-2.872	-2.570
D.gold_index	-4.273	-2.335	-1.648	-1.283
UKPPI_sur.ind	-3.373	-3.982	-3.422	-3.130
D.UKPPI_sur.ind	-6.681	-2.335	-1.648	-1.283

The Dickey Fuller test results indicate that the two series are both I(1) integrated (Table 7.67), while the Schwarz (1978) information criterion suggests using a lag length of one month in the model.

Table 7.68: Johansen Test for Cointegration - Gold & the UK PPI, Indexed Surprise

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	0	-501.80073	.	24.0228	12.53
1	3	-489.95856	0.04824	0.3384*	3.84
2	4	-489.78935	0.00071		

In contrary to the results observed for consumer price inflation surprise in the United Kingdom (Table 7.51), gold is indeed a long-run hedge against PPI surprises in the UK. The Johansen test results in Table 7.68 indicate that gold was cointegrated with producer price inflation in the UK between January 1974 and January 2014. The cointegration relationship between the two series therefore allow to proceed with the Bierens and Martins (2010) test for time-invariancy in the cointegration relationship between gold and inflation surprise.

Table 7.69: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the UK PPI, Indexed Surprise

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	15.78	4.61	5.99	0.00037
m = 2	21.00	7.78	9.49	0.00032
m = 3	24.59	10.64	12.59	0.00041
m = 4	40.10	13.36	15.51	0.00000

The results in Table 7.69 provide strong evidence for time-variation in the cointegration relationship between the two series. A Gregory and Hansen (1996a) test is used to detect the shifts in cointegration between gold and producer price inflation surprise in the UK (Table 7.70).

Table 7.70: Gregory and Hansen Test - Gold & the UK PPI, Indexed Surprise

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-3.20	401	Jun. 2007	-5.47	-4.95	-4.68
Z_t	-3.23	402	Jul. 2007	-5.47	-4.95	-4.68
Z_α	-20.46	402	Jul. 2007	-57.17	-47.04	-41.85

The results in Table 7.70 suggest that a shift in cointegration occurred around mid-2007. Results somewhat in line with the Bai and Perron (2003a) procedure indicating a break around the recent Global Financial Crisis.

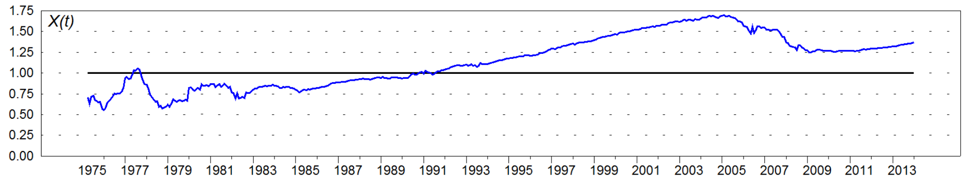
Table 7.71: Bai and Perron Multiple Break Test - Gold & the UK PPI, Indexed Surprise

	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	1.089	0.006	171.03	0
2	DZ(1,2)	1.385	0.003	475.30	0
3	DZ(1,3)	1.703	0.006	268.91	0

Breakpoint	Lower 95%	-	Upper 95%
Aug-79	Jun-79	to	Nov-79
Dec-07	Aug-07	to	Feb-08

A visualisation of the evolving relationship between gold and producer price surprise inflation in the UK is helpful to easily identify when gold offered a protection against producer price inflation surprise in the United Kingdom.

Figure 7.19: Recursive Plot of Johansen's Trace Statistic for Gold and the Indexed Surprise UK PPI (Scaled by the 5% Critical Value) - All Parameters



It can be seen on Figure 7.19 that up until the early 1990s, gold was cointgerated with the UK PPI surprise index. Hence, the break in the relationship occurred a few years before the break identified for the nominal UK PPI (Figure 7.17) and the predicted UK PPI (Figure 7.18). The shift identified by the Gregory and Hansen (1996a) procedure (Table 7.70) can be seen in Figure 7.19, where around mid-2007, the blue line starts to fall, pointing towards a proactive effect of the 2008 crisis, though the effect was not strong enough to push both series back to a cointegration relationship. The Bai and Perron (2003a) results also indicate an important effect of the 2008 crisis (Table 7.71), it seems indeed, that global financial turmoils have a positive effect on gold's ability to hedge PPI surprise inflation in the UK (Table 7.71). The first time window identified by the Bai and Perron (2003a) test, between June 1979 and November 1979 indicates the time window during which the Johansen Trace Statistic was at it's lowest point during the entire period considered. Gold did indeed fully acted out it's role as an effective hedge against inflation surprise during the energy crisis of 1979. As a concluding remark, it should be noted that even though gold is not a hedge against PPI surprise in the UK since 1991, financial crises and international financial turmoils have a positive relationship on the gold-inflation relationship, underlining the inflation hedging capacities of gold during economic storms. However, in line with the results for nominal and predicted inflation, evidence for a negative relationship between the inflation hedging potential of gold and interest rates is observed. The break in cointegration between the two series, set around the late 1980s is in line with the Bank of England high interest policy, that was overall hurting the cointegration relationship between gold and the UK PPI.

7.1.2.2.4 Concluding Remarks

Gold was cointegrated with all the PPI measures considered between January 1974 and January 2014, but this relationship proved to be time-varying in all cases. Concerning the nominal and the predicted UK PPI rates, the relationship changed during the late 1990s (Figures 7.17 and 7.18). Regarding the inflation surprise index created, the relationship changed during the late 1980s (Figures 7.19). In the light of shifts in cointegration between gold and all the three series considered in this chapter around the late 1980s, evidence is found for the importance of interest rates in the gold/inflation relationship. Having indeed doubled the interest rate in about one year, the negative long-run relationship between interest rates and the price of gold (see Baur (2011) and Erb and Harvey (2006)) was detrimental for gold's inflation hedging capacities. In the light of this known relationship, it becomes more evident why gold stopped being cointegrated with inflation surprise around 1990. Furthermore, it should be noticed, that the two series in question fell back towards a cointegration relationship around 2008 when the interest rates in the United Kingdom fell sharply. The UK interest rates are indeed an important factor in the relationship between gold and official Producer Price inflation in the United Kingdom. However, an important effect of the oil crisis of 1979 shouldn't be forgotten. The energy crisis was detrimental for the hedging potential of gold against nominal and predicted inflation, but didn't eliminate the cointegration relationship between gold and inflation surprise. Regarding the effects of the global financial turmoils of the late 1990s, it should be noticed that crises have a negative effect on gold's inflation hedging potential in general, results in line with those obtained for the United States of America. More recently, gold was not able to effectively hedge inflation in the UK, urging manufacturers to reconsider their portfolio positions, even though gold might have proved to be a reliable investment in the part.

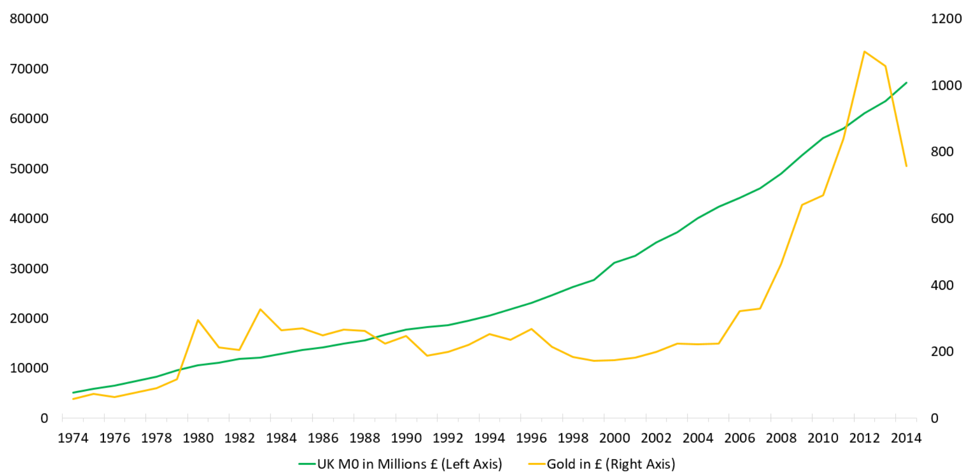
7.1.2.3 Narrow Money

Narrow money in the United Kingdom, or M0 Money by its official term, is calculated by the Bank of England and consists of sterling notes and coins in circulation as well as the banks' operational deposits with the Bank of England. It is therefore the most liquid measure of money in the British economy. Similar to the argumentation for US Money Zero Maturity, focusing on the relationship between gold and UK M0 Money allows to get an exposure to the systematic effects of interest rates in the UK. Previous results indeed showed potential for the importance of interest rates in the gold/inflation relationship. Being by definition a reactive relationship, deriving predicted and surprise M0 series would make no sense and the following part therefore focuses solely on the relationship between gold and nominal narrow money supply in the United Kingdom.

7.1.2.3.1 Gold in £ and Narrow Money

A clear upwards trend can be observed in UK narrow money between January 1974 and January 2014 (Figure 7.20). It is noteworthy, that the high interest rate policy of the Bank of England in the late 1980s did not cause a break in the growth of money supply. On the other hand, the price of gold was falling between 1983 and 2004. From around the mid 2000s, both series are increasing very sharply, while the gold price start to plummet from 2012 onward.

Figure 7.20: UK Narrow Money and Gold in £ between 1974 and 2014



The Schwarz Bayesian Information Criterion suggest working with a lag length of one month in the system while the Augmented Dickey Fuller Test indicates that both series are integrated of order 1 (Table 7.72).

Table 7.72: Augmented Dickey Fuller Test - Gold & UK M0

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-0.181	-3.442	-2.871	-2.570
D.Gold	-23.542	-2.334	-1.648	-1.283
UKM0	2.882	-3.981	-3.421	-3.130
D.UKM0	-4.825	-2.334	-1.648	-1.283

The Johansen test for cointegration indicates a long-run cointegration relationship between gold and narrow money in the United Kingdom (Table 7.73).

Table 7.73: Johansen Test for Cointegration - Gold & UK M0

Maximum Rank	**Parms**	**LL**	**Eigenvalue**	**Trace Statistic**	**5% Critical Value**
0	0	-5353.9299	.	439.0339	12.53
1	1	-5135.8045	0.59701	2.7832*	3.84
2	2	-5134.4129	0.00578		

Building upon the cointegration relationship identified, Bierens and Martins (2010) propose a method to test for time-variation in the cointegration relationship of the two series.

Table 7.74: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & UK M0

Chebyshev Time Polynomials	**Test Statistic**	**10% Critical Value**	**5% Critical Value**	**P Value**
m = 1	4.05	4.61	5.99	0.13186
m = 2	5.76	7.78	9.49	0.21787
m = 3	9.84	10.64	12.59	0.13160
m = 4	14.39	13.36	15.51	0.07208

Taking into account the p-value, results in Table 7.74 are only statistically significant with a Chebyshev order of 4, in which case there is evidence for time-variation in the relationship at the 10% confidence interval. The Gregory and Hansen (1996a) procedure is used to understand when the shift in the cointegration relationship between gold and narrow money in the UK occurred.

Table 7.75: Gregory and Hansen Test - Gold & UK M0

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-2.51	297	Sep. 1998	-5.47	-4.95	-4.68
Z_t	-2.60	308	Aug. 1999	-5.47	-4.95	-4.68
Z_α	-16.93	308	Aug. 1999	-57.17	-47.04	-41.85

Two major shifts are identified by the Gregory and Hansen (1996a) procedure: the first in September 1998 and the second in August 1999 (Table 7.75). The Bai and Perron (2003a) procedure identifies two break windows, the first in line with the Gregory and Hansen (1996a) results, and the second one around the recent financial crisis (Table 7.76).

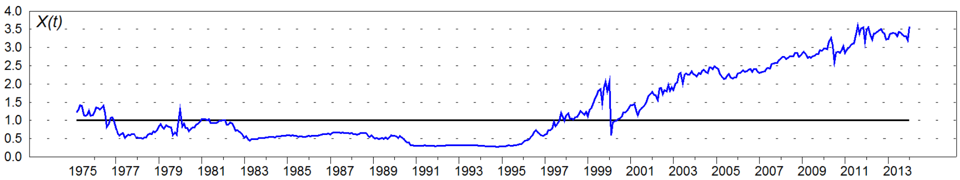
Table 7.76: Bai and Perron Multiple Break Test - Gold & UK M0

	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	0.014	0.000	47.206	0
2	DZ(1,2)	0.007	0.000	43.670	0
3	DZ(1,3)	0.014	0.000	95.772	0

Breakpoint	Lower 95%	-	Upper 95%
May-96	Jan-96	to	May-98
Nov-08	Jun-08	to	Jan-09

The shift and break periods in the late 1990s identified by the Gregory and Hansen (1996a) procedure (Table 7.75) and the Bai and Perron (2003a) test (Table 7.76) can clearly be identified in Figure 7.21. The graphical evidence indeed shows that the two series stop to be cointegrated around that time and are recently far away from a cointegration relationship.

Figure 7.21: Recursive Plot of Johansen's Trace Statistic for Gold and UK Narrow Money (Scaled by the 5% Critical Value) - All Parameters



7.1.2.3.2 Concluding Remarks

Considering the entire time window of 40 years, gold was cointegrated with M0 money in the UK (Table 7.73) but this relationship was varying through time (Table 7.74). Indeed, during the late 1990s, gold stopped to be cointegrated with money supply, results in line with those for the nominal UK PPI (Figure 7.17). This again points towards the detrimental nature of global financial turmoils for the inflation hedging ability of gold in the United Kingdom. The Bai and Perron (2003a) procedure points towards a break occurring in November 2008 (Table 7.76) - indeed, the picture is the same to what is observed during the global economic events of the late 1990s, early 2000s. Economic crises seem to push the two series towards cointegration for a very short period of time, but have a negative effect on the relationship between the series on the medium- and long-term.

The results in the United Kingdom are all aligned: in more recent times, gold is not cointegrated with different inflation measures any longer. The break in cointegration happened in 2010 for the CPI (Figure 7.12), in 1999 for the PPI (Figure 7.17) and in 1998 for narrow money (Figure 7.21). Crisis events as well as high interest rates have a long-run negative effect on gold's ability to hedge inflation in the United Kingdom.

Considering more recent time windows, the positive effect of low interest rates seems to have been outshined by the negative market climate on a global scale. Even though the results for the nominal UK PPI in Figure 7.17 seem to indicate that gold and inflation returned to a cointegration relationship towards the end of the sample, this conclusion should be considered with a certain distance as gold is not a hedge against money supply in the United Kingdom - the very root of inflation (Figure 7.21).

All figures can be found again in Appendix G.

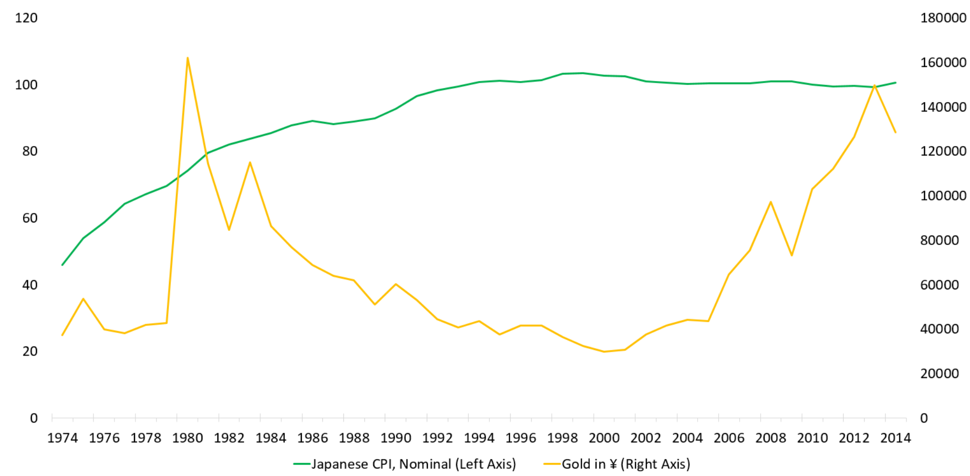
7.1.3 Japan

Japan is traditionally a rather active player on the gold market, where gold is considered both an attractive investment, but also a vital industrial asset for the countries overwhelmingly important electronic industry. However, Japan is going through very complicated economic times since the early 1990s and the explosion of the asset price bubble around that period, which led to surprisingly long periods of deflation and stagnating prices.

7.1.3.1 Consumer Price Index

The deflationary episodes of the Japanese CPI can clearly be seen in Figure 7.22.

Figure 7.22: The nominal Japanese CPI and Gold in ¥ between 1974 and 2014



Furthermore, between 1980 and 2000, the price of gold in ¥ was trending downwards while the Japanese Consumer Price Index was indeed rising. From the late 1990s to the end of the observation period, the price of gold sharply increased against a stagnating CPI. A last note is the very clear effect of the 1979 energy crisis that led to a strong increase of the price of gold (Figure 7.22).

7.1.3.1.1 Gold in ¥ and the Nominal Consumer Price Index

In a first step, the optimal lag length to use in the system has to be identified via the method proposed by Schwarz (1978). The results point towards a lag length of three months to use.

The Augmented Dickey Fuller (Dickey and Fuller (1979, 1981)) procedure indicates that both series are non-stationary (Table 7.77) which allows to proceed with the formal cointegration testing procedure.

Table 7.77: Augmented Dickey Fuller Test - Gold & the Japanese CPI, Nominal

Variable Considered	**Test Statistic**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
Gold	-1.066	-3.443	-2.871	-2.570
D.Gold	-5.978	-2.335	-1.648	-1.283
JPCPI	-2.635	-3.981	-3.421	-3.130
D.JPCPI	-3.203	-2.335	-1.648	-1.283

The Johansen test for cointegration indicates that gold and the Japanese Consumer Price Index were cointegrated between January 1974 and January 2014 (Table 7.78).

Table 7.78: Johansen Test for Cointegration - Gold & the Japanese CPI, Nominal

Maximum Rank	**Parms**	**LL**	**Eigenvalue**	**Trace Statistic**	**5% Critical Value**
0	8	-5037.4025	.	24.2680	12.53
1	11	-5025.9425	0.04682	1.3480*	3.84
2	12	-5025.2685	0.00282		

The positive long-run relationship between the two series can be tested for time-variancy using the Bierens and Martins (2010) procedure.

Table 7.79: Bierens and Martins (2010) Test for Time-varying Cointegration - Gold & the Japanese CPI, Nominal

Chebyshev Time Polynomials	**Test Statistic**	**10% Critical Value**	**5% Critical Value**	**P Value**
m = 1	0.65	4.61	5.99	0.72420
m = 2	20.95	7.78	9.49	0.00032
m = 3	29.26	10.64	12.59	0.00005
m = 4	30.27	13.36	15.51	0.00019

The results in Table 7.79 indicate that the relationship between gold in ¥ and the Japanese CPI evolved through time. Shifts in the cointegration relationship are identified with a Gregory and Hansen (1996a) test.

Table 7.80: Gregory and Hansen Test - Gold & the Japanese CPI, Nominal

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-2.82	394	Oct. 2006	-5.47	-4.95	-4.68
Z_t	-3.40	397	Jan. 2007	-5.47	-4.95	-4.68
Z_α	-20.48	397	Jan. 2007	-57.17	-47.04	-41.85

Two shifts are identified in Table 7.80, one occurring in October 2006 and the other one in January 2007. The Bai and Perron (2003a) multiple break procedure supports the findings of the Gregory and Hansen (1996a) procedure and identifies a breakpoint in January 2007 (Table 7.81).

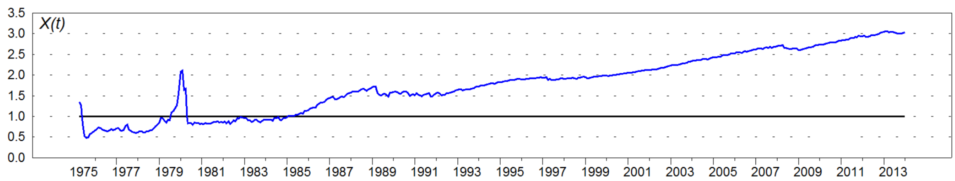
Table 7.81: Bai and Perron Multiple Break Test - Gold & the Japanese CPI, Nominal

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	1013.340	21.482	47.172	0
2	DZ(1,2)	456.7328	12.206	37.419	0
3	DZ(1,3)	1091.169	20.813	52.428	0

Breakpoint	Lower 95%	-	Upper 95%
Jan-86	Oct-85	to	Mar-88
Jan-07	May-06	to	Apr-07

The second breakpoint identified by the Bai and Perron (2003a) procedure (Table 7.81) occurs in January 1986, set within a rather long time window between October 1985 and March 1988. A visualisation of the changing relationship between gold and the Japanese CPI is obtained by plotting the Johansen Trace Test Statistic (Figure 7.23). If the blue line is set below the horizontal scale, the two series are cointegrated.

Figure 7.23: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal Japanese CPI (Scaled by the 5% Critical Value) - All Parameters



The results in Figure 7.23 nicely support the results identified by the formal testing procedure. Especially the breakpoint identified by the Bai and Perron (2003a) test (Table 7.81) can be easily observed, where the cointegration relationship between the series stops around late 1985, early 1986. It can be seen in Figure 7.22, that around that period, the gold price starts to fall while inflation climbs until the mid 1990s; therefore evolving in the opposite direction. The early period of the datasample considered is driving the overall cointegration relationship identified by the Johansen procedure (Table 7.78), while time-variation is evident (Table 7.79) considering the short break in the relationship around 1980 and from 1986 onwards (Figure 7.23). Great price fluctuation of the price of gold during the 1979 energy crisis can be observed in Figure 7.22 and were harmful to the inflation hedging ability of gold during that period. Beckmann and Czudaj (2013) find evidence for a much larger number of regime shifts during the 1970s, our results augment the authors findings by showing that breaks in the cointegration relationship indeed occurred in 1974 and 1980, but that otherwise, gold and the Japanese CPI were cointegrated (Figure 7.23). In regard to Japans deflationary episode between 1998 up until the end of the time window considered (Figure 7.22), it seems that in contrary to the USA, deflationary periods lead to a negative relationship between gold and inflation in Japan. Indeed, Hoang et al. (2016) study the relationship between gold and the Japanese CPI and find that it is always negative. Working with a longer time window, we indeed provide evidence for a negative relationship around that period, but argue that the relationship is positive during the early part of the sample. Furthermore, special caution should be taken when interpreting the results as gold was an attractive investment between 2004 and 2012, though at the price of rather speculative elements (Figure 7.22).

In conclusion, findings provide evidence for a poor ability of gold to be used as an effective inflation hedge in Japan in more recent times. A major reason is the deflation the economy is going through and the speculative nature that gold has received in Japan, where it's price fluctuated greatly during the last 10 years of the sample.

7.1.3.1.2 Gold in ¥ and the Predicted Consumer Price Index

An ARIMA(6,1,5) model was used to derive predicted values of Japanese consumer price inflation. Information relevant for the model selection can be found in Appendix I.

Following the Schwarz Bayesian Information Criterion, we work with a lag length of 13 months in the system. The Augmented Dickey Fuller test indicates that both series are I(1) integrated (Table 7.82), allowing to continue with the formal cointegration investigation.

Table 7.82: Augmented Dickey Fuller Test - Gold & the Japanese CPI, Predicted

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-1.474	-3.443	-2.871	-2.570
D.Gold	-5.493	-2.335	-1.648	-1.283
JPCPI	-2.997	-3.981	-3.421	-3.130
D.JPCPI	-4.079	-2.335	-1.648	-1.283

The next step consists of investigating the possible long-run relationship between the two series using the method proposed by Johansen.

Table 7.83: Johansen Test for Cointegration - Gold & the Japanese CPI, Predicted

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	48	2605.7810	.	6.2492*	12.53
1	51	2608.3087	0.01077	1.1938	3.84
2	52	2608.9056	0.00255		

The results in Table 7.83 indicate that gold was not cointegrated with the predicted CPI in Japan between January 1974 and January 2014. Since no cointegration relationship exists between the two series, we are unable to proceed with the investigation for time-variancy proposed by Bierens and Martins (2010). However, a Gregory and Hansen (1996a) test can be used to detect shifts in the cointegration relationship (Table 7.84).

Table 7.84: Gregory and Hansen Test - Gold & the Japanese CPI, Predicted

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-2.57	408	Jan. 2008	-5.47	-4.95	-4.68
Z_t	-2.56	308	Sep. 1999	-5.47	-4.95	-4.68
Z_α	-13.53	308	Sep. 1999	-57.17	-47.04	-41.85

The breakpoints identified by the Bai and Perron (2003a) procedure are somehow different and point towards different time windows.

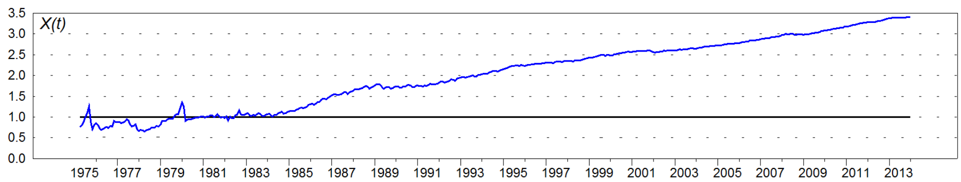
Table 7.85: Bai and Perron Multiple Break Test - Gold & the Japanese CPI, Predicted

	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	2.571	0.005	472.16	0
2	DZ(1,2)	2.311	0.004	512.92	0
3	DZ(1,3)	2.504	0.007	366.38	0

Breakpoint	Lower 95%	-	Upper 95%
Feb-88	Nov-87	to	Oct-88
Mar-06	Oct-05	to	Oct-06

Indeed, results in Table 7.85 indicate two breaks, the first in February 1988 and the second in March 2006. A visualisation of the evolving relationship between gold and the predicted Japanese CPI is helpful in understanding the relationship between the series.

Figure 7.24: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted Japanese CPI (Scaled by the 5% Critical Value) - All Parameters



It can clearly be seen in Figure 7.24 that gold and the predicted Japanese CPI were not cointegrated over the major part of the observation period. Indeed, gold and the predicted CPI were only cointegrated between 1975 and 1980, though the connection was not strong enough to drive the cointegration relationship over the entire sample. The second shift identified by the Gregory and Hansen (1996a) procedure in Table 7.84 indicates the very slight drop of the Johansen Trace Test Statistic (Figure 7.24) while the first break identified by the Bai and Perron (2003a) test (Table 7.85) also points towards a drop of the blue line towards the horizontal scale (Figure 7.24). In conclusion, it can be asserted that gold is not an effective hedge against predicted consumer price inflation in Japan, an explanation can be found in the unique development of the Japanese CPI rate since the late 1990s, a period of deflation and stagnating prices. It is noteworthy, that even though the overall direction of the trace statistic is very similar to that of the nominal Japanese CPI rate (Figure 7.23), the cointegration relationship between gold and the predicted Japanese CPI stopped earlier and was never very strong anyway (Table 7.24). Similar to the conclusion drawn for the Japanese CPI, it must be said that gold is not an effective inflation hedge in Japan as it is indeed unable to hedge both nominal and predicted headline consumer price inflation.

7.1.3.1.3 Gold in ¥ and Consumer Price Inflation Surprise

Consumer price inflation surprise in Japan is defined as the difference between the nominal Japanese CPI and the predicted Japanese CPI. The Schwarz (1978) Criterion suggests to use a lag length of six months in the system, while the Augmented Dickey Fuller Test indicates that both series are stationary (Table 7.86).

Table 7.86: Augmented Dickey Fuller Test - Gold & the Japanese CPI, Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
D.ln_gold	-5.493	-2.335	-1.648	-1.283
surprise_JPCPI	-3.563	-2.335	-1.648	-1.283

Following the findings in Table 7.86, an ARDL model is fitted to test the long-run relationship between the two series (Table 7.87).

Table 7.87: ARDL Test - Gold & the Japanese CPI, Surprise

F-Statistic	1% Critical Value	2.5% Critical Value	5% Critical Value	10% Critical Value
244.076	6.84	5.77	4.94	4.04

t-Statistic	1% Critical Value	2.5% Critical Value	5% Critical Value	10% Critical Value
-22.083	-3.43	-3.13	-2.86	-2.57

The results of the ARDL test indicate a positive relationship at levels between the two series. A next step consists of indexing the two series in order to obtain non-stationary data and apply the formal testing procedure proposed in the Methodology section.

The Schwarz Bayesian Information Criterion recommends using a lag length of seven months in a model consisting of the price of gold and an index of Japanese surprise inflation.

Table 7.88: Augmented Dickey Fuller Test - Gold & the Japanese CPI, Indexed Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
gold_index	-1.474	-3.443	-2.871	-2.570
D.gold_index	-5.493	-2.335	-1.648	-1.283
JPCPI_sur.ind	-3.772	-3.982	-3.422	-3.130
D.JPCPI_sur.ind	-3.722	-2.335	-1.648	-1.283

While the results in Table 7.88 should be considered with some distance as the critical values reached are not as confident as for previous models, the Augmented Dickey Fuller Test does indeed indicate that the price of gold and the inflation surprise index are integrated of order 1. The two time series are fitted into a Johansen model (Table 7.89).

Table 7.89: Johansen Test for Cointegration - Gold & the Japanese CPI, Indexed Surprise

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	24	956.42140	.	5.5930*	12.53
1	27	958.38662	0.00828	1.6626	3.84
2	28	959.21792	0.00351		

The results suggest that no cointegration relationship can be observed between gold and Japanese CPI surprise between 1974 and 2014. These results make it impossible to proceed with the Bierens and Martins (2010) procedure, and we should instead pursue the investigations by identifying breaks using the Gregory and Hansen (1996a) test.

Table 7.90: Gregory and Hansen Test - Gold & the Japanese CPI, Indexed Surprise

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-2.70	395	Dec. 2006	-5.47	-4.95	-4.68
Z_t	-2.57	402	Jul. 2007	-5.47	-4.95	-4.68
Z_α	-12.15	402	Jul. 2007	-57.17	-47.04	-41.85

The results in Table 7.90 indicate two shifts in the relationship between gold and inflation surprise, both rather close to one another: the first one in December 2006 and the second one in July 2007.

Table 7.91: Bai and Perron Multiple Break Test - Gold & the Japanese CPI, Indexed Surprise

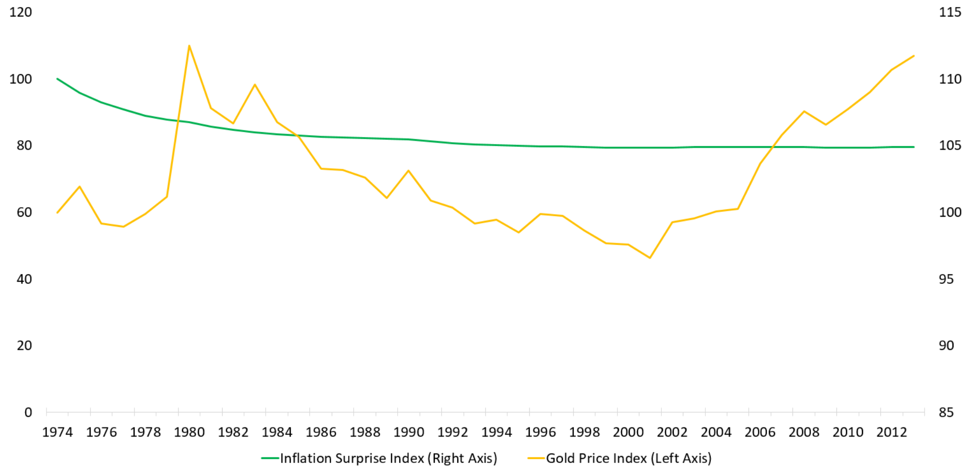
	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	1.080	0.003	370.15	0
2	DZ(1,2)	1.251	0.001	856.26	0
3	DZ(1,3)	1.360	0.003	490.15	0

Breakpoint	Lower 95%	-	Upper 95%
Apr-79	Mar-79	to	Jul-79
Mar-06	Nov-05	to	Jun-06

The Bai and Perron (2003a) procedure (Table 7.91) indicates a breakpoint earlier than the Gregory and Hansen (1996a) model results. Furthermore, another break points towards April 1979, in line with the 1979 energy crisis.

Figure 7.25 clearly shows the large movements of gold against a nearly static Japanese CPI surprise index. In conclusion, it can be said that golds was not a hedge against consumer price inflation surprise in Japan (Table 7.89). Figure 7.25 indicates that inflation surprise was falling in Japan over the past 40 years - pointing towards the importance of deflationary episodes for the gold/inflation relationship in Japan. A break in the upwards trending gold price is identified around 2008, but the very volatile influence of the 1979 Oil Crisis (Table 7.91) can also be identified on Figure 7.25.

Figure 7.25: Japanese CPI Surprise Index and Gold between 1974 and 2014



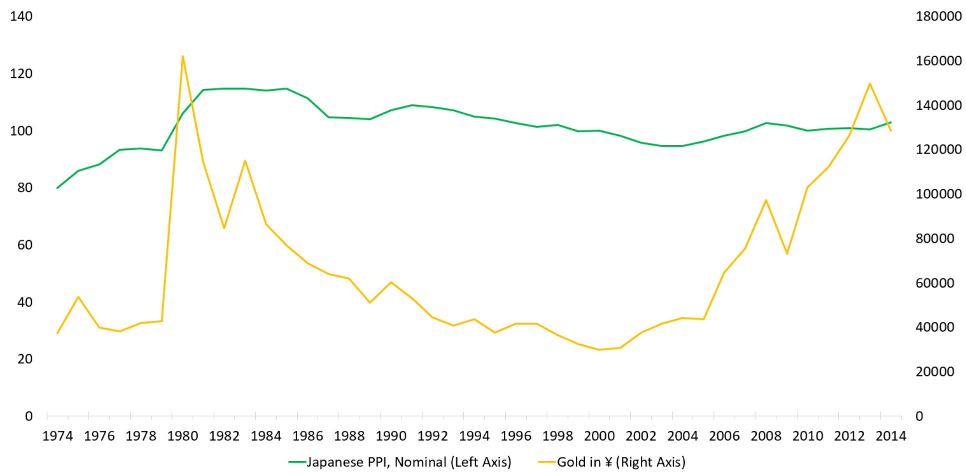
7.1.3.1.4 Concluding Remarks

This section analysed the relationship between the price of gold in ¥ and three different measures of Consumer Price Inflation in Japan between January 1974 and January 2014. Evidence showed that gold was only cointegrated with nominal inflation on the long-run (Table 7.78) but that this relationship was time-varying (Table 7.79). Considering the entire sample, gold was only cointegrated with nominal and predicted inflation in the late 1970s and early 1980s (Figures 7.23 and 7.24), though this cointegration relationship was not strong enough for predicted inflation to drive the entire observation period. Across the board, evidence uncovers the detrimental effect of the 1979 energy crisis on the gold/inflation relationship in Japan (Figures 7.23 and 7.24), and even more so the effect of deflation that lead to a negative relationship between the two series (Hoang et al. (2016)). Considering the price movements of gold against stagnating prices in Japan (Figure 7.22), it should be clarified that gold reached aspects of a speculative asset more so than an attractive hedging instrument. The formal procedure applied in the analysis above indeed shows that gold is not an effective hedge against consumer price inflation in Japan, but the heavy price fluctuations of the price of gold in ¥ are indicating that gold is rather unlikely to become an inflation hedging instrument in the near future. This conclusion is of high value to regulators, investors and decision makers who should strongly reconsider their investment in gold as a protection against price changes in the Japanese economy.

7.1.3.2 Producer Price Index

The Japanese Producer Price Index is calculated by the Bank of Japan and reports changes in the prices of goods bought and sold by companies in the country. The time frame considered is monthly and lasts from January 1974 to January 2014 - the two series are plotted in Figure 7.26.

Figure 7.26: The nominal Japanese PPI and Gold in ¥ between 1974 and 2014



The deflationary episode the Japanese PPI went through since the early 1980s is much more pronounced than what was observed earlier for the Japanese CPI (Figure 7.22). Indeed, the PPI in Japan is in a downward trend, while the price of gold quite heavily fluctuated over the past 40 years. A sharp increase followed by a drastic fall is noted during the early 1980s, while the price was again heavily increasing since the early 2000s.

7.1.3.2.1 Gold in ¥ and the Nominal Producer Price Index

The lag length used in the following analysis was fixed at three months following the approach of Schwarz (1978).

The Augmented Dickey Fuller Test indicates that the price of gold and the Japanese PPI are both I(1) series (Table 7.92).

Table 7.92: Augmented Dickey Fuller Test - Gold & the Japanese PPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-1.066	-3.443	-2.871	-2.570
D.Gold	-5.978	-2.335	-1.648	-1.283
JPPPI	-2.801	-3.442	-2.871	-2.570
D.JPPPI	-4.703	-2.335	-1.648	-1.283

The Johansen procedure is used to detect a possible long-run relationship between the two series. However, results in Table 7.93 indicate that the two series were not cointegrated between January 1974 and January 2014.

Table 7.93: Johansen Test for Cointegration - Gold & the Japanese PPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	8	-4947.7477	.	3.1601*	12.53
1	11	-4946.4180	0.00555	0.5006	3.84
2	12	-4946.1677	0.00105		

The investigation is continued with a detection of the shifts in the relationship between gold and the nominal Japanese PPI.

Table 7.94: Gregory and Hansen Test - Gold & the Japanese PPI, Nominal

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-3.17	401	May. 2007	-5.47	-4.95	-4.68
Z_t	-3.57	398	Feb. 2007	-5.47	-4.95	-4.68
Z_α	-23.61	398	Feb. 2007	-57.17	-47.04	-41.85

The results in Table 7.94 indicate a shift in the relationship between the two series around early 2007, findings in line with the Bai and Perron (2003a) multiple break procedure that points towards two breaks: the first in January 1988 and the second in December 2016 (Table 7.95).

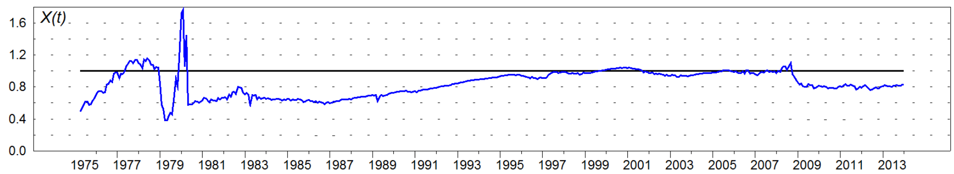
Table 7.95: Bai and Perron Multiple Break Test - Gold & the Japanese PPI, Nominal

	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	706.623	13.547	52.160	0
2	DZ(1,2)	429.228	11.912	36.032	0
3	DZ(1,3)	1075.193	19.506	55.121	0

Breakpoint	Lower 95%	-	Upper 95%
Jan-88	Aug-87	to	Mar-92
Dec-06	Apr-06	to	Jan-07

In order to understand the evolving relationship between the series more easily, Johansen's Trace Statistic is plotted and scaled by the 5% critical value (Figure 7.27). If the blue line is above the horizontal scale, the two series are not cointegrated.

Figure 7.27: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal Japanese PPI (Scaled by the 5% Critical Value) - All Parameters



The results for the nominal Japanese PPI are very revealing. Gold and the PPI did not share a long-run relationship between January 1974 and January 2014, as indicated by the Johansen test results (Table 7.93). Figure 7.27 does however indicate that gold and the nominal PPI were cointegrated between 1980 and 1995. It seems that the energy crisis of 1979, during which the blue line in Figure 7.27 shoots upwards, as well as the years between 1995 and 2008, during which the blue line is consistently crossing the horizontal scale, are responsible for the negative relationship between the two series. The shift back to cointegration around 2008 is somehow indicated by the Gregory and Hansen (1996a) procedure as well as the Bai and Perron (2003a) test, pointing towards early indications of a shifting relationship between the two series (Tables 7.94 and 7.95). Another important observation is that the breaking points identified by Tables 7.94 and 7.95 point towards the short time window of strong inflation during the period considered.

The first time window identified by Bai and Perron (2003a) is also observed by Beckmann and Czudaj (2013) and is likely pointing towards the low value of the Trace Statistic, a value it will not reach again throughout the rest of the sample period. Beckmann and Czudaj (2013) also point towards regime shifts in the late 1970s, the mid 1990s, and around 2008, all evidenced by Figure 7.27. It should be noted however, that the Global Financial Crisis of 2008 seems to have had a positive effect on gold's inflation hedging ability in Japan. Indeed, since 2008, gold is again a hedge against inflation, results very different to the Japanese CPI (Figure 7.23). However, the distance of the plotted trace statistic towards the horizontal scale does not suggest a strong hedging ability of gold; producers should therefore keep a close eye on the evolving relationship as it is quite likely that gold's ability to hedge price changes in Japan is likely to vanish away in the near future.

7.1.3.2.2 Gold in ¥ and the Predicted Producer Price Index

An ARIMA(2,1,2) model is used to derive predicted values of the Japanese Producer Price Index - more information can be found in Appendix J. The Schwarz Bayesian Information Criterion recommends using a lag length of two months in the system.

The Augmented Dickey Fuller test is used to analyse the order of integration of the two time series.

Table 7.96: Augmented Dickey Fuller Test - Gold & the Japanese PPI, Predicted

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
ln_gold	-1.474	-3.443	-2.871	-2.570
D.ln_gold	-5.493	-2.335	-1.648	-1.283
pred_JPPPI	-3.038	-3.443	-2.871	-2.570
D.pred_JPPPI	-4.843	-2.335	-1.648	-1.283

The results in Table 7.96 indicate that both series are I(1) integrated, though the confidence interval for the predicted Japanese Producer Price Index is weaker than for other measures considered earlier in this analysis.

Table 7.97: Johansen Test for Cointegration - Gold & the Japanese PPI, Predicted

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	4	2505.2352	.	9.2771*	12.53
1	7	2509.5795	0.01801	0.5885	3.84
2	8	2509.8738	0.00123		

The Johansen test detects no long-run cointegration relationship between gold and the predicted Japanese PPI (Table 7.97). Overall, gold is therefore not a good long-run hedge against predicted inflation in Japan. The procedure from Bierens and Martins (2010) can only be run if a positive long-run relationship is detected by the Johansen test. The analysis is therefore continued by looking at shifts identified from a Gregory and Hansen (1996a) procedure.

Table 7.98: Gregory and Hansen Test - Gold & the Japanese PPI, Predicted

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-2.94	330	Jul. 2001	-5.47	-4.95	-4.68
Z_t	-3.09	391	Aug. 2006	-5.47	-4.95	-4.68
Z_α	-16.54	391	Aug. 2006	-57.17	-47.04	-41.85

The results in Table 7.98 indicate two shifts in the relationship between gold and the predicted Japanese Producer Price Index, the first one occurring in July 2001 and the second one occurring in August 2006. A break around early 2006 is also identified by the Bai and Perron (2003a) procedure.

Table 7.99: Bai and Perron Multiple Break Test - Gold & the Japanese PPI, Predicted

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	2.394	0.003	702.858	0
2	DZ(1,2)	2.297	0.003	727.936	0
3	DZ(1,3)	2.495	0.005	544.848	0

Breakpoint	Lower 95%	-	Upper 95%
Sep-88	Dec-87	to	Apr-90
Nov-05	Jun-05	to	Jan-06

The results in Table 7.99 suggest another break window between December 1987 and April 1990, with the breakpoint occurring in September 1988. A visualisation of the evolving relationship between gold and the predicted Japanese PPI is helpful in understanding when the two series were cointegrated.

Figure 7.28: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted Japanese PPI (Scaled by the 5% Critical Value) - All Parameters

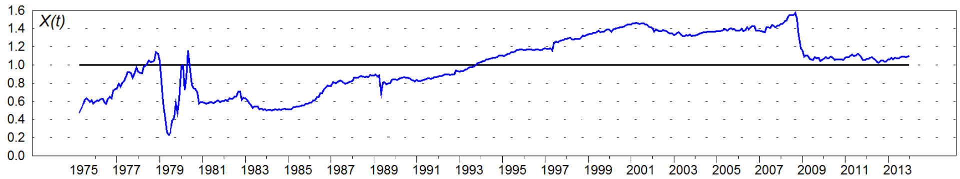


Figure 7.28 indicates the early and mid 1990s as the point in time during which gold stopped to be cointegrated with the predicted Japanese PPI. However, in contrary to the findings for the nominal Japanese PPI (Figure 7.27), the relationship indeed stops and doesn't shift back to cointegration up until the end of the observation period. Also, the 1979 energy crisis has a very different effect on the relationship between gold and the predicted PPI: it is strengthening the cointegration relationship and not merely enhancing volatility in the gold/inflation relationship like it did for gold and the nominal PPI (Figure 7.27). Despite the positive effect on gold's inflation hedging ability that was observed for the Global Financial Crisis of 2008 in Figure 7.27, gold entirely stopped to be a hedge against predicted inflation since 1993. The first shift identified by the Gregory and Hansen (1996a) procedure, occurring in July 2001 can be recognised in Figure 7.28, where the Trace Statistic reaches a local maximum. A similar observation can be made for the first break window identified by the Bai and Perron (2003a) procedure (Table 7.99), where the Trace Statistic increases sharply and plunges back down around the early 1990s (Figure 7.28). Contrasting the pronounced break in the cointegration relationship between gold and the predicted PPI against a stagnation of the relationship between gold and the nominal PPI, it is of high importance to note that the break is accompanied by drastically diminishing interest rates in Japan. Indeed, throughout the 1990s, the interest rate set by the Bank of Japan fell from around 6% to nearly 0%, deteriorating the relationship between gold and anticipated inflation. In contrary to the expectations of market participants, even though the monetary policy of Japan was at historically low points, the Producer Price Index stagnated up until 2005 to only pick up again in 2006, an important year for the long-run relation ship between the two series as indicated by the results in Tables 7.98 and 7.99.

7.1.3.2.3 Gold in ¥ and Producer Price Inflation Surprise

Producer Price inflation surprise is the difference between the nominal and the predicted PPI. We follow Schwarz (1978) and include no lag into the system. A Dickey Fuller procedure indicates that the two series are stationary (Table 7.100), recommending the use of an ARDL model when analysing the relationship between the two series.

Table 7.100: Augmented Dickey Fuller Test - Gold & the Japanese PPI, Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
D.ln_gold	-5.497	-2.335	-1.648	-1.283
surprise_JPPPI	-5.472	-2.335	-1.648	-1.283

The ARDL test indeed indicates a positive relationship at levels between the two series (Table 7.101).

Table 7.101: ARDL Test - Gold & the Japanese PPI, Surprise

F-Statistic	1% Critical Value	2.5% Critical Value	5% Critical Value	10% Critical Value
259.941	6.84	5.77	4.94	4.04

t-Statistic	1% Critical Value	2.5% Critical Value	5% Critical Value	10% Critical Value
-22.416	-3.43	-3.13	-2.86	-2.57

In a next step, the two I(0) series are indexed to proceed with the formal testing procedure outlined in earlier sections of this thesis.

The Schwarz Bayesian Information Criterion recommends using a lag length of one month in the system and the Augmented Dickey Fuller Test indicates that the two time series are non-stationary (Table 7.102).

Table 7.102: Augmented Dickey Fuller Test - Gold & the Japanese PPI, Indexed Surprise

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
gold_index	-1.474	-3.443	-2.871	-2.570
D.gold_index	-5.493	-2.335	-1.648	-1.283
JPPPI_sur.ind	-0.949	-3.443	-2.871	-2.570
D.JPPPI_surind	-5.454	-2.335	-1.648	-1.283

The Johansen test indicates that the two series are not cointegrated (Table 7.103), making it impossible to apply the methodology proposed by Bierens and Martins (2010) to test for time-variation in the relationship between the two series.

Table 7.103: Johansen Test for Cointegration - Gold & the Japanese PPI, Indexed Surprise

Maximum Rank	**Parms**	**LL**	**Eigenvalue**	**Trace Statistic**	**5% Critical Value**
0	0	163.76347	.	2.5095*	12.53
1	3	165.00638	0.00518	0.0237	3.84
2	4	165.01823	0.00005		

Shifts in the relationship between the two series can be detected with the Gregory and Hansen (1996a) procedure.

Table 7.104: Gregory and Hansen Test - Gold & the Japanese PPI, Indexed Surprise

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-4.16	378	Jul. 2005	-5.47	-4.95	-4.68
Z_t	-4.26	384	Jan. 2006	-5.47	-4.95	-4.68
Z_α	-35.37	384	Jan. 2006	-57.17	-47.04	-41.85

Indeed, the results in Table 7.104 suggest two shifts, one in July 2005 and the other one in January 2006. A similar breaking period is also identified by the Bai and Perron (2003a) procedure.

Table 7.105: Bai and Perron Multiple Break Test - Gold & the Japanese PPI, Indexed Surprise

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	1.031	0.002	604.900	0
2	DZ(1,2)	0.995	0.002	553.364	0
3	DZ(1,3)	1.089	0.002	438.842	0

Breakpoint	Lower 95%	-	Upper 95%
Sep-90	Mar-90	to	Jun-95
Dec-05	Aug-05	to	Feb-06

Table 7.105 also suggests a break during the rather long time window between March 1990 and June 1995.

Figure 7.29: Japanese PPI Surprise Index and Gold between 1974 and 2014

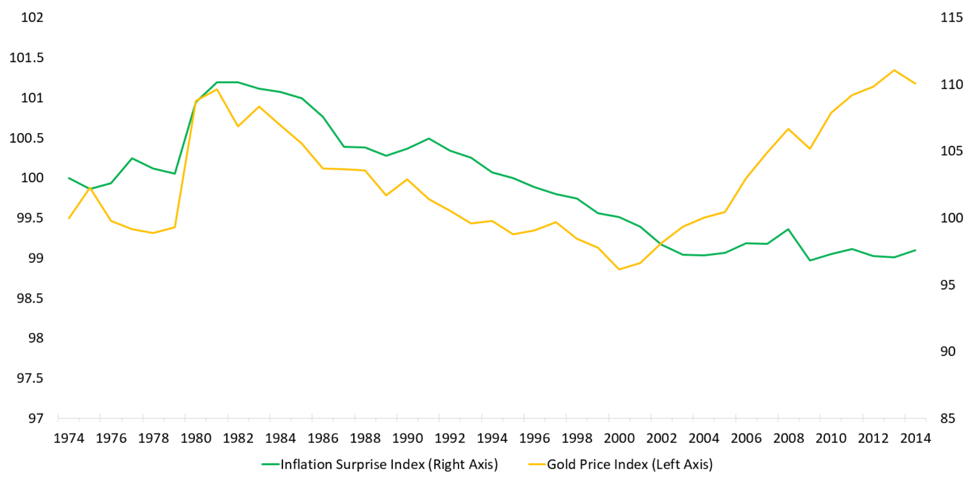


Figure 7.29 suggests that the two series moved in similar directions up until 2006, where a strong increase of the gold price can be observed against a stagnating Inflation Surprise Index. So while the Johansen procedure indicates that no cointegration existed between the two series on the long-run (Table 7.103), a certain similarity in the movements is undeniable in Figure 7.29. However, a simple comovements of series does not immediately imply cointegration. The Gregory and Hansen (1996a) and the Bai and Perron (2003a) procedure both indicate a change in the relationship around mid-2005/early-2006 (Tables 7.104 and 7.105), a time during which the nominal Japanese PPI peaked up (a zoom on the movements of the Japanese PPI rate can be found in Appendix J). Overall however, gold is not an effective hedge against surprises of the Japanese Producer Price Index.

7.1.3.2.4 Concluding Remarks

The above section has analysed the relationship of gold in ¥ and three different PPI measures for Japan. Gold was never cointegrated with any of the measures (Tables 7.93, 7.97 and 7.103) strongly questioning the ability of the precious metal to be used as a hedging instrument. A shift in the relationship between gold and inflation can be observed around the mid/early 1990s (Figures 7.27 and 7.28), a time during which the Bank of Japan started an historical low interest rate politic. It is only for the nominal PPI that gold plunged back into cointegration and therefore into the possibility to be used as a hedge, even though this relationship is still quite weak. Furthermore, it seems that the Financial Crisis of 2008 had a positive effect on the relationship between gold and inflation, strengthening the view of gold as a safe haven asset during troublesome times (Baur and Lucey (2010)). However, the conclusion of this part has to be that gold was not an effective hedge against producer price inflation in Japan and should not be used as such - an important finding for producers and regulators who should strongly reconsider their financial exposure to the yellow metal.

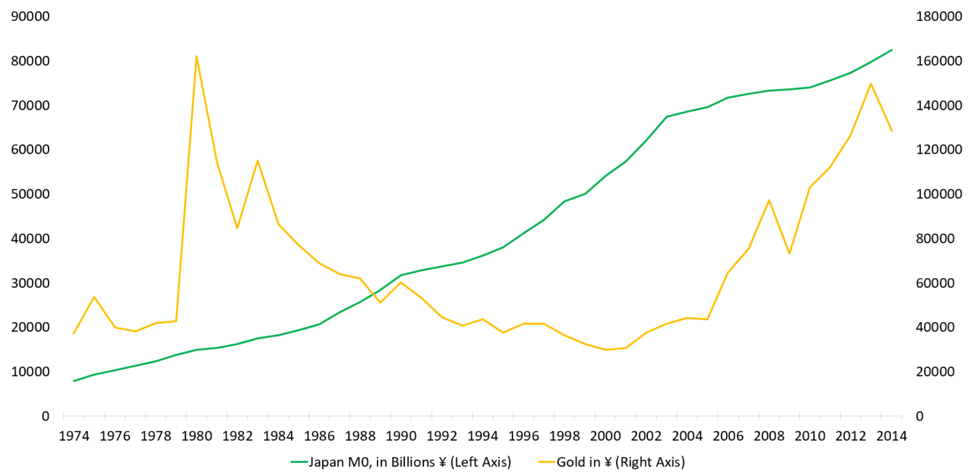
7.1.3.3 Narrow Money

Narrow money in Japan, or M0 money by its formal name, is the most liquid measurement of money in the Asian economy and consists of the in circulation as well as other assets easily convertible into cash. The section above discussed the possible importance of interest rate for the relationship between gold and inflation in Japan. Regressing narrow money against the price of gold will therefore allow an exposure to interest rates and a better understanding of the relationship between gold and the very root of inflation: money. Indeed, Carlson and Keen (1996) argued that liquid money systematically reflects interest rates effects. In a manner similar to what was done for narrow money in the USA and the UK, the testing procedure is only applied to nominal M0 money, as the response of gold to money is reactive in nature rather than proactive. In other words, market actors anticipate changes in inflation but not changes in money supply as it is viewed as a fixed aggregate published by the Bank of Japan.

7.1.3.3.1 Gold in ¥ and Narrow Money

A look at Figure 7.30 reveals an obvious upward trend in Japanese money supply between January 1974 and January 2014. On the other hand, the price of gold was in a downward trend between the early 1980s and the early 2000s. A very strong increase in the price of gold between 2001 and 2012 is observable. However, a sharp drop of the gold price is undeniable towards the end of the sample period. The reader will also note the strong effect of the 1979 oil crisis, where the price of gold peaked up to reach the maximum point of the sample period, just to fall back sharply soon after reaching that maximum.

Figure 7.30: Japanese Narrow Money and Gold in ¥ between 1974 and 2014



The Schwarz (1978) criterion suggests using a lag length of 13 months in the system while the Augmented Dickey Fuller procedure comfortably suggests that the two series are non-stationary (Table 7.106).

Table 7.106: Augmented Dickey Fuller Test - Gold & Japanese M0

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Gold	-1.066	-3.443	-2.871	-2.570
D.Gold	-5.978	-2.335	-1.648	-1.283
JPM0	-2.614	-3.981	-3.421	-3.130
D.JPM0	-2.500	-2.335	-1.648	-1.283

In a next step a Johansen test is run to detect a possible long-run relationship between the two series.

Table 7.107: Johansen Test for Cointegration - Gold & Japanese M0

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	48	-7979.7812	.	7.3225*	12.53
1	51	-7977.5784	0.00937	2.9168	3.84
2	52	-7976.1200	0.00621		

The results in Table 7.107 suggest that gold and narrow money in Japan were not cointegrated over the long-run. Being unable to detect a positive long-run relationship between the two series, we do not proceed with a Bierens and

Martins (2010) test for time-variation, but indeed pursue the investigation with the procedure proposed by Gregory and Hansen (1996a) to detect shifts in the relationship between the two series.

Table 7.108: Gregory and Hansen Test - Gold & Japanese M0

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-3.37	321	Sep. 2000	-5.47	-4.95	-4.68
Z_t	-3.62	333	Sep. 2001	-5.47	-4.95	-4.68
Z_α	-24.84	333	Sep. 2001	-57.17	-47.04	-41.85

Results in Table 7.108 suggest two shifting points in the relationship between gold and narrow money in Japan: September 2000 and September 2001.

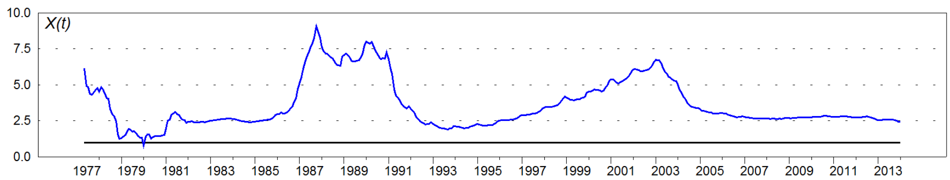
Table 7.109: Bai and Perron Multiple Break Test - Gold & Japanese M0

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	5.330	0.127	42.098	0
2	DZ(1,2)	0.960	0.025	38.432	0
3	DZ(1,3)	1.621	0.039	41.743	0

Breakpoint	Lower 95%	-	Upper 95%
Nov-85	Oct-85	to	Oct-86
Sep-09	Jul-09	to	Nov-11

The observations are different for the Bai and Perron (2003a) test results, where two breakpoints are indicated: November 1985 and September 2009.

Figure 7.31: Recursive Plot of Johansen's Trace Statistic for Gold and Japanese Narrow Money (Scaled by the 5% Critical Value) - All Parameters



The first break window identified by the Bai and Perron (2003a) test in Table 7.109, between October 1985 and October 1986 can be recognised in Figure 7.31, where a very steep increase away from the cointegration threshold begins. The second time window observed, between July 2009 and November 2011, is not obvious from a look at Figure 7.31, as the trace statistic seems to stagnate around that period and no drastic upward or downward change can be observed around that time. A similar observation is made for the results indicated by the Gregory and Hansen (1996a) test in Table 7.31, where the trace statistic seems to shift upwards, but without reaching a local maximum, which it will only reach later. The shift indicated by Gregory and Hansen (1996a) relates to the point in time at which the gold price breaks away from a downward trend and starts shifting back up (Figure 7.30). In conclusion, the results in Table 7.107 and Figure 7.31 suggest that gold was not cointegarted with Japanese narrow money throughout the sample and is therefore not an effective hedge against an increasing money supply in Japan.

7.1.3.3.2 Concluding Remarks

Considering all the results of the above analysis, it can be said that gold is not an effective hedge against inflation in Japan. Since the early 1980s, gold is not cointegrated with the Japanese CPI and since the mid 1990s, gold is not cointegrated with the PPI.

Indeed, gold is not an effective hedge against nominal inflation and recent price volatility suggests that it is a risky asset to hold rather than a financial asset with hedging or safe haven potential. In the light that gold was never cointgerated with money supply in Japan, an investment in gold as a protection against inflation should be strongly reconsidered.

All Figures can be found again in Appendix K for a clearer summary of the relationship between gold and different inflation measures in Japan.

7.2 Silver

The amount of research done on the relationship between silver and inflation is in no aspect comparable to the extensive investigations that exist about the gold-inflation relationship. However, the close relationship between gold and silver, as well as the *precious metal* aspects of the white metal pushes for a formal investigation into the matter of a better understanding of the relationship between silver and different inflation indices in the United States of America, the United Kingdom, and Japan. Unlike gold, where the extent of the research suggests considering the relationship between gold and both predicted and surprise inflation, the following section on silver will only present the results between silver and the nominal inflation series as this is, in its own, providing a strong contribution by uncovering insights into the relationship between silver and inflation.

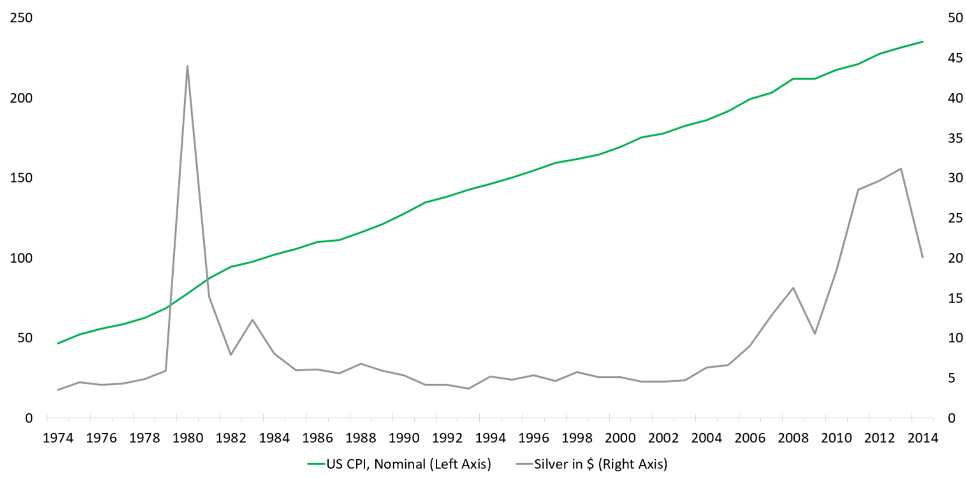
7.2.1 United States of America

In 2015, nearly 42% of the total demand for silver in the United States stemmed from the investment side; with about 26 million ounces more, the industrial demand for silver was only about 26% stronger (The Silver Institute (2016)). On the silver market, the United States remain a global player, the reason being both the size and importance of the country on the global silver market but also the fact that the official silver price is quoted in US Dollars.

7.2.1.1 Silver in $ and the Nominal Consumer Price Index

When considering a plot of the nominal US CPI against the price of silver, an upwards trend of the US CPI can be observed (Figure 7.32). However, the price of silver seem to have stagnated between 1985 and 2003 though it's price was increasing between 2005 and 2013. A strong fall in price can be observed towards the end of the sample. The effects of the Hunt brothers cornering the silver market are clearly expressed around the early 1980s, where the silver price is extremely volatile.

Figure 7.32: The nominal US CPI and Silver in $ between 1974 and 2014



The optimal lag length to use in the model is determined using the Schwarz Bayesian Information Criterion (Schwarz (1978)) and points to a lag length of three months.

The Augmented Dickey Fuller test indicates that the two series are integrated of order one (Table 7.110), indicating that the Johansen cointegration procedure can be run on these two variables.

Table 7.110: Augmented Dickey Fuller Test - Silver & the US CPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Silver	-1.757	-3.442	-2.871	-2.570
D.Silver	-9.525	-2.334	-1.648	-1.283
USCPI	-2.690	-3.981	-3.421	-3.130
D.USCPI	-4.380	-2.335	-1.648	-1.283

Indeed, the Johansen test indicates that silver and the US CPI are cointegrated and identifies two cointegration vectors (Table 7.111).

Table 7.111: Johansen Test for Cointegration - Silver & the US CPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	8	-1226.7352	.	72.9446	12.53
1	11	-1193.6228	0.12938	6.7199	3.84
2	12	-1190.2629	0.01396		

The positive long-run relationship identified is tested for time-variation in a next step. The Bierens and Martins (2010) results are displayed in Table 7.112.

Table 7.112: Bierens and Martins (2010) Test for Time-varying Cointegration - Silver & the US CPI, Nominal

Chebyshev Time Polynomials	**Test Statistic**	**10% Critical Value**	**5% Critical Value**	**P Value**
m = 1	11.43	4.61	5.99	0.00329
m = 2	24.58	7.78	9.49	0.00006
m = 3	24.74	10.64	12.59	0.00038
m = 4	29.98	13.36	15.51	0.00021

Indeed, the Bierens and Martins (2010) test results suggest that the long-run relationship between the two variables is time-varying. The Gregory and Hansen (1996a) procedure identifies shifts in the long-run cointegration relationship between silver and the US CPI in the early 2000s (Table 7.113).

Table 7.113: Gregory and Hansen Test - Silver & the US CPI, Nominal

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-4.08	338	Feb. 2002	-5.47	-4.95	-4.68
Z_t	-4.95	360	Dec. 2003	-5.47	-4.95	-4.68
Z_α	-46.61	360	Dec. 2003	-57.17	-47.04	-41.85

The Bai and Perron (2003a) results however indicate one major breaks in the relationship during the 1980s and another one in March 2010 (Table 7.114).

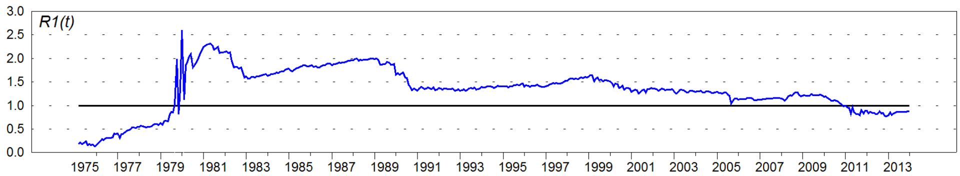
Table 7.114: Bai and Perron Multiple Break Test - Silver & the US CPI, Nominal

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	0.117	0.005	24.699	0
2	DZ(1,2)	0.043	0.001	30.291	0
3	DZ(1,3)	0.123	0.003	46.553	0

Breakpoint	Lower 95%	-	Upper 95%
Jun-84	Dec-83	to	Jun-88
Mar-10	Sep-09	to	Aug-10

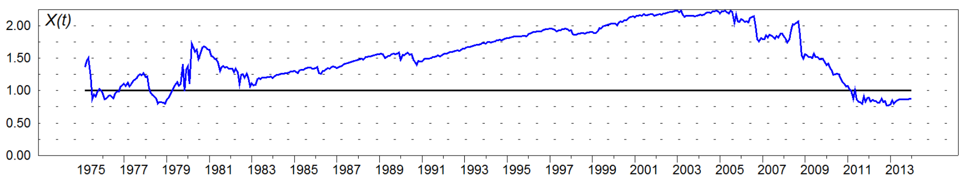
A striking observation is the very long time window identified by the Bai and Perron (2003a) procedure (Table 7.114), between December 1983 and June 1988, with a breakpoint in June 1984. Visualising the changes of the Johansen Test Trace Statistic between 1974 and 2014 allows for a simple and comprehensive understanding of the changing relationship between the two variables over time (Figure 7.33). The reader will note that the Trace Statistic plotted offers a comprehensive visualisation of the shift between parameters in the Johansen equation - hence offering an exposure to the stochastic elements caused by the very volatile year of 1980.

Figure 7.33: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US CPI (Scaled by the 5% Critical Value) - Long-Run Parameters



If the blue line in Figure 7.33 is below the horizontal black line, the two series are cointegrated. A striking observation is the break in cointegration around the 1980s due to the heavy price fluctuations following the speculations of the Hunt brothers; a break that seems to have stopped the cointegration relationship between the two series from 1980 up until 2011. Even though the shifts identified by the Gregory and Hansen (1996a) procedure around 2002 and 2003 can not be identified in Figure 7.33 they do indeed point towards the start of a strong upwards trend of the price of silver for 10 years to come (Figure 7.32) and towards a maximum value of the Trace Statistic for all parameters as can be seen in Figure 7.34.

Figure 7.34: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US CPI (Scaled by the 5% Critical Value) - All Parameters



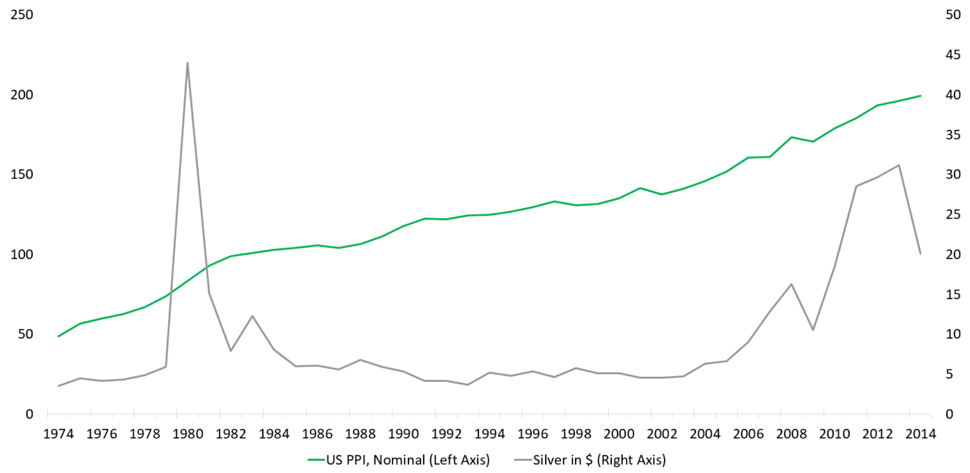
The results identified by the Bai and Perron (2003a) procedure are easier to recognise in Figure 7.33. The first window lasting from December 1983 to June 1988 points towards the rise of the Trace Statistic away from a cointegration relationship;

throughout that period, the price of silver was indeed decreasing against a steadily rising CPI rate in the United States of America (Figure 7.32). The second time window, between September 2009 and August 2010, identifying a breakpoint in March 2010 can be observed in Figure 7.33, where the two series return to a cointegration relationship that will last up until the end of the sample period in January 2014. The Johansen test results suggest a positive long-run relationship between silver and the US CPI (Table 7.111), a finding in line with Taylor (1998) who find evidence for silver to be a long-run hedge against US inflation between 1914 and 1996, but also a short-run hedge, mainly during the 1979 OPEC crisis, results supported in Figure 7.33. Adrangi et al. (2003) take into account a shorter monthly time window between 1967 and 1999 but still find evidence for a positive long-run relationship between silver and the US CPI. However, the results of the Bierens and Martins (2010) procedure in Table 7.112 underpinned by the results in Figure 7.33 suggest that the cointegration relationship between silver and the US CPI was varying through time. Though strong evidence of cointegration is provided for the early part of the sample, the events affecting the silver market in 1980 have been very detrimental to the relationship between the two series. It therefore seems, that the positive long-run relationship between the two series is driven by the early part of the sample and that an empirical conclusion should be considered with rigorous care when keeping the results of the above analysis in mind. Bampinas and Panagiotidis (2015) take into account a longer and more recent time window and argue that in both, a time-invariant and a time-variant framework, no long-run cointegration relationship exists between silver and the US CPI. The results presented in this section suggest that the Silver Thursday events of 1980 led to a drastic change in the relationship between silver and inflation: though the two series seem to be indeed positively correlated on the long-run, such a relationship can't be observed throughout the 1980s and the 1990s; indeed, Apergis et al. (2014) consider a time window between 1981 and 2010 and results indicate a negative relationship between silver and the US CPI.

7.2.1.2 Silver in $ and the Nominal Producer Price Index

The observation for the US PPI are very similar to those of the US CPI, with the difference that American producer prices don't seem to have increased as sharply as American consumer prices over the period considered. Both time series are plotted in Figure 7.35, where an upward trend of the PPI can immediately be observed.

Figure 7.35: The nominal US PPI and Silver in $ between 1974 and 2014



The Schwarz Bayesian Information Criterion recommends working with a lag length of two months in the system, while the Augmented Dickey Fuller Test indicates that the two series are non-stationary (Table 7.115).

Table 7.115: Augmented Dickey Fuller Test - Silver & the US PPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Silver	-1.757	-3.442	-2.871	-2.570
D.Silver	-9.525	-2.334	-1.648	-1.283
USCPI	-1.583	-3.981	-3.421	-3.130
D.USCPI	-5.248	-2.335	-1.648	-1.283

The Johansen procedure indicates that the two series are cointegrated of higher rank (Table 7.116), indicating that the series do indeed have a positive long-run relationship.

Table 7.116: Johansen Test for Cointegration - Silver & the US PPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	4	-1541.1533	.	49.1235	12.53
1	7	-1521.1242	0.08023	9.0654	3.84
2	8	-1516.5915	0.01875		

According to the procedure proposed by Bierens and Martins (2010), the long-run relationship identified in Table 7.116 is however found to be time-varying.

Indeed, the results in Table 7.117 suggest an evolving relationship between the two time series over the sample period.

Table 7.117: Bierens and Martins (2010) Test for Time-varying Cointegration - Silver & the US PPI, Nominal

Chebyshev Time Polynomials	**Test Statistic**	**10% Critical Value**	**5% Critical Value**	**P Value**
m = 1	6.06	4.61	5.99	0.04831
m = 2	17.97	7.78	9.49	0.00125
m = 3	18.61	10.64	12.59	0.00487
m = 4	21.03	13.36	15.51	0.00706

An understanding on when the changes in the relationship between the series occurs is first provided by the Gregory and Hansen (1996a) procedure (Table 7.118).

Table 7.118: Gregory and Hansen Test - Silver & the US PPI, Nominal

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-4.25	340	Apr. 2002	-5.47	-4.95	-4.68
Z_t	-5.02	360	Dec. 2003	-5.47	-4.95	-4.68
Z_α	-48.09	360	Dec. 2003	-57.17	-47.04	-41.85

Two shifts in cointegration are identified: the first in April 2002 and the second in December 2003. The results obtained are very similar to those obtained in Table 7.113 for the US CPI; akin of course to the similarity of the two series. The investigation is continued with the Bai and Perron (2003a) test for multiple breaks (Table 7.119).

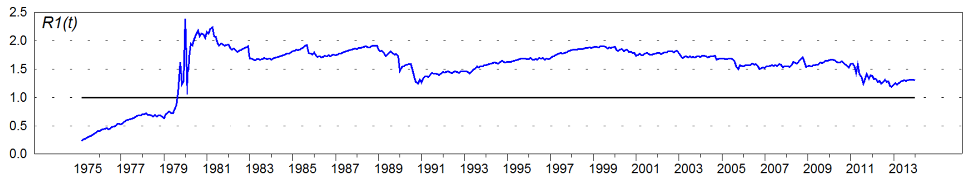
Table 7.119: Bai and Perron Multiple Break Test - Silver & the US PPI, Nominal

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	0.11217	0.004	25.125	0
2	DZ(1,2)	0.05206	0.002	30.793	0
3	DZ(1,3)	0.14654	0.003	47.281	0

Breakpoint	Lower 95%	-	Upper 95%
Jun-84	Jun-83	to	Dec-89
Mar-10	Sep-09	to	Aug-10

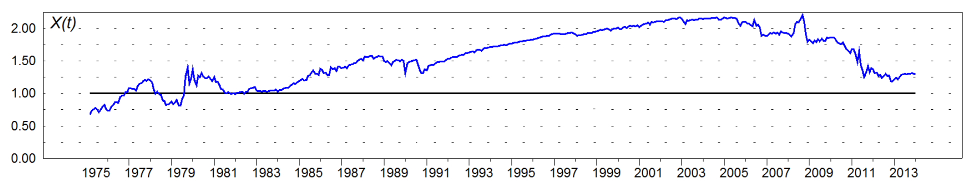
The two breaks identified for the US PPI are the same as those identified for the US CPI (Table 7.114): June 1984 and March 2010. Figure 7.36 offers a visualisation of the changes of the Johansen Test Trace Statistic between 1974 and 2014 in order to get a better understanding of when the two series are cointegrates. The higher rank component is taken into account in order to get a better understanding of the effect of the price fluctuations around 1980.

Figure 7.36: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US PPI (Scaled by the 5% Critical Value) - Long-Run Parameters



Results in Figure 7.36 suggest that silver and the US PPI were only cointegrated during the very beginning of the sample. A detrimental effect of the massive price fluctuations in the 1980s can easily be observed; furthermore, just like the case of the US CPI, the speculations of the Hunt brothers were so detrimental on the silver-inflation relationship, that the two series never reverted back to cointegration henceforth. Indeed, the graphical results of the Trace Statistic for all parameters suggest that the two series were cointegrated during the earlier part of the sample (Figure 7.37).

Figure 7.37: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US PPI (Scaled by the 5% Critical Value) - All Parameters



Even though the results identified by the Gregory and Hansen (1996a) procedure (Table 7.118) can not be recognised in Figure 7.36 they point towards a maximum in Figure 7.37. The first time window outlined by the Bai and Perron (2003a) procedure (Table 7.119), between June 1983 and December 1989 is in line with a steady trend away from the horizontal scale of cointegration amongst the two series. The second time window identified, between September 2009 and August 2010, set during the financial crisis, marks a constant decrease of the trace statistic, even though the two series never revert back to cointegration. In conclusion, it can be said that the results identify a cointegration relationship between silver and the US PPI, but that this relationship is of an higher order - pointing to a more complex short-run relationship between the series. Only in the first part of the sample the two series are found to be cointegrated; the troublesome events in 1980 led to a stop in the relationship from which the two series never recovered. The higher order relationship suggests that the relationship between the two series is deeper and likely to be driven by variables constituting the CPI, oil being the most prominent candidate. The complexity of the results observed for silver in comparison to gold reflect the industrial nature of the asset and therefore the difficult relationship between silver and inflation. An investigation into the relationship between silver and money supply is not only beneficial in the light of the role of money supply as a proxy for *real* inflation, but will also uncover more details about the higher rank relationship between silver and *official* inflation in the United States of America.

7.2.1.3 Silver in $ and Money Zero Maturity

The results presented above have uncovered a stochastic trend in the relationship between silver and *official* inflation indices. Understanding the relationship between silver and Money Zero Maturity, a reliable measure of liquid money in the American economy will provide a deeper understanding of the silver-inflation relationship as well as an exposure to changes in interest rates (Carlson and Keen (1996)). Figure 7.38 provides a graphical visualisation of the price of silver and the amount of liquid money in the American economy between January 1974 and January 2014.

A clear upwards trend of the amount of liquid money in the US economy can immediately be observed, as well as the effect of the Hunt brothers' speculations on the price of silver, causing very heavy fluctuations of the silver price around 1980.

The procedure proposed by Schwarz (1978) is followed and a lag length of 14 months is build into the system. The Augmented Dickey Fuller test identifies both time series as non-stationary (Table 7.120).

Figure 7.38: Money Zero Maturity and Silver in $ between 1974 and 2014

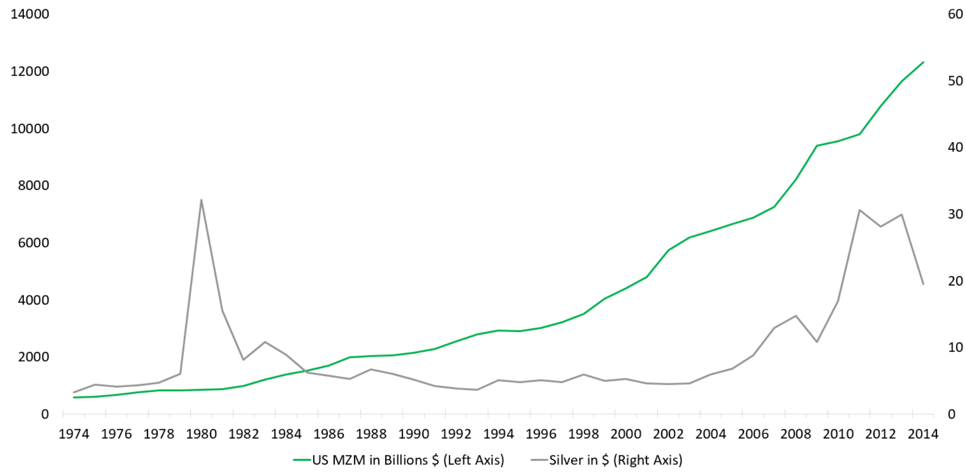


Table 7.120: Augmented Dickey Fuller Test - Silver & US MZM

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Silver	-2.054	-3.442	-2.871	-2.570
D.Silver	-11.721	-2.334	-1.648	-1.283
MZM	1.009	-3.982	-3.422	-3.130
D.MZM	-3.192	-2.335	-1.648	-1.283

The Johansen test for cointegration identifies a positive long-run relationship between the two series (Table 7.121) and the higher rank points towards a stochastic element in the relationship.

Table 7.121: Johansen Test for Cointegration - Silver & US MZM

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	52	-3132.6603	.	35.3827	12.53
1	52	-3118.4193	0.05917	6.9007	3.84
2	56	-3114.9690	0.01467		

In other words, the relationship between silver and money zero maturity was positive between 1974 and 2014, a result that is now being tested with the approach proposed by Bierens and Martins (2010) for time-variancy in the cointegration relationship.

Table 7.122: Bierens and Martins (2010) Test for Time-varying Cointegration - Silver & US MZM

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	4.67	4.61	5.99	0.09688
m = 2	7.50	7.78	9.49	0.11185
m = 3	8.20	10.64	12.59	0.22350
m = 4	11.99	13.36	15.51	0.15164

Considering the p-values displayed in Table 7.122, only the results at the Chebyshev order 1 are statistically significant. However, the results are somewhat conflicting as they suggest to accept the null-hypothesis of time-invariancy at the 5% level and to reject the null-hypothesis at the 10% level. In the light of these conflicting results, the 5% level should be prioritised and the relationship between silver and inflation should be considered to be invariant through time.

Shifts in the long-run relationship between the series are identified through the procedure proposed by Gregory and Hansen (1996a) and displayed in Table 7.123.

Table 7.123: Gregory and Hansen Test - Silver & US MZM

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-4.28	327	Mar. 2001	-5.47	-4.95	-4.68
Z_t	-4.57	364	Apr. 2004	-5.47	-4.95	-4.68
Z_α	-41.33	364	Apr. 2004	-57.17	-47.04	-41.85

Two shifts are identified in Table 7.123: the first in March 2001 and the second in April 2004. The Bai and Perron (2003a) procedure is used to identify breaks in the long-run relationship between silver and US money zero maturity from January 1974 to January 2014.

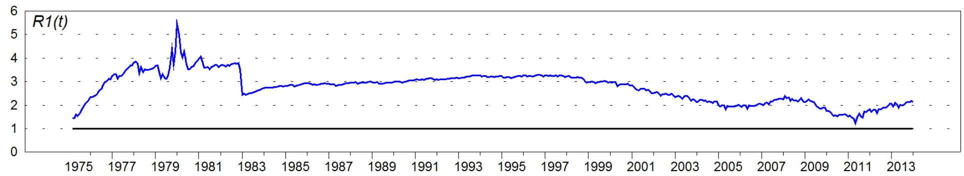
Table 7.124: Bai and Perron Multiple Break Test - Silver & US MZM

	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	0.00939	0.000	23.293	0
2	DZ(1,2)	0.00148	0.000	31.536	0
3	DZ(1,3)	0.00267	0.000	44.386	0

Breakpoint	Lower 95%	-	Upper 95%
Jul-84	Jun-84	to	Dec-86
Sep-10	May-09	to	Oct-11

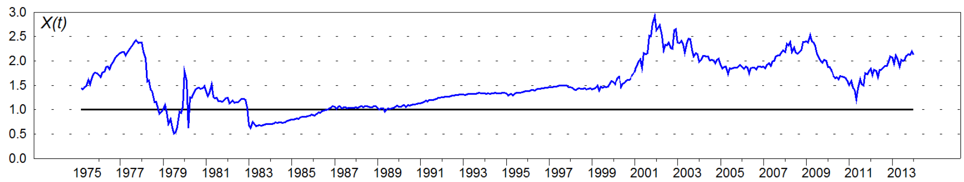
Two breakpoints are identified in Table 7.124, the first in July 1984 and the second in September 2010. A visualisation of the long-run parameters of the Trace Statistic of the Johansen test is useful to conclude the analysis.

Figure 7.39: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US MZM (Scaled by the 5% Critical Value) - Long-Run Parameters



Results in Figure 7.39 suggest a constant higher rank in the relationship between silver and US money zero maturity. A cointegration relationship of rank 2 suggests that a stochastic effect is present in the relationship, so in other words, short-run cointegration relationships are very likely. The results of Table 7.122 can nicely be observed in Figure 7.39, where indeed, the cointegration vector seems time-invariant as it never crosses the horizontal black line. An exposure to short-run cointegration is provided by looking at all of the parameters of the Johansen Trace Statistic, where a blue line below the horizontal scale indicates cointegration.

Figure 7.40: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US MZM (Scaled by the 5% Critical Value) - All Parameters



The results in Figure 7.40 indicate short-run cointegration windows between silver and US MZM around the late 1970s and the mid 1980s. The findings are somewhat in line with the Gregory and Hansen (1996a) test results (Table 7.123) pointing towards a sharp increase in 2001, though the shift around April 2004 can't be observed on any of the above pictures. The first time window identified by Bai and Perron (2003a) is in line with one of the short periods of cointegration in the sample, where the trace statistic is below the value of 1.00 (Figure 7.40); the second time window, between May 2009 and October 2011 points towards the drastic drop of the trace statistic, nearly reverting to a cointegration relationship (Figure 7.40), explained by the strong increase of the price of silver around that period (Figure 7.38). In conclusion, it can be said, that silver is not an effective long-run hedge against money supply in the United States of America. The higher cointegration rank identified by the Johansen procedure (Table 7.121) suggests that short-run cointegration dynamics might be driving the relationship: such dynamics have indeed been identified towards the early part of the sample but seem to die out towards the end.

7.2.1.4 Concluding Remarks

In the United States of America, silver was not an effective hedge against inflation. Concerning all three measures proposed, silver and inflation were only cointegrated towards the early part of the sample though a cointegration relationship appears again towards the end of the sample for the US CPI. The heavy price fluctuations in 1980 have been very detrimental for silver's inflation hedging ability, but the relationship between the two series has to be watched closely in the near future as a diminishing Trace Statistic seems to suggest that the series are reverting back to a cointegration relationship, meaning that silver would again become an effective long-run hedge against inflation in the United States of America. Economically, these results imply that while silver was not an effective inflation hedge over the past 40 years, formal results indicate that the financialisation of the white precious metal could turn it into an attractive inflation hedge over the years to come.

For a more comprehensive comparison, all Figures can be found again in Appendix D.

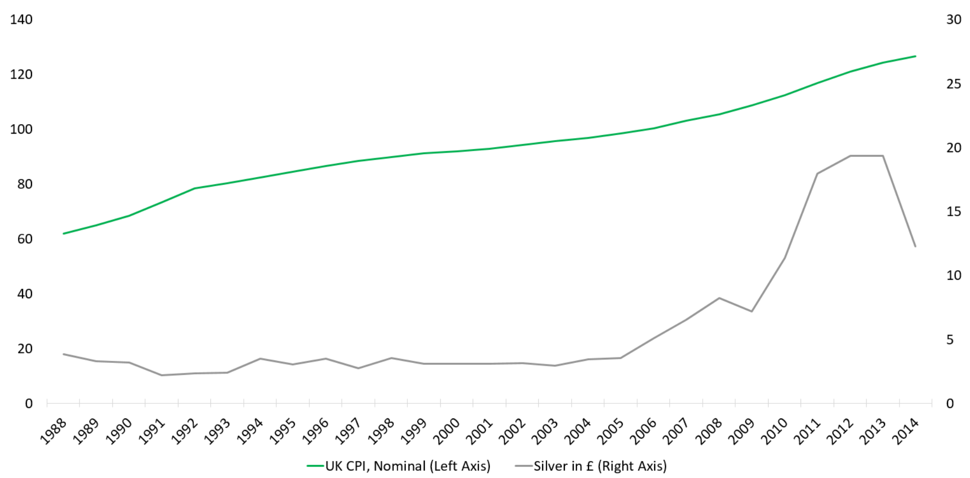
7.2.2 The United Kingdom of Great Britain and Northern Ireland

In the light that the London Bullion Market Association (LBMA) is responsible for fixing the official price of silver an understanding of the relationship between the price of silver in £ and different inflation indices in the UK is of high interest. The following section offers an investigation into the long-run relationship between gold and the CPI, the PPI and narrow money in the United Kingdom of Great Britain and Northern Ireland.

7.2.2.1 Silver in £ and the Nominal Consumer Price Index

The UK CPI was first calculated in January 1988, so the very volatile period of 1980 is not present in the sample.

Figure 7.41: The nominal UK CPI and Silver in £ between 1988 and 2014



It can be seen in Figure 7.41 that the UK CPI was steadily trending upwards against a stagnating price of silver up until around 2005, where the price of the precious metal starts to increase sharply just to drop back down towards the end of the sample.

Working with a lag length of one month in the system (Schwarz (1978)), the two time series are first tested for stationarity following Dickey and Fuller (1979, 1981).

Table 7.125: Augmented Dickey Fuller Test - Silver & the UK CPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Silver	-1.144	-3.456	-2.878	-2.570
D.Silver	-4.511	-2.339	-1.650	-1.285
UKCPI	-1.330	-3.988	-3.428	-3.130
D.UKCPI	-2.371	-2.340	-1.650	-1.285

The results in Table 7.125 indicate that both series are integrated of order 1, allowing to proceed with a Johansen procedure for cointegration.

Table 7.126: Johansen Test for Cointegration - Silver & the UK CPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	0	-558.87939	.	81.9013	12.53
1	3	-519.03134	0.22542	2.2052*	3.84
2	4	-517.92874	0.00704		

The results in Table 7.126 suggest that the two variables are cointegrated and have a positive long-run relationship. The relationship can be tested for time-variancy by means of the Bierens and Martins (2010) procedure, results are displayed in Table 7.127.

Table 7.127: Bierens and Martins (2010) Test for Time-varying Cointegration - Silver & the UK CPI, Nominal

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	1.66	4.61	5.99	0.43627
m = 2	9.89	7.78	9.49	0.04230
m = 3	17.94	10.64	12.59	0.00639
m = 4	18.50	13.36	15.51	0.01776

Results in Table 7.127 should be considered in light of the p value, only significant at a Chebyshev polynomials level of 2 and above; where the test statistic suggests rejecting the null hypothesis of time-invariancy. In light of time-variation in the long-run relationship between the two series, the Gregory and Hansen (1996a) procedure is used to identify shifts in the cointegration relationship.

Table 7.128: Gregory and Hansen Test - Silver & the UK CPI, Nominal

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-3.76	266	Feb. 2010	-5.47	-4.95	-4.68
Z_t	-3.92	265	Jan. 2010	-5.47	-4.95	-4.68
Z_α	-32.39	265	Jan. 2010	-57.17	-47.04	-41.85

Results in Table 7.128 indicate that a shift in the cointegration relationship between silver and the UK CPI occurred early 2010. In a next step, the procedure by Bai and Perron (2003a) is used to identify breaks in the relationship between the two series (Table 7.129).

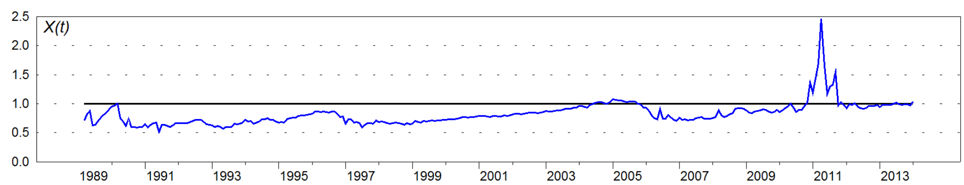
Table 7.129: Bai and Perron Multiple Break Test - Silver & the UK CPI, Nominal

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	0.036	0.001	27.846	0
2	DZ(1,2)	0.077	0.002	36.297	0
3	DZ(1,3)	0.150	0.002	69.943	0

Breakpoint	Lower 95%	-	Upper 95%
Feb-92	May-91	to	Mar-92
Aug-96	Nov-95	to	Oct-96

The results in Table 7.129 identify two breakpoints: in February 1992 and in August 1996. The Trace Statistic of the Johansen test is plotted in Figure 7.42 and provides a simple visualisation of when the two series are cointegrated.

Figure 7.42: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal UK CPI (Scaled by the 5% Critical Value) - All Parameters



As pointed out by the Johansen test results, the two time series were comfortably cointegrated between 1988 and 2014, with a short break between 2010 and 2012, results in line with the Gregory and Hansen (1996a) test results (Table 7.128). Another break can be observed between 2004 and 2006 (Figure 7.42) and it also seems that the cointegration relationship between the series is very weak towards the end of the sample, where the trace statistic is close to 1.00. Even though the first time window identified by the Bai and Perron (2003a) procedure can not be observed in Figure 7.42, the second one, between November 1995 and October 1996, is in line with a steady increase of the trace statistic towards a break in cointegration - which it never reaches. The positive relationship between silver and inflation in the United Kingdom is in line with the findings of Bampinas and Panagiotidis (2015) who themselves considered a longer time frame, but don't point towards a break around 2011 when the price of silver stops increasing as sharply as it did in the two previous years (Figure 7.41). Considering the results for the relationship between gold and the UK CPI in Figure 7.13, a very similar relationship between silver and the UK CPI can be observed. However, especially towards the end of the sample, silver remains in a cointegration relationship while gold fails to function as a hedging instrument towards later periods. Investors and regulators should therefore keep an open eye on the development of the relationship between precious metals and consumer price inflation in the UK as silver might continue to be the superior inflation hedge in the future.

7.2.2.2 Silver in £ and the Nominal Producer Price Index

The sample period considered when studying the relationship between silver and the Producer Price Index in the United Kingdom is lasting from January 1974 to January 2014 - hence including the very volatile period of 1980, where the Hunt brothers speculations led to strong movements of the silver price. A steady increase of the PPI rate can be observed in Figure 7.43 alongside a recent price increase of the price of silver in 2005.

The approach proposed by Schwarz (1978) is followed and a lag length of two months is built into the system. The two series are identified as non-stationary (Dickey and Fuller (1979, 1981)) and the test results are displayed in Table 7.130.

Figure 7.43: The nominal UK PPI and Silver in £ between 1974 and 2014

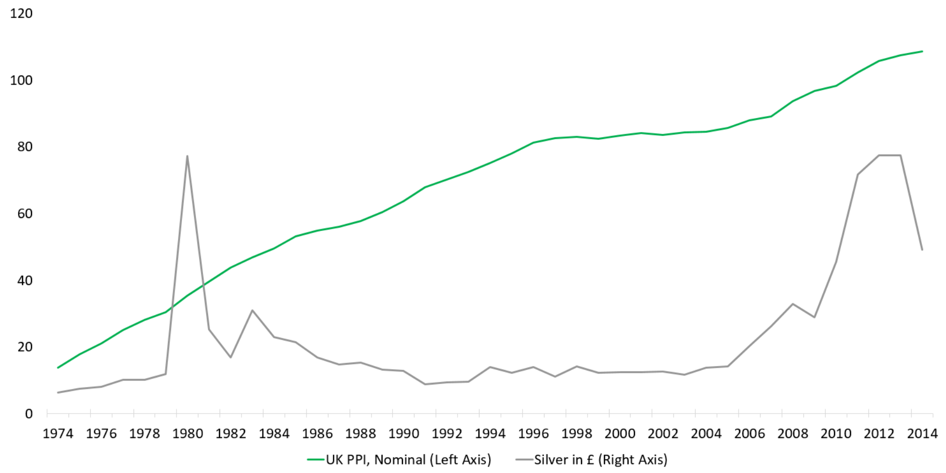


Table 7.130: Augmented Dickey Fuller Test - Silver & the UK PPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Silver	-1.494	-3.442	-2.871	-2.570
D.Silver	-8.398	-2.334	-1.648	-1.283
UKPPI	-2.027	-3.981	-3.421	-3.130
D.UKPPI	-4.393	-2.335	-1.648	-1.283

In a next step, the cointegration relationship between the two series is tested by means of the Johansen procedure (Johansen (1991)), where a long-run cointegration relationship of higher order is identified (Table 7.131).

Table 7.131: Johansen Test for Cointegration - Silver & the UK PPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	4	-648.49524	.	48.9557	12.53
1	7	-626.76838	0.08672	5.5020	3.84
2	8	-624.01737	0.01142		

The higher rank identified is due to the outliers in the early 1980s - findings similar to the United States of America. The Bierens and Martins (2010) procedure is now used to identify time-variation in the silver-PPI relationship.

Table 7.132: Bierens and Martins (2010) Test for Time-varying Cointegration - Silver & the UK PPI, Nominal

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	4.23	4.61	5.99	0.12080
m = 2	13.14	7.78	9.49	0.01062
m = 3	26.64	10.64	12.59	0.00017
m = 4	29.30	13.36	15.51	0.00028

Considering statistical significance in light of the p values, only the results provided with a Chebyshev order of two and above are significant and do suggest time-variancy in the long-run relationship between silver and the UK PPI. Shifts in the cointegration relationship can be derived by means of the Gregory and Hansen (1996a) procedure displayed in Table 7.133.

Table 7.133: Gregory and Hansen Test - Silver & the UK PPI, Nominal

	Test Statistic	Breakpoint	Date	1% Critical Value	5% Critical Value	10% Critical Value
ADF	-3.91	257	May 1995	-5.47	-4.95	-4.68
Z_t	-4.56	300	Dec. 1998	-5.47	-4.95	-4.68
Z_α	-41.56	300	Dec. 1998	-57.17	-47.04	-41.85

Two shifts are identified in the relationship between the two time series: the first in May 1995 and the second in December 1998. The investigation is continued with the Bai and Perron (2003a) procedure allowing for multiple breaks in the silver inflation relationship.

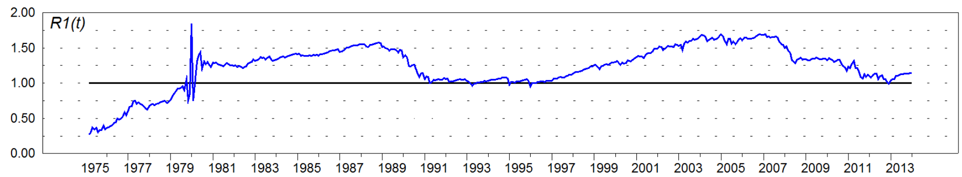
Table 7.134: Bai and Perron Multiple Break Test - Silver & the UK PPI, Nominal

	Variable	Coefficient	Standard Error	T Statistic	Sign.
1	DZ(1,1)	0.133	0.005	26.931	0
2	DZ(1,2)	0.050	0.002	32.317	0
3	DZ(1,3)	0.162	0.003	58.321	0

Breakpoint	Lower 95%	-	Upper 95%
May-85	Dec-84	to	Jun-87
Sep-09	Mar-09	to	Nov-09

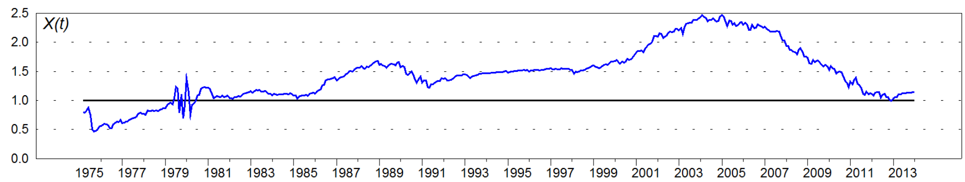
Two breaks are identified in Table 7.134: the first in May 1985 and the second in September 2009, around the Global Financial crisis. The Trace Statistic of the long-run parameters of the Johansen procedure is plotted to get a better understanding of the effects of outliers in the sample - pushing the cointegration rank up to the value of two (Table 7.131).

Figure 7.44: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal UK PPI (Scaled by the 5% Critical Value) - Long-Run Parameters



Results in Figure 7.44 suggest that during the early part of the sample, the two series were cointegrated - a relationship abruptly stopped by the strong price fluctuations in 1980. The cointegration relationship can also be observed in Figure 7.45 - plotting the trace statistic of the Johansen test at lower rank.

Figure 7.45: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal UK PPI (Scaled by the 5% Critical Value) - All Parameters

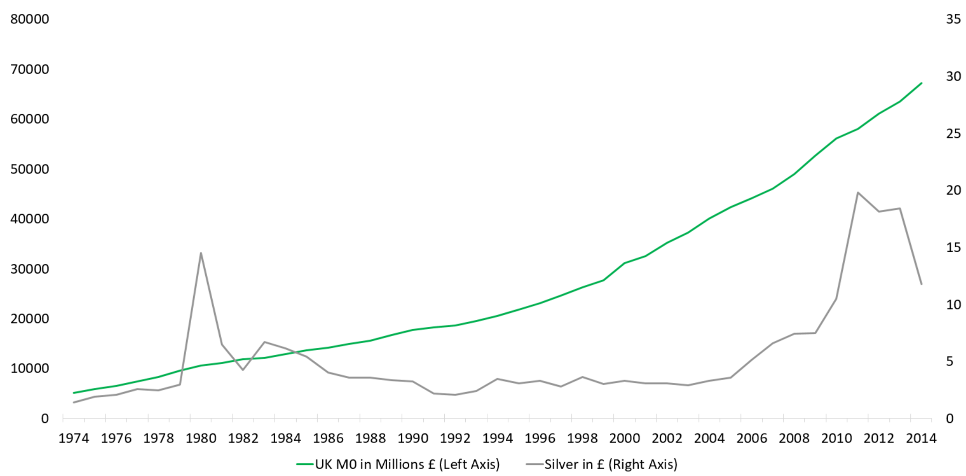


The cointegration relaionship of the late 1970s can easily be observed in Figure 7.45 - where indeed, the fluctuations of 1980 led to a stop in the cointegration relationship up until the end of the sample. The higher rank identified by the Johansen procedure (Table 7.131) points towards short term dynamics in the cointegration relationship between the two series: Figure 7.44 seems to point towards such dynamics between 1991 and 1997 - another very short period is observed around 2013. The first shift identified by the Gregory and Hansen (1996a) procedure (Table 7.133) in May 1995 can't be observed immediately in the two Figures, but the second shift in December 1998 is in line with the beginning of a long trend upwards of the Trace Statistic until 2005 (Figures 7.44 and 7.45) - note that both the price of silver and the PPI rate were stagnating during that time window (Figure 7.43). Regarding the results of the Bai and Perron (2003a) procedure displayed in Table 7.134, the first breakpoint of May 1985 is in line with the end of the fluctuations of the Trace Statistic around the horizontal scale in Figure 7.45, pointing towards the start of a period away from cointegration. The second time window identified, between March 2009 and November 2009 is in line with a short fallback of the price of silver during a long-run bullish period between 2005 and 2012 (Figure 7.43). In conclusion, it can be said that silver was a hedge against producer price inflation in the United Kingdom during the beginning of the sample and during short periods. However, silver shouldn't be considered a reliable PPI hedge in the UK - but indeed the hedging potential should be considered in sub samples, mostly in the light of individual periods of crises.

7.2.2.3 Silver in £ and Narrow Money

Understanding the relationship between silver and money supply in the United Kingdom provides an exposure to the effects of interest rate changes and a deeper understanding of the silver-inflation relationship in the country. A strong upwards shift can be observed for money supply in the United Kingdom between 1974 and 2014, as well as a strong rise of the price of silver between 2006 and 2012 (Figure 7.46).

Figure 7.46: UK Narrow Money and Silver in £ between 1974 and 2014



A lag length of one month is built into the system, following the methodology of Schwarz (1978) while the Augmented Dickey Fuller test results indicate that the two series are integrated of order one (Table 7.135).

Table 7.135: Augmented Dickey Fuller Test - Silver & UK M0

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Silver	-2.032	-3.442	-2.871	-2.570
D.Silver	-22.048	-2.334	-1.648	-1.283
UKM0	2.882	-3.981	-3.421	-3.130
D.UKM0	-4.825	-2.334	-1.648	-1.283

The Johansen test for cointegration indicates that the two series are cointegrated of rank 2 (Table 7.136), indicating a positive long-run relationship between the two series driven by short-term dynamics in the relationship.

Table 7.136: Johansen Test for Cointegration - Silver & UK M0

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	0	-3845.4444	.	443.0748	12.53
1	3	-3628.2024	0.59553	8.5909	3.84
2	4	-3623.9070	0.01774		

The long-run relationship between the two series is tested for time-variancy with the method proposed by Bierens and Martins (2010).

Table 7.137: Bierens and Martins (2010) Test for Time-varying Cointegration - Silver & UK M0

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	5.47	4.61	5.99	0.06487
m = 2	8.71	7.78	9.49	0.06873
m = 3	10.12	10.64	12.59	0.11955
m = 4	12.26	13.36	15.51	0.14000

Conflicting results are provided in Table 7.137 when considering a Chebyshev order of one: where the null-hypothesis of time-invariancy is rejected at the 10% level but accepted at the 5% level. It can however be concluded, that the Bierens and Martins (2010) test suggests a time-invariant cointegration vector.

Shifts in the long-run relationship between the two time series can be identified with the Gregory and Hansen (1996a) procedure identifying two points in time: May 2001 and November 2002 (Table 7.138).

Table 7.138: Gregory and Hansen Test - Silver & UK M0

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-4.08	329	May 2001	-5.47	-4.95	-4.68
Z_t	-4.20	347	Nov. 2002	-5.47	-4.95	-4.68
Z_α	-37.75	347	Nov. 2002	-57.17	-47.04	-41.85

In a next step, the Bai and Perron (2003a) multiple break analysis is used to identify breaks in the relationship between silver and the UK monetary base. Results are displayed in Table 7.139.

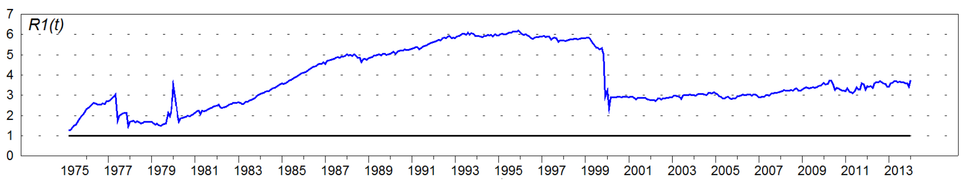
Table 7.139: Bai and Perron Multiple Break Test - Silver & UK M0

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	0.000	0.000	28.191	0
2	DZ(1,2)	0.000	0.000	37.975	0
3	DZ(1,3)	0.000	0.000	58.604	0

Breakpoint	Lower 95%	-	Upper 95%
Nov-85	Aug-85	to	Jul-87
Aug-10	Dec-09	to	Mar-11

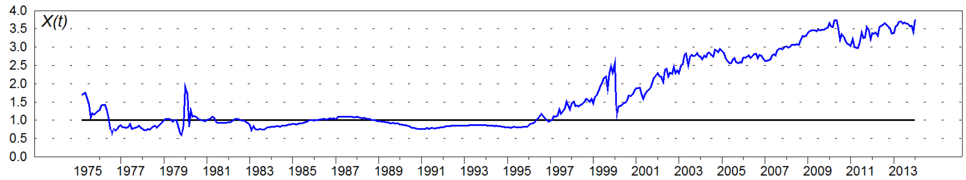
The results point towards two breaks: the first in November 1985 and the second in August 2010. In a final step, plotting the Johansen test Trace Statistic of the long-run parameters provides insights into the relationship between the series over the past 40 years (Figure 7.47).

Figure 7.47: Recursive Plot of Johansen's Trace Statistic for Silver and UK Narrow Money (Scaled by the 5% Critical Value) - Long-Run Parameters



The results in Figure 7.47 suggest a constant higher rank in the relationship between silver and the monetary base in the United Kingdom - pointing towards short-term effects in the cointegration relationship between the two series. Akin to the Bierens and Martins (2010) test results in Table 7.137, the cointegration vector indeed seems to be invariant through time; however, in order to get a better understanding of short-term cointegration between the two series, the Johansen test Trace Statistic of all parameters is plotted, indicating short-term cointegration when the blue line is below the horizontal scale (Figure 7.48).

Figure 7.48: Recursive Plot of Johansen's Trace Statistic for Silver and UK Narrow Money (Scaled by the 5% Critical Value) - All Parameters



Indeed, up until 1997, short periods of cointegration are observed between silver and money supply in the United Kingdom. In contrary to the results found for the UK PPI (Figure 7.44 and 7.45), the troublesome year of 1980 did not have such an important effect on the relationship between the series. The results provided by the Gregory and Hansen (1996a) procedure in Table 7.138 seem somehow delayed to the shift around 1999 suggested in Figures 7.47 and 7.48; a probable explanation could be that the formal procedure points towards the starting points of constant rises from the Trace Statistic up until the very end of the sample. The break in cointegration during the 1980s is nicely identified by the Bai and Perron (2003a) procedure, suggesting a breakperiod between August 1985 and July 1987, results in line with the observations in Figure 7.48; a period during which the price of silver was indeed decreasing against an increasing monetary base (Figure 7.46). The second time window identified, between December 2009 and March 2011 (Table 7.139), points towards the short drop of the Trace Statistic after reaching a maximum value in the sample (Figure 7.47). In conclusion, it can be said that the cointegration relationship between silver and money supply in the United Kingdom is driven by short-term periods (Table 7.136) which occurred in the first half of the sample and seem to have vanished away with time (Figure 7.48). The conclusion should indeed suggest that silver is not an effective hedge against money supply in the United Kingdom and should not be used as such.

7.2.2.4 Concluding Remarks

In the United Kingdom, silver was an effective hedge against the consumer price index, but not against the producer price index nor against increases in the monetary base. While silver was cointegrated with the UK CPI nearly throughout the entire sample, except for a short break in 2011, the same can not be said about the relationship with the two other inflation measures. However, both investors and regulators will have to watch the developments between silver and the UK CPI closely as the cointegration relationship between the two series was very weak towards the end of the sample. Regarding the UK PPI, a cointegration relationship only existed during the early part of the sample, up until 1980 where the severe volatility of the silver price was detrimental for the positive long-run relationship. However, when considering the results for money supply in the United Kingdom, short-term windows of cointegration were lasting longer, until the late 1990s, when cointegration did indeed entirely stopped since that point in time. Even though silver was the better inflation hedge against the Consumer Price Index, gold should be preferred when hedging against changes in the PPI and the monetary base.

All Figures shown in this section are displayed again in Appendix H.

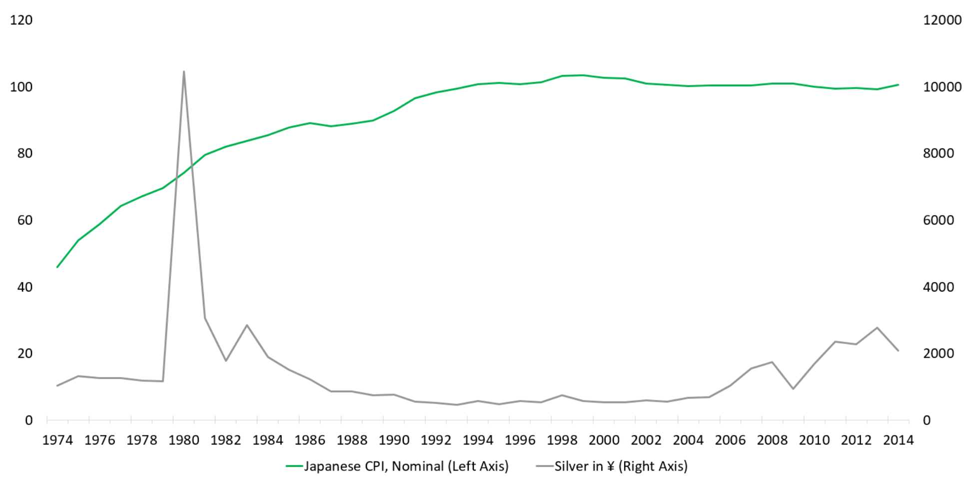
7.2.3 Japan

The Japanese demand for silver is very strongly driven by the industrial side (The Silver Institute (2016)), while a growing demand for physical silver as an investment asset could also be observed over the past years. When considering the results in this chapter, the reader should keep in mind that the Japanese economy was going through a period of both deflation and disinflation since the early 1990s, a period known as the *Lost Decade*.

7.2.3.1 Silver in ¥ and the Nominal Consumer Price Index

The period of deflation starting in the early 1990s can easily be observed in Figure 7.49, plotting the price of silver in ¥ against the nominal Japanese CPI rate. Furthermore, the effects of the Hunt brothers' cornering of the silver market is also observed around 1980. Throughout the 1980s and up until 2004, a downward trend of the price of silver in Japan can be observed. Since 2005 however, it seems that the price is shifting back upwards, with a short fallback around the recent Global Financial Crisis.

Figure 7.49: The nominal Japanese CPI and Silver in ¥ between 1974 and 2014



In a first step the Schwarz (1978) procedure is used to determine the optimal lag length to use in the system, a lag length of three months is identified.

Furthermore, the results of the Augmented Dickey Fuller procedure indicate that the two series are integrated of order 1, allowing to proceed with the Johansen procedure (Table 7.140).

Table 7.140: Augmented Dickey Fuller Test - Silver & the Japanese CPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Silver	-2.588	-3.442	-2.871	-2.570
D.Silver	-10.934	-2.334	-1.648	-1.283
JPCPI	-2.635	-3.981	-3.421	-3.130
D.JPCPI	-3.203	-2.335	-1.648	-1.283

Following the method proposed by Johansen (1995), the two time series are tested for cointegration in order to understand if a long-run relationship exists between the two time series.

Table 7.141: Johansen Test for Cointegration - Silver & the Japanese CPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	8	-3730.5977	.	49.4446	12.53
1	11	-3708.2919	0.08911	4.8329	3.84
2	12	-3705.8754	0.01006		

Results in Table 7.141 indicate that the two time series are cointegrated of higher rank, indicating that the positive long-run relationship is driven by short-term stochastic elements.

In order to identify these elements, the Bierens and Martins (2010) procedure is applied to test for time-variation in the cointegration relationship between the series (Table 7.142).

Table 7.142: Bierens and Martins (2010) Test for Time-varying Cointegration - Silver & the Japanese CPI, Nominal

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	1.00	4.61	5.99	0.60547
m = 2	24.03	7.78	9.49	0.00008
m = 3	29.14	10.64	12.59	0.00006
m = 4	29.51	13.36	15.51	0.00026

Keeping the p Values in mind, statistically significant results are obtained with a number of four Chebyshevs time polynomials. These results indeed suggest that the relationship between silver and the Japanese Consumer Price Index is time-varying.

In a next step, the Gregory and Hansen (1996a) test is used to detect shifts in the relationship between the two variables; results are displayed in Table 7.143.

Table 7.143: Gregory and Hansen Test - Silver & the Japanese CPI, Nominal

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-4.71	395	Nov. 2006	-5.47	-4.95	-4.68
Z_t	-5.36	398	Feb. 2007	-5.47	-4.95	-4.68
Z_α	-49.97	398	Feb. 2007	-57.17	-47.04	-41.85

Two shifts are identified: the first in November 2006 and the second in February 2007. The two shifts are therefore very close to those identified between gold and the Japanese CPI (Table 7.80). Following Bai and Perron (2003a), the breakpoints identified between silver and the Japanese CPI (Table 7.144) are different from those identified between gold and the Japanese CPI (Table 7.81).

Table 7.144: Bai and Perron Multiple Break Test - Silver & the Japanese CPI, Nominal

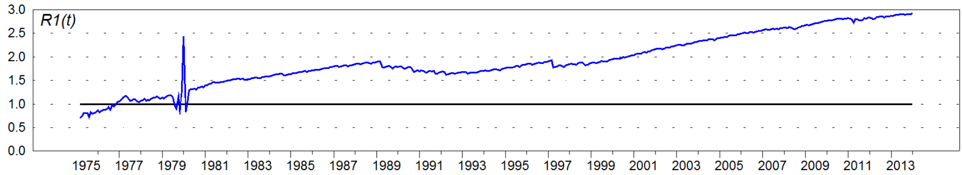
	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	28.441	0.836	34.009	0
2	DZ(1,2)	6.778	0.459	14.750	0
3	DZ(1,3)	19.065	0.735	25.951	0

Breakpoint	Lower 95%	-	Upper 95%
May-85	Apr-85	to	Feb-88
Mar-06	Jan-05	to	May-06

Two breakpoints are identified in Table 7.144: one in May 1985 and the second one in March 2006.

In light of identified short-run stochastic movements, the investigation is completed by plotting the Trace Statistic of the long-run parameters of the cointegration model between silver and the Japanese CPI. The visualisation of the changing relationship is displayed in Figure 7.50.

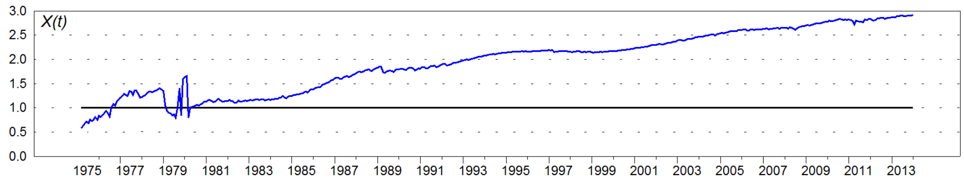
Figure 7.50: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal Japanese CPI (Scaled by the 5% Critical Value) - Long-Run Parameters



The observations in Figure 7.50 suggest that a cointegration relationship between silver and the Japanese CPI only existed in the very early years of the sample. The effects of the Hunt Brothers in 1980 can very easily be observed, though the return of the blue line below the horizontal scale suggests that the long-run parameters of the cointegration equation were at first not negatively affected. However, after a very short return of the two time series to a relationship of cointegration, the Trace Statistic gradually shifts upwards, far off from a cointegration relationship between the two time series.

In order to get a better understanding of the parameters driving the cointegration relationship identified in Table 7.141, all parameters are reestimated and plotted in Figure 7.51.

Figure 7.51: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal Japanese CPI (Scaled by the 5% Critical Value) - All Parameters



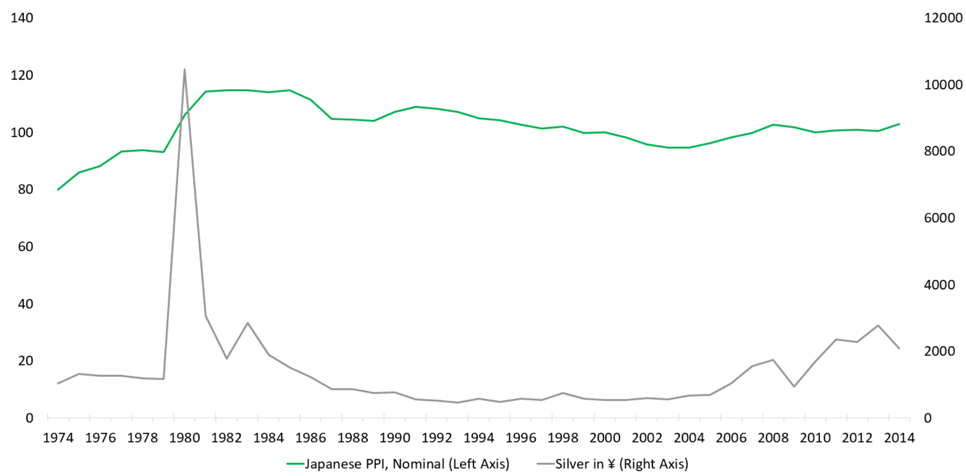
The observations between Figure 7.50 and 7.51 are very similar, indicating that the long-run parameters drive the silver-inflation relationship in Japan. While silver might have served as an inflation hedge in the very early years of the sample, this surely is not true any longer since the early 1980s. The very volatile year of 1980 affected the long-run parameters more strongly than the short-run parameters, indicating the long-term detrimental effect of the Hunt brothers for the silver-inflation relationship. While the two shifts identified by the Gregory and Hansen (1996a) procedure can't be observed in both Figure 7.50 and 7.51 a breakpoint shortly before the crisis, in March 2006, is also identified by the Bai and Perron (2003a) procedure (Table 7.144) - indicating an event around 2006 and

2007. Considering the nominal silver price displayed in Figure 7.49, this period was indeed drawn by the beginning of a bullish period of the silver price. The other time window identified by the Bai and Perron (2003a) procedure in Table 7.144, between April 1985 and February 1988, is in line with a sharp increase of the cointegration parameters away from a cointegration relationship (Figure 7.51), akin to the start of a break away from cointegration lasting up until the end of the sample period, while the price of silver was falling against a rise in inflation during the same period (Figure 7.49). It can therefore be concluded, that silver is not an effective hedge against inflation in Japan. Indeed, since the early 1980s, silver and the Japanese CPI are not cointegrated any longer and the white precious metal therefore fails to offer protection against rising prices in the Asian economy.

7.2.3.2 Silver in ¥ and the Nominal Producer Price Index

In Japan, the Producer Price Index reports the changes in the price of goods bought and sold by companies on the national territory. Similarly to the Japanese CPI, the Japanese PPI is in a downward trend since the early 1990s - the beginning of a period of deflation in Japan. While the PPI trended upwards during the beginning of the sample, it is noteworthy to mention that the deflationary episodes of Japan have pushed the PPI measure in 2014 below that of 1982 (Figure 7.52).

Figure 7.52: The nominal Japanese PPI and Silver in ¥ between 1974 and 2014



A sharp increase of the silver price in 1980 can very easily be observed, alongside a steady decrease of the price up until around 2005, where the price has shifted back up up until 2013.

The Schwarz (1978) procedure suggests building in a lag length of four months into the system, while the Augmented Dickey Fuller test indicates that the two series are I(1) integrated (Table 7.145).

Table 7.145: Augmented Dickey Fuller Test - Silver & the Japanese PPI, Nominal

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Silver	-2.588	-3.442	-2.871	-2.570
D.Silver	-10.934	-2.334	-1.648	-1.283
JPPPI	-2.801	-3.443	-2.871	-2.570
D.JPPPI	-4.703	-2.335	-1.648	-1.283

In a next step, the Johansen test is used to identify a possible cointegration relationship amongst the two series.

Table 7.146: Johansen Test for Cointegration - Silver & the Japanese PPI, Nominal

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	12	-3624.3133	.	20.3649	12.53
1	15	-3614.2690	0.04124	0.2764*	3.84
2	16	-3614.1309	0.00058		

Results indicate that the two series are indeed cointegrated and had a positive long-run relationship between January 1974 and January 2014. The stability of the cointegration relationship can be tested using the method proposed by Bierens and Martins (2010) - results are displayed in Table 7.147.

Table 7.147: Bierens and Martins (2010) Test for Time-varying Cointegration - Silver & the Japanese PPI, Nominal

Chebyshev Time Polynomials	Test Statistic	10% Critical Value	5% Critical Value	P Value
m = 1	7.34	4.61	5.99	0.02549
m = 2	26.93	7.78	9.49	0.00002
m = 3	33.86	10.64	12.59	0.00001
m = 4	35.15	13.36	15.51	0.00003

The Bierens and Martins (2010) results suggest strong evidence that the cointegration relationship between silver and the Producer Price Index in Japan is changing through time. Identifying breaks can be done using both the procedure proposed by Gregory and Hansen (1996a) to identify shifts in the relationship, and by using the Bai and Perron (2003a) procedure identifying multiple breaks in the long-run relationship between the two series.

Table 7.148: Gregory and Hansen Test - Silver & the Japanese PPI, Nominal

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-4.67	81	Sep. 1980	-5.47	-4.95	-4.68
Z_t	-5.90	80	Aug. 1980	-5.47	-4.95	-4.68
Z_α	-59.27	80	Aug. 1980	-57.17	-47.04	-41.85

All three testing procedures of the Gregory and Hansen (1996a) test point towards two shifts: in August 1980 and in September 1980 (Table 7.148), a year during which the price of silver was extremely volatile.

Table 7.149: Bai and Perron Multiple Break Test - Silver & the Japanese PPI, Nominal

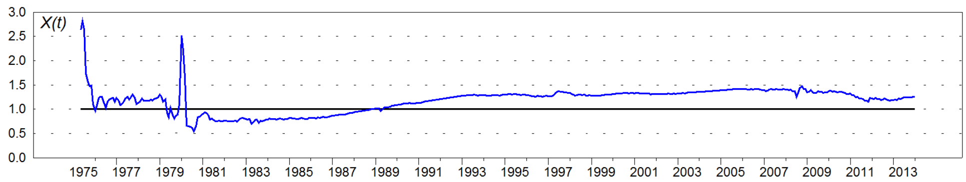
	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	20.260	0.581	34.882	0
2	DZ(1,2)	6.570	0.433	15.159	0
3	DZ(1,3)	18.914	0.714	26.499	0

Breakpoint	Lower 95%	-	Upper 95%
Jun-85	May-85	to	Nov-88
Mar-06	Feb-05	to	Apr-06

The results of the Bai and Perron (2003a) procedure (Table 7.149) suggest two breakpoints: the first in June 1985 and the second in March 2006.

The recursive Trace Statistic of all parameters of the Johansen procedure is plotted in order to visualise the evolving relationship between the two time series (Figure 7.53).

Figure 7.53: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal Japanese PPI (Scaled by the 5% Critical Value) - All Parameters

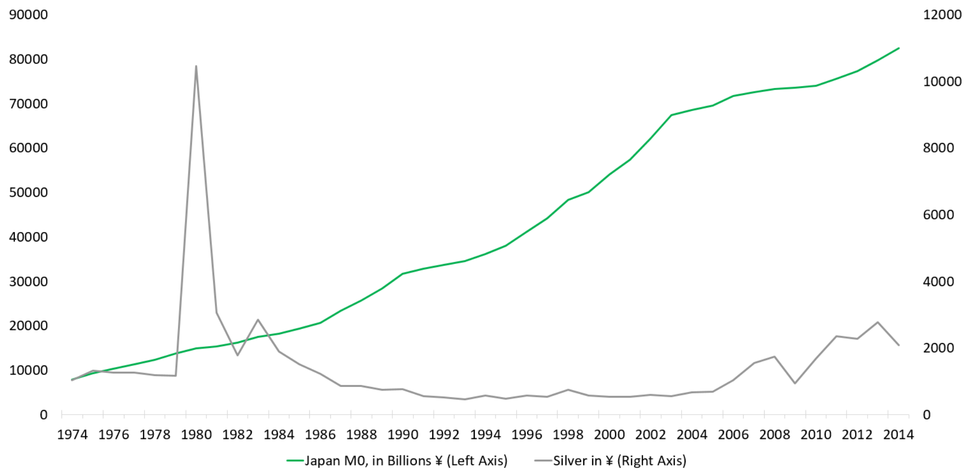


Results in Figure 7.53 suggest that the 1980s are driving the cointegration relationship between silver and the Japanese PPI. The first time window identified by the Bai and Perron (2003a) procedure in Table 7.149, between May 1985 and November 1988, nicely points towards the end of the cointegration relationship between silver and the Japanese PPI. The shift identified by Gregory and Hansen (1996a) in 1980 is in line with the global minimum reached by the trace statistic around that period (Table 7.148 and Figure 7.53). Similar to the Bai and Perron (2003a) results for the Japanese CPI (Table 7.144), it seems that something was happening around 2006-2007 for the Japanese PPI as well (Table 7.149). Again, while this can't be observed in Figure 7.53, it is indeed pointing towards the beginning of a bullish period for the silver price in 2006 (Figure 7.52). It can be concluded, that while the Johansen test suggests that silver was a hedge against producer price inflation in Japan, a more formal investigation reveals that this was not the case throughout the sample. Indeed, silver is not a protection against the Japanese PPI since 1990; however, in the light that this is the beginning of a deflationary period for the country, special care should be taken when jumping to conclusions. Given that silver was a hedge during periods of inflation, a very careful observation of the relationship between silver and the PPI in the near future should be provided. Very interestingly, it seems that the Hunt's brothers undertaking in 1980 were supporting the silver-inflation relationship. In the light that the PPI is jumping as well around that same year (Figure 7.52), the results shed more light on the importance of silver as an industrial asset in Japan. Strong silver price volatility therefore also directly influences the PPI itself.

7.2.3.3 Silver in ¥ and Narrow Money

Understanding the relationship between silver and Narrow Money in Japan offers an exposure to the relationship between the precious metal and interest rates (Carlson and Keen (1996)). The two series are displayed in Figure 7.54.

Figure 7.54: Japanese Narrow Money and Silver in ¥ between 1974 and 2014



While the monetary base in Japan was clearly trending upwards between January 1974 and January 2014, the price of silver decreases throughout the 1980s and only starts rising again in 2005. The very important effect of the Hunt brothers' cornering of the silver market in 1980 can very easily be observed in Figure 7.54, where the price of the precious metal is extremely volatile.

Following Schwarz (1978), a lag length of 13 months is built into the system and the Augmented Dickey Fuller procedure identifies both series as non-stationary (Table 7.150).

Table 7.150: Augmented Dickey Fuller Test - Silver & Japanese M0

Variable Considered	Test Statistic	1% Critical Value	5% Critical Value	10% Critical Value
Silver	-2.588	-3.442	-2.871	-2.570
D.Silver	-10.934	-2.334	-1.648	-1.283
JPM0	-2.614	-3.981	-3.421	-3.130
D.JPM0	-2.500	-2.335	-1.648	-1.283

The Johansen test is used to see if the two variables are cointegrated.

Table 7.151: Johansen Test for Cointegration - Silver & Japanese M0

Maximum Rank	Parms	LL	Eigenvalue	Trace Statistic	5% Critical Value
0	48	-6704.1385	.	8.2268*	12.53
1	51	-6701.4676	0.01135	2.8850	3.84
2	52	-6700.0251	0.00615		

The results in Table 7.151 suggest that silver and narrow money in Japan were not cointegrated and therefore did not have a positive long-run relationship between January 1974 and January 2014. Unable to detect a cointegrating vector, we can't run the Bierens and Martins (2010) procedure and hence proceed to detect cointegration shifts via the Gregory and Hansen (1996a) procedure.

Table 7.152: Gregory and Hansen Test - Silver & Japanese M0

	Test Statistic	**Breakpoint**	**Date**	**1% Critical Value**	**5% Critical Value**	**10% Critical Value**
ADF	-4.07	133	Jan. 1985	-5.47	-4.95	-4.68
Z_t	-5.95	135	Mar. 1985	-5.47	-4.95	-4.68
Z_α	-63.07	135	Mar. 1985	-57.17	-47.04	-41.85

While two shifts are identified around early 1985 by the Gregory and Hansen (1996a) procedure (Table 7.152), the Bai and Perron (2003a) results suggest another break around September 2010 (Table 7.153).

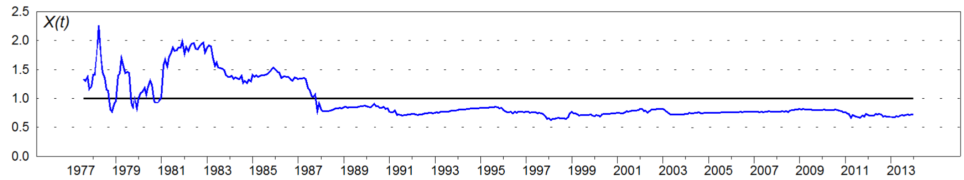
Table 7.153: Bai and Perron Multiple Break Test - Silver & Japanese M0

	Variable	**Coefficient**	**Standard Error**	**T Statistic**	**Sign.**
1	DZ(1,1)	0.155	0.005	33.620	0
2	DZ(1,2)	0.016	0.001	20.135	0
3	DZ(1,3)	0.032	0.001	21.723	0

Breakpoint	Lower 95%	-	Upper 95%
Nov-84	Oct-84	to	Nov-86
Sep-10	May-10	to	Mar-12

A visualisation of the development of the Trace Statistic for all parameters in the Johansen equation is helpful to understand when the two series were cointegrated and how this relationship might have evolved over time (Figure 7.55).

Figure 7.55: Recursive Plot of Johansen's Trace Statistic for Silver and Japanese Narrow Money (Scaled by the 5% Critical Value) - All Parameters



The results in Figure 7.55 are rather surprising when considered in the light of the cointegration results suggested by the Johansen test (Table 7.151). While formal test results suggested that silver and Japanese narrow money are not cointegrated, Figure 7.55 is suggesting that the two series are cointegrated since the late 1980s. A local minimum is reached around 1985, in line with the shift suggested by the Gregory and Hansen (1996a) procedure (Table 7.152). The shift back towards cointegration however occurs around 1988 and is not captured by the formal test results presented above. Similar to the Gregory and Hansen (1996a) test, the Bai and Perron (2003a) procedure identifies a breakpoint period ranging from October 1984 to November 1986 - suggesting therefore that the first half of the 1980s drove the two series to be cointegrated. Throughout the 1980s, the Bank of Japan was lowering interest rates resulting in a sharp increase of money supply into the economy while the price of silver was falling. It seems that only once the price of silver started to be more stable (Figure 7.54) it started to become a hedge against a rise in money supply in the Asian economy. The second breakwindow identified by the Bai and Perron (2003a) procedure (Table 7.153), between May 2010 and March 2012 points towards the substantial price rally that silver was going through (Figure 7.54). Concerning money supply, it seems that even though the Johansen test suggests that the series were not cointegrated over the entire sample period, a weak but existing cointegration relationship is identified between 1988 and 2014, suggesting that silver was an effective hedge against inflation during that time-period. A very important results for both investors and regulators given that gold was indeed never an effective hedge against increases in money supply throughout the same period of time (Figure 7.31).

7.2.3.4 Concluding Remarks

In the above chapter, the hedging potential of silver against three inflation measures in Japan has been identified. Results suggest that silver was not an effective hedge against the Japanese CPI in general. Concerning the Japanese PPI, silver seems to be a good hedge during inflationary periods; it is only since the PPI rates are decreasing that the cointegration relationship between the series stopped - akin to the industrial importance of the white precious metal in the Japanese economy. Investors and researchers should therefore keep an open eye on the development of the PPI rates in the near future. Regarding the hedging potential of silver against money supply in Japan, it seems that silver was indeed a good hedge between 1988 and 2014, when gold failed to be. In the light that inflation is rooted in an increase of money in the economy, silver could be considered the superior inflation hedge in Japan in comparison to gold, that only offered very limited inflation hedging advantages if any; results offering interesting implications to market actors relying on precious metals in order to protect their portfolio from inflation.

All Figures can be found in Appendix L for a more comprehensive comparison.

7.3 Conclusion

Previous works by Beckmann and Czudaj (2013), Batten et al. (2014), and Bampinas and Panagiotidis (2015) uncover time-variation in the relationship between precious metals and inflation.

However, these previous works fail to highlight changes in the relationship and formally time the occurrence of such changes. This chapter built up on the mentioned literature and highlights the following key findings:

1. Gold is a good protection in the USA and the UK, but not in Japan.

2. In the USA, gold can't hedge inflation during times of crises. Indeed, results suggest that gold was only able to hedge inflation during the recent Global Financial Crisis because the American economy went to a period of deflation. Policymakers should therefore reconsider their use of the yellow metal as a quality guarantee for the US Dollar as gold and the American currency have evolved away from one another since the end of the Bretton Woods agreement.

3. In the UK, gold was a reliable hedge against inflation since 2008 and the strong increase of speculative activities on the price of gold. In a way similar to the USA, the price of gold has developed a life on its own which is detached from monetary quality of the pound sterling. Similar to the USA, British policymakers should be aware that gold can't serve as a guarantee of monetary quality *per se*.

4. Japan is truly a case on its own. Due to the long lasting deflationary episodes the Asian economy went through, gold failed to serve as a hedge against inflation. In terms of policymaking, actors should be aware that changes in the strength of the Yen is a direct reflection of the economic strength of the country and not of the amount of gold held by the Central Bank.

5. Results for silver are more complex, where the metal serves only as a short-run hedge in the USA, and isn't an inflation hedge in Japan. In the UK, however, silver proved to be a better hedge than gold.

6. In the USA, silver is not an effective hedge against inflation. The heavy price fluctuations in 1980 have been very detrimental for silver‚Äôs inflation hedging ability, but the relationship between the two series has to be watched closely as results seems to suggest that the series are reverting towards a

cointegration relationship, meaning that market actors and policymakers could use silver to protect themselves from inflation.

7. In the UK, silver was an effective hedge only against the consumer price index. Investors and regulators will have to watch the developments between silver and the UK CPI closely as the cointegration relationship between the two series is very weak towards the end of the sample. Even though silver is a better inflation hedge against the Consumer Price Index, gold should be preferred when hedging against changes in the PPI and the monetary base.

8. In Japan, silver is not a good inflation hedge for the same reasons as gold wasn't. However, due to the industrial nature of the metal, and in line with the importance of industrial developments of the Asian economy on the strength of the national currency, policymakers should be aware that silver is a better hedge against changes in money supply than gold is.

CHAPTER 8

EXTREME BOUNDS ANALYSES OF GOLD AND SILVER

The previous chapter uncovered the complexity in the relationship between precious metals and inflation. More generally, the relationship between gold or silver, and every macroeconomic variable is very likely to be more complex than believed or even stated by fellow researchers. An interesting question is therefore to gain better insights into the association between the price of precious metals and a set of possible drivers. Using Extreme Bounds Analysis (EBA) in the spirit of Leamer (1983), Granger and Uhlig (1990) and Sala-I-Martin (1997) this chapter examines the determinants of the prices of gold and silver between 2003 and 2015. A wide variety of potentially explanatory variables are identified, a naive and more sophisticated EBA analyses are applied and results indicate that though traditional explanatory variables still play an important role in determining the price of gold, other less traditional variables seem more important than initially suggested in influencing its price.

Considering gold, a striking importance of British economic uncertainty and the S&P Case-Shiller National Home Price Index is observed. Results also shed more light on the nature of gold purchases in China, where it seems to act as a luxury good rather than a financial asset. Furthermore, evidence questions the stand-alone position of the US Dollar effect on gold in comparison to other international currencies.

The important effect of multiple currencies is also identified for silver. Furthermore, results indicate a strong relationship between the two main precious metals, as well as an importance of inflation indices other than the US CPI. However, throughout the different sophisticated model specifications, results uncover that silver is the more speculative asset than gold.

Individual graphics can be found in Appendices M and N, while a brief investigation into the drivers of platinum, palladium and oil is provided in Appendix O.

8.1 Gold

O'Connor et al. (2015) identify many variables that influence the price of gold. Facing a theoretically infinite number of potential variables, previous research focuses on a few, economically logical variables. Baur (2013a) argues that the overall strength or weakness of the relationships remains unclear, as a relationship found may in fact not be robust to alternative model specifications. This chapter addresses the issue by running millions of possible regressions, extracting the distribution of coefficient and analysing the same in order to derive which variables are explanatory - and which fail to be.

8.1.1 An Unconstrained Extreme Bounds Analysis

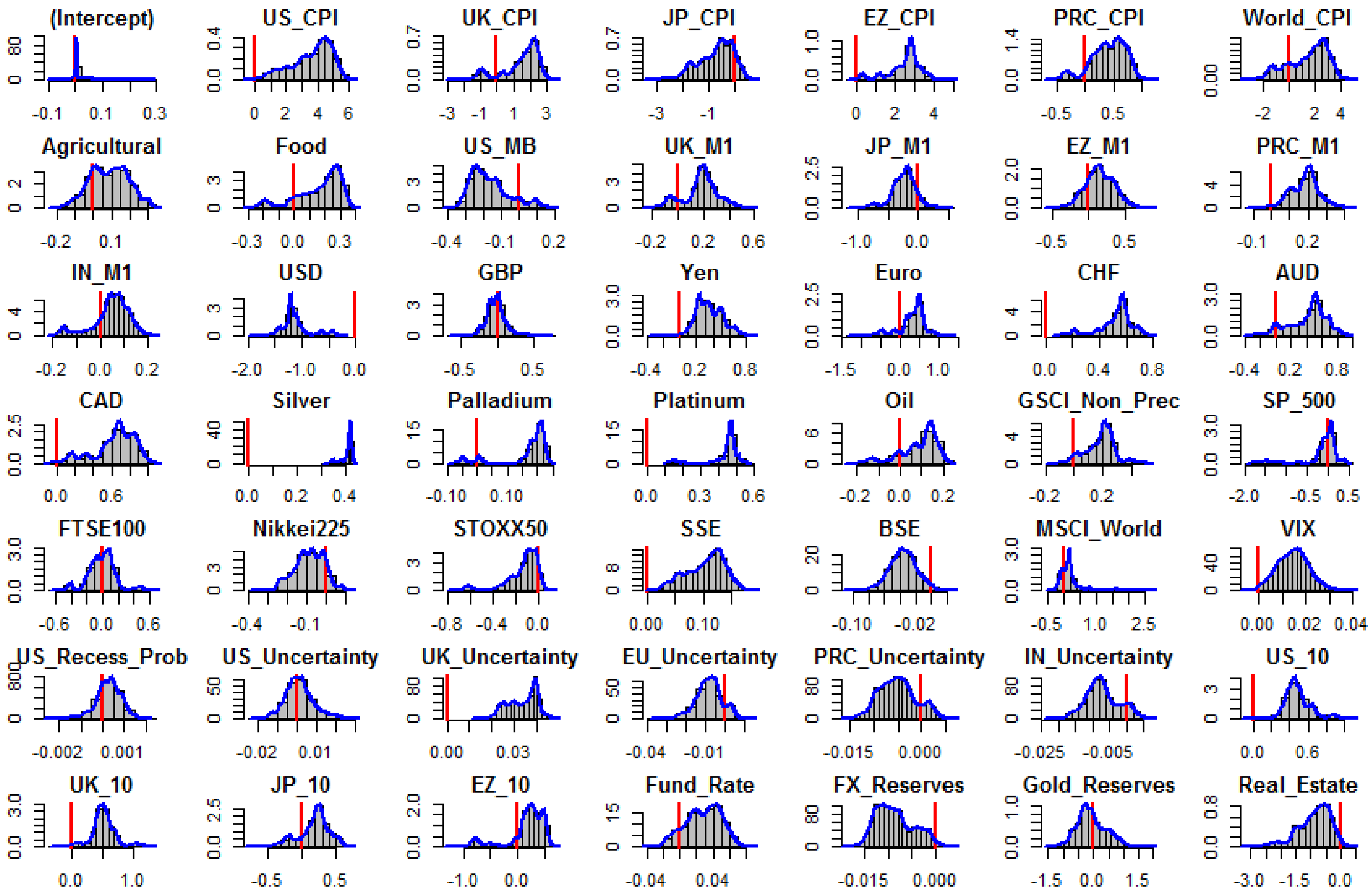
In a first run, a naive Extreme Bounds Analysis allocating the same weight to each variable is considered. The relevant literature is followed and the maximum amount of variables k in the regression is fixed to three within the Sala-I-Martin procedure.

Graphical results underpinned by the Sala-I-Martin (1997) test results can be found in Figure 8.1 and Table O.3.

Table 8.1: Naive Extreme Bounds Analysis Results for Gold

Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)	Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)
(Intercept)	fixed	24.380	75.620	Oil	focus	14.634	85.366
US_CPI**	focus	2.721	97.279	GSCI_Non_Prec*	focus	7.140	92.860
UK_CPI	focus	17.350	82.650	S&P_500	focus	51.450	48.550
JP_CPI	focus	68.496	31.504	FTSE100	focus	50.850	49.150
EZ_CPI**	focus	2.606	97.394	Nikkei225	focus	78.692	21.308
PRC_CPI	focus	28.634	71.366	STOXX50	focus	80.779	19.221
World_CPI	focus	25.859	74.141	SSE**	focus	3.024	96.976
Agricultural	focus	31.331	68.669	BSE	focus	73.158	26.842
Food	focus	17.512	82.488	MSCI_World	focus	28.379	71.621
US_MB	focus	84.178	15.822	VIX	focus	14.362	85.638
UK_M1	focus	32.377	67.623	US_Recess_Prob	focus	43.255	56.745
JP_M1	focus	67.076	32.924	US_Uncertainty	focus	46.721	53.279
EZ_M1	focus	40.010	59.990	UK_Uncertainty**	focus	1.174	98.826
PRC_M1	focus	18.448	81.552	EU_Uncertainty	focus	72.837	27.163
IN_M1	focus	41.695	58.305	PRC_Uncertainty	focus	71.097	28.903
USD***	focus	99.982	0.018	IN_Uncertainty	focus	76.570	23.430
GBP	focus	54.962	45.038	US_10**	focus	2.001	97.999
Yen**	focus	4.472	95.528	UK_10**	focus	4.559	95.441
Euro	focus	16.300	83.700	JP_10	focus	33.847	66.153
CHF***	focus	0.831	99.169	EZ_10	focus	25.214	74.786
AUD*	focus	7.335	92.665	Fund_Rate	focus	21.103	78.897
CAD**	focus	1.660	98.340	FX_Reserves	focus	79.739	20.261
Silver***	focus	0.000	100	Gold_Reserves	focus	51.836	48.164
Palladium*	focus	7.702	92.298	Real_Estate	focus	77.315	22.685
Platinum***	focus	0.020	99.980				

Figure 8.1: Naive Extreme Bounds Analysis Results for Gold



8.1.1.1 99% Confidence Interval

Considering the 99% confidence level for the Sala-I-Martin (1997) test results (Table O.3 and Figure 8.1), we find that currencies and precious metals are strongly associated with the price of gold. The US Dollar has a negative correlation with gold in 99.98% of the regressions whereas the Swiss Franc is positively associated with the price of gold in 99.17% of the cases. The price of silver is always positively associated with the price of gold throughout all of the regressions and platinum is positively associated with gold in 99.98% of the regressions.

The observed negative relationship between gold and the US Dollar is not very surprising and in line with many previous studies such as Tully and Lucey (2007) who find evidence for the US Dollar to be the most important factor in determining the price of gold - results confirmed by Sari et al. (2010), Pukthuanthong and Roll (2011) and O'Connor and Lucey (2012). From the hundred of thousands of regressions ran, only very few have a positive relationship with the price of gold - underlining the important and strong relationship between gold and the US Dollar (Table O.3). Indeed, a weak US Dollar making gold purchases cheaper for the rest of the world, alongside an increased attractiveness of investing in the yellow metal for national investors as a protection against a weakening US Dollar both act in favour of a strong gold price.

Though some attention was paid to the relationship between gold and currencies other than the US Dollar, amongst which the Swiss Franc, research on the relationship between gold and non-dollar currencies is fairly small. Baur and Glover (2012) examine the theoretical ability of gold to act as a safe haven for currencies other than the US Dollar. Building upon the co-movement between the price of gold and the USD/CHF exchange rate, Reboredo (2013b) argues in favour of the existence of a dependence between gold and US Dollar depreciation against other currencies - hence strengthening gold's position as a hedge against the US Dollar. Antonakakis and Kizys (2015) work with weekly data between January 6, 1987 and July 22, 2014 to find that within a VAR framework, the USD/CHF exchange rate is the largest transmitter of volatility spillovers to commodities. The EBA results displayed above point towards a very important correlation between a strong Swiss Franc and a high gold price - indeed the price of gold is positively associated with an appreciation of the Swiss Franc against other currencies.

The positive relationship between gold and silver is not very surprising and is the subject of many previous studies such as Escribano and Granger (1998), Adrangi et al. (2000) and Liu and Chou (2003)). The coefficients across all regressions are positive (Table O.3) which can also be observed on Figure 8.1. Even though a strong relationship is also observed between gold and platinum, one should be very careful when trying to derive an empirical observation as Kearney and Lombra (2009) provide evidence for the time-varying nature of the relationship between both metals; a relation usually deemed to be negative, though the last 12 years seem to be an example for the few exceptions in which the relationship between gold and platinum goes through runs of positivity.

8.1.1.2 95% Confidence Interval

Taking into account the 95% confidence level, other variables, amongst which inflation rates as well as other currencies, seem to play an important role in determining the price of gold. The US American and the Eurozone CPI both share a positive relationship with the price of gold in more than 97% of the regressions. Having already discussed the importance of the US Dollar and the Swiss Franc exercised on the price of gold, two other currencies, the Japanese Yen and the Canadian Dollar are both positively associated with gold in 95.53% and 98.34% of the regressions respectively (Table O.3). The last three variables that are associated with the price of gold above the 95% confidence level are the SSE Composite Index, the index for British Economic Uncertainty, as well as both the US and the UK 10 years government bond index.

The results observed for the relationship between gold and inflation are in line with a vast amount of previous studies such as Wang et al. (2011) for the United States or Beckmann and Czudaj (2013) for the Eurozone. However, in the light of the findings highlighted earlier in this thesis, results for US inflation should be treated with care due to the time-varying nature of the relationship between the American Consumer Price Index and the price of gold during the period observed. It should be noted that Chinese liquid money is the only liquid money indicator that has a somewhat significant positive relationship with gold (Table O.3). The observed correlation between an increased amount of liquid money in China and an increase in the price of gold could either be due to the consumer behaviour of Chinese market participants who buy luxury goods in good economic times, or it could be an indication of the importance of gold's role as a hedge against a drop of the Renminbis' purchasing power. A clearer answer to these hypotheses is given by other Chinese variables and discussed later in this result section.

The strong relationship between the Yen, the Canadian Dollar and the price of gold is again supported by previous studies, such as Capie et al. (2005) who look at gold's ability to act as a hedge against currencies and conclude that the hedging ability is time-varying and depends on non-predictable political and economic events. Furthermore, Sjaastad (2008) works with data from 1991 to 2004 and finds that the Yen is, after the US Dollar, the dominant currency influencing the price of gold. O'Connor and Lucey (2010) warn researchers when jumping to conclusions about the relationship between gold and international currencies as the positive correlation between gold and a currency could simply be due to the law of averages. Erb and Harvey (2013) state that gold was a currency hedge for both the Canadian Dollar and the Japanese Yen during the monthly 1975-2012 period. Reboredo (2013b) augments these findings for the CAD and finds that gold has safe haven abilities against USD-CAD exchange rates in market downturns. Results challenged by the positive relationship observed in Figure 8.1.

The relatively low importance of equity markets played on the price of gold is rather surprising. The only index found to be associated with the price of gold over the observed period was the SSE Composite Index. Results somewhat in line with Baur and McDermott (2010) who look at daily, weekly and monthly stock returns of a multitude of countries and find that gold is neither a hedge nor a safe haven against stock market declines in China; gold is however found to be a safe haven during periods of extreme volatility or uncertainty in China. The results for the Chinese Economic Uncertainty Index indicate that in more than 70% of the cases high uncertainty in China is associated with a low price of gold - a probable indication that Chinese demand is mainly directed towards jewelry and luxury products rather than gold's hedging capacities. Baur and Lucey (2010) are checking the hedging and safe haven ability of gold for stock and bond returns in the USA, the UK and Germany. For both the US and the UK, gold was a hedge and a safe haven against falling stock market returns between November 1995 and November 2005; the results above however indicate a rather even distribution of coefficients for both the S&P 500 and the FTSE100. Baur and McDermott (2010) build upon the finding and the methodology of Baur and Lucey (2010) and expand the country sample under study. Evidence point towards the hedging and safe haven ability of gold against European stock markets; in an EBA framework, over 80% of the coefficients for the Euro Stoxx 50 are negative (Table O.3), suggesting results in line with Baur and McDermott (2010). The authors also look at stock markets in

India and Japan, against which they found gold to be neither a hedge nor a safe haven. Results for the BSE and the Nikkei 225 indicate that approximately 75% of the coefficients are negative (Table O.3), proving that the negative relationship between these two stock markets and the price of gold is not very strong.

Both the US 10 year and the UK 10 year Government bond index are positively associated with the price of gold. Baur and Lucey (2010) find that for both countries, gold was neither a hedge nor a safe haven. Gold's positive correlation with bonds is evidence of the metals' alleged ability to offer protection against stormy financial climates; a virtue the metal shares with high quality Government debt.

The final variable to fall into the 95% confidence interval of the Sala-I-Martin test results is that of economic uncertainty in the United Kingdom (Table O.3). An interesting result in contrast to what is observed for the FTSE (Table O.3), but an indication that investors in gold have an exposure to the UK economy that they hedge through an investment in precious metal. In the light that the official price of gold is set in London, the capital city of the United Kingdom, the findings for UK Uncertainty reflect the geographical and geopolitical importance of gold's main market.

Considering the results for UK Economic Uncertainty, the UK 10 year Government bond index and the US 10 year Government bond index, the reader should however keep in mind the timeframe of our dataset: 2003 to 2015, a time drawn by global financial difficulties.

8.1.1.3 90% Confidence Interval

Taking into account the 90% confidence interval, three additional variables are found to be explanatory: the Australian Dollar, the price of palladium and the S&P GSCI Non-precious metal index.

A discussion about the interaction of gold with currencies other than the US Dollar was provided earlier in this chapter.

Palladium has a much weaker relationship to gold as silver and platinum (Table O.3) and only few articles have looked at the relationship between both precious metals. Chng and Foster (2012) find that the convenience yield of gold affects palladium returns but that palladiums convenience yield is not affected by gold. Batten et al. (2015) consider return and volatility spillovers amongst all four precious metals and find that palladium is a relatively separate market from the three other precious metals.

The close relationship between gold and non precious metals (Table O.3) is an indication of the industrial importance of gold; indeed, good economic environments lead to an increased demand for gold and non-precious metals as industrial production factors.

8.1.2 More Sophisticated Extreme Bounds Analyses

The bulk of previous academic work focuses on univariate approaches to explain the relationship between the price of gold and one other given variable. The section above took a sober approach to which variables influence the price of gold and looked at the matter by allocating an equal weight to each individual variable. A question that arises however, is to possibly reconsider the model once initial regressions indicate statistical significance for certain time series. In other words, should one fix variables that are indicated as statistically significantly associated with the price of gold, or should one only fix variables that are by definition associated with the price of gold? Fixed variables would then be present in each and every equation considered in the model. This section proposes a selection of models constructed in regard to the results obtained by the unconstrained Extreme Bounds Analysis above.

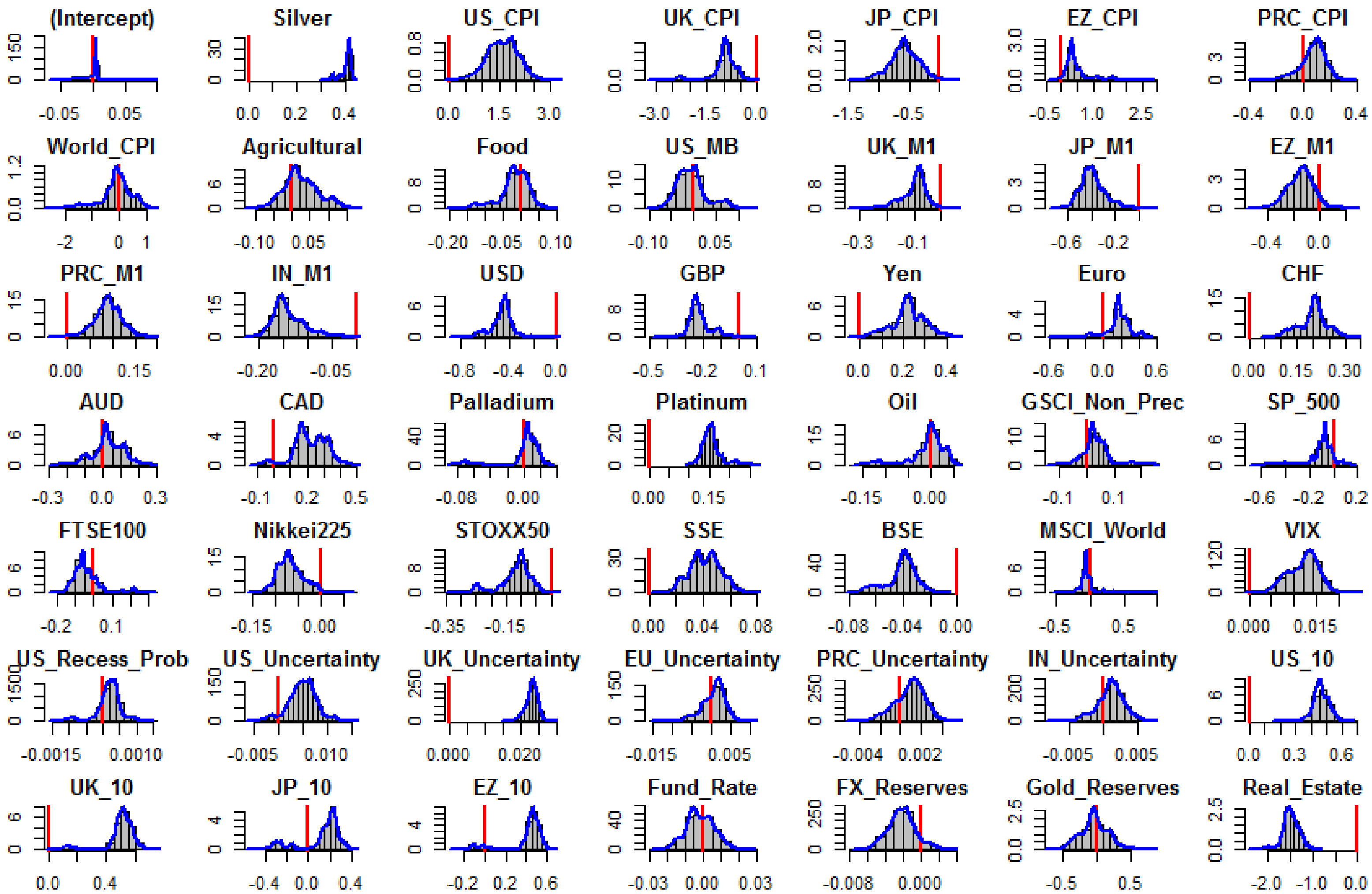
8.1.2.1 Model 1: Fixing Silver

The results in Table O.3 indicated that 100% of the regression coefficients of silver are positive. In other words, silver shares a positive correlation with the price of gold in all cases considered. The first model is philosophically based on the alleged exchangeability of gold and silver on financial markets - where one precious metals is often considered to be a good substitute of the other (O'Connor et al. (2015)). As uncovered previously in this thesis through a thorough review of the literature on gold and silver, many researchers focus on the relationship between gold and silver alone (see Adrangi et al. (2000), Lucey and Tully (2006b) or Baur and Tran (2014) for example). This model conciliates previous research on the linear relationship between gold and silver and uncovers the importance of additional variables that must be considered in a model explaining the price of gold by considering silver price movements. The density distribution results of the Sala-I-Martin (1997) procedure are displayed in Table 8.2 and Figure 8.2.

Table 8.2: Sophisticated Extreme Bounds Analysis Results for Gold - Model 1: Fixing Silver

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	30.316	69.684	Oil	focus	48.354	51.646
US_CPI*	focus	5.967	94.033	GSCI_Non_Prec	focus	29.751	70.249
UK_CPI	focus	85.806	14.194	S&P_500	focus	80.155	19.845
JP_CPI	focus	73.893	26.107	FTSE100	focus	68.089	31.911
EZ_CPI	focus	27.874	72.126	Nikkei225	focus	86.675	13.325
PRC_CPI	focus	43.581	56.419	STOXX50*	focus	94.644	5.356
World_CPI	focus	51.484	48.516	SSE	focus	10.952	89.048
Agricultural	focus	40.663	59.337	BSE	focus	85.065	14.935
Food	focus	56.770	43.230	MSCI_World	focus	66.427	33.573
US_MB	focus	52.827	47.173	VIX*	focus	8.861	91.139
UK_M1	focus	65.680	34.320	US_Recess_Prob	focus	43.973	56.027
JP_M1	focus	86.789	13.211	US_Uncertainty	focus	27.886	72.114
EZ_M1	focus	64.137	35.863	UK_Uncertainty***	focus	0.810	99.190
PRC_M1	focus	24.837	75.163	EU_Uncertainty	focus	45.255	54.745
IN_M1	focus	82.334	17.666	PRC_Uncertainty	focus	43.262	56.738
USD***	focus	99.693	0.307	IN_Uncertainty	focus	42.158	57.842
GBP*	focus	92.173	7.827	US_10***	focus	0.319	99.681
Yen**	focus	4.245	95.755	UK_10**	focus	2.124	97.876
Euro	focus	17.724	82.276	JP_10	focus	33.771	66.229
CHF*	focus	7.891	92.109	EZ_10*	focus	7.539	92.461
AUD	focus	40.041	59.959	Fund_Rate	focus	52.816	47.184
CAD*	focus	7.276	92.724	FX_Reserves	focus	62.622	37.378
Silver***	fixed	0.000	100	Gold_Reserves	focus	51.001	48.999
Palladium	focus	44.528	55.472	Real_Estate**	focus	98.059	1.941
Platinum***	focus	0.290	99.710				

Figure 8.2: Sophisticated Extreme Bounds Analysis Results for Gold - Model 1: Fixing Silver



8.1.2.1.1 99% Confidence Interval

Regression results in Table 8.2 and Figure 8.2 indicate that five variables are significantly associated with gold at the 99% confidence level: silver, the US Dollar, platinum, UK economic uncertainty, and finally, the US 10 year Government bond index. Except for the US Dollar, all variables are positively associated with the price of gold. As discussed above, a weak US Dollar is linked to a strong price of gold, akin to the precious metal's safe haven ability as a refuge from a drop of the purchasing power of the American currency. In a model fixing silver as an explanatory variable, two new variable appear to be significant at the 99% confidence level: the UK economic uncertainty index and the US 10 years Government bond index. Model 1 consists of the two most recognised and accepted precious metals, the importance of UK uncertainty and the US bond index is understandable in the light of gold being a safe have asset during economic troubles. Regarding the strong positive link with the American bond index, an explanation is that US government debt is considered a very safe investment by market actors during troublesome times, an alleged virtue it shares with American Government debt.

8.1.2.1.2 95% Confidence Interval

Table 8.2 shows only three variables to be significant at the 95% confidence level: the Yen, the UK 10 year Government bond index, and the S&P Case-Shiller National Home Price Index. Both the Yen and UK Government debt remained significant at the 95% confidence level, just like in the previous unconstrained model specification. However, it seems that real estate plays an important role in the new model specification. Indeed, as can be easily taken from Figure 8.2, higher real estate prices in the US are linked to a lower price of gold. Different explanations can be found for that relationship: real estate and precious metals can be considered to be substitute investments, where an investor allocating wealth into real estate freezes up financial means he could have invested into precious metals. A more plausible explanation however, is to be found in the speculative nature of American real estate and the crash it was going through during the time period considered in this study. The real estate crash of the 2008 Financial Crisis induced market actors to invest into precious metals as a refuge against collapsing prices, therefore directly linking falling real estate prices with climbing precious metal prices.

8.1.2.1.3 90% Confidence Interval

The following variables are significant at the 90% confidence level in Model 1 (Table 8.2): the US CPI, the Pound Sterling, the Swiss Franc, the Canadian Dollar, the EURO STOXX 50, the VIX, and the Euro Zone 10 year Government Bond index. The importance of currencies has been discussed earlier on and a deeper analysis should be provided on the newly appearing variables: the Euro STOXX 50, the VIX, and Euro Zone Government debt. The relationship between gold and European equity is negative, meaning that the price of gold is high when European equity prices are low, providing further evidence to support the observations of Baur and McDermott (2010). The positive correlation with the volatility index is akin to the usage of precious metals as hedging and safe haven assets in finance: where investors rush to investing in gold during financial turmoils (see Baur and Lucey (2010)). Finally, the positive relationship with eurozone debt is evidence for the safety of medium term European Government debt; a finding similar to what is observed for the US 10 year Governemnt bond index: gold and national debt are substitutes on financial markets, where both investments are considered safe during economic downturns.

8.1.2.1.4 Sign Shifts

It can be taken from Table 8.2, and more easily observed in Figure 8.2, that certain variables changed their signs when fixing the price of silver in every regression. More specifically, the following variables were either largely positively or negatively associated with gold and changed signs in a model specification fixing the price of silver: the UK CPI, UK money supply, Eurozone money supply, Indian money supply, European economic uncertainty, Chinese economic uncertainty, and finally, Indian economic uncertainty. The first interesting observation is the effect of Model 1 on British macroeconomic variables. Indeed, not only does the pound sterling becomes a significant variable at the 90% confidence level, but the UK CPI and UK liquid money changes signs. While the majority of the regressors were positive in the unconstrained model (Table O.3 and Figure 8.1), they become negative under the new model specification (Table 8.2 and Figure 8.2). So when the price of silver is fixed in a model explaining price movements of gold, the inflation hedging potential of gold in the United Kingdom seems to vanish away. Indeed, a high CPI and an increase in liquid money are linked to a low price of gold. In the light that fixing the LBMA price of silver also led to a rising importance of UK uncertainty in determining the price of gold, a possible explanation could be that inflationary pressure is channeled through the price of silver in the UK. A similar observation is made for Eurozone and Indian money supply, where a high amount of money in circulation would have a negative effect on the price of gold. Indeed, fixing silver in every regression channels out the effect exercised from inflation directly on the price of gold, most possibly to the similar price movements of both metals: evidence pointing to the similarities between gold and silver as financial assets. The last interesting observation is that the regressors of European, Chinese and Indian economic uncertainty now tend to be slightly more positive than negative. Akin to gold and silver as effective refuges during economic uncertain times, a higher economic uncertainty measure does indeed seems to be associated with a higher price of gold. It should however be noted, that the three variables are far from being statistically significant; the observation is mainly that the majority of the regressors are positive rather than negative (Table 8.2).

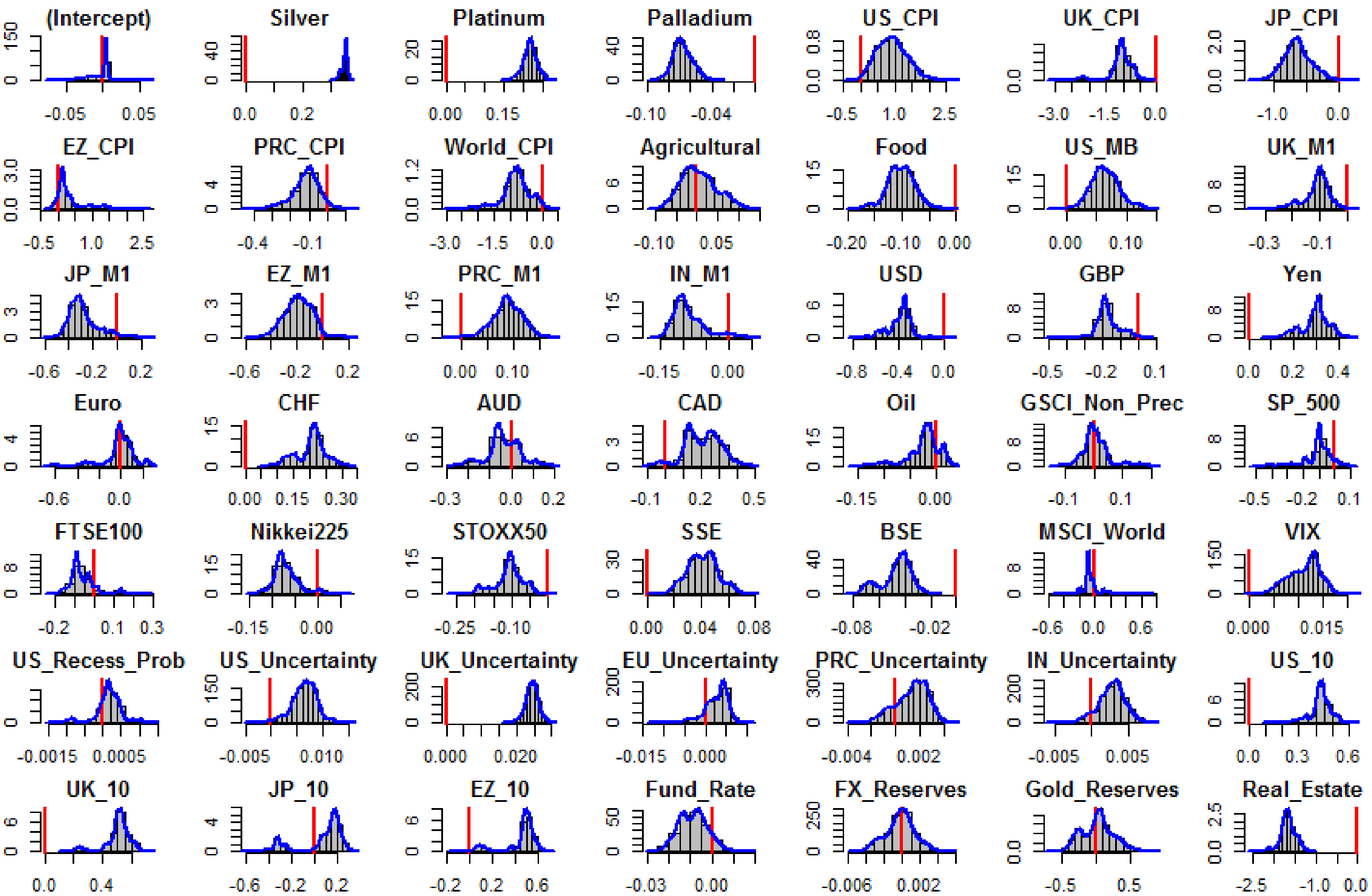
8.1.2.2 Model 2: Fixing White Precious Metals

An extension of Model 1 is provided by fixing the price of silver, platinum and palladium. This is akin to previous research on the four commodities as the main precious metals. Though some previous papers, such as Chng and Foster (2012) do not exclude the possibility to consider the four metals as a single asset class, other such as Batten et al. (2010) and Batten et al. (2014) argue that different macroeconomic variables influence the four different metals, warning researchers and investors to treat them as a single asset class. Regression results of the Sala-I-Martin (1997) procedure fixing silver, platinum and palladium are displayed in Table 8.3 and in Figure 8.3.

Table 8.3: Sophisticated Extreme Bounds Analysis Results for Gold - Model 2: Fixing Silver, Platinum and Palladium

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	32.753	67.247	Oil	focus	65.422	34.578
US_CPI	focus	19.188	80.812	GSCI_Non_Prec	focus	48.301	51.699
UK_CPI	focus	88.556	11.444	S&P_500	focus	83.901	16.099
JP_CPI	focus	76.716	23.284	FTSE100	focus	74.881	25.119
EZ_CPI	focus	35.923	64.077	Nikkei225	focus	87.504	12.496
PRC_CPI	focus	60.226	39.774	STOXX50**	focus	93.458	6.542
World_CPI	focus	73.351	26.649	SSE	focus	10.675	89.325
Agricultural	focus	48.272	51.728	BSE	focus	88.449	11.551
Food	focus	86.003	13.997	MSCI_World	focus	74.088	25.912
US_MB	focus	23.343	76.657	VIX**	focus	9.861	90.139
UK_M1	focus	67.842	32.158	US_Recess_Prob	focus	44.067	55.933
JP_M1	focus	79.930	20.070	US_Uncertainty	focus	21.387	78.613
EZ_M1	focus	68.051	31.949	UK_Uncertainty***	focus	0.422	99.578
PRC_M1	focus	24.861	75.139	EU_Uncertainty	focus	35.486	64.514
IN_M1	focus	72.725	27.275	PRC_Uncertainty	focus	39.599	60.401
USD**	focus	98.891	1.109	IN_Uncertainty	focus	31.090	68.910
GBP	focus	86.690	13.310	US_10***	focus	0.820	99.180
Yen***	focus	0.930	99.070	UK_10**	focus	1.549	98.451
Euro	focus	47.872	52.128	JP_10	focus	38.774	61.226
CHF**	focus	6.793	93.207	EZ_10**	focus	5.091	94.909
AUD	focus	60.381	39.619	Fund_Rate	focus	67.528	32.472
CAD**	focus	7.872	92.128	FX_Reserves	focus	50.414	49.586
Silver***	fixed	0.000	100	Gold_Reserves	focus	48.909	51.091
Palladium**	fixed	95.191	4.809	Real_Estate***	focus	99.169	0.831
Platinum***	fixed	0.064	99.936				

Figure 8.3: Sophisticated Extreme Bounds Analysis Results for Gold - Model 2: Fixing Silver, Platinum and Palladium



8.1.2.2.1 99% Confidence Interval

Fixing white precious metals weakens the importance of the US Dollar as an explanatory variable of the price of gold (Tables O.3, 8.2 and 8.3) but strengthen the importance of real estate compared to the first model specification, where real estate was within the 95% confidence interval (Table 8.2). The following variables are explanatory at the 99% confidence level: silver, platinum, the Yen, the UK economic uncertainty index, the US 10 years Government bond index, and finally, the S&P Case-Shiller National Home Price Index. Except for real estate, all variables are positively associated with the price of gold (Figure 8.3). An explanation about real estate becoming explanatory was provided in the previous section, and the fact that the variable becomes explanatory at the 99% confidence interval when fixing all white precious metals is a suggestion for the resemblance of the four precious metals between each other: all providing an alleged refuge during the recent Global Financial Crisis triggered by the real estate burst. The importance of silver, platinum, British economic uncertainty and US government debt has been discussed earlier on and it should be noted that Model 2 yields results identical to the first model in that respect. The rising importance of the Yen, switching from an explanatory variable at the 95% confidence level to the 99% confidence level indicates the importance that the Asian country plays in the white precious metal market, especially in regard to industrial demand. In 2014, Japan had the third biggest demand for silver in industrial applications (The Silver Institute (2016)) and was one of the major players on both the platinum and the palladium market (Gold Field Mineral Services Ltd. (2015)).

8.1.2.2.2 95% Confidence Interval

Only three explanatory variables are identified by the 95% confidence interval: palladium, the US Dollar and the UK 10 year Government bond index. Palladium was identified as explanatory in the unconstrained model (Table O.3) at the 90% confidence level and fixing the variable indeed leads to a rising importance of the relationship between palladium and gold. An explanation is provided through the similarity of the four precious metals. Regarding the drop in importance of the US Dollar in favour of a rising importance of the Yen is an indication that the effect of the purchasing power of the US Dollar is not as important on white precious metals as it is on gold. Indeed, in an unconstrained model, the US Dollar is explanatory at the 99% confidence interval, while it drops to the 95% confidence interval when the three white precious metals are fixed in the model. So when the price movements of gold are explained by price movements of white precious metals, the level of the US Dollar is less important than the price fluctuations of other metals - even though the official prices are quoted in that very currency. UK medium term Government debt remains at the 95% confidence level, an observation identical to the unconstrained approach and the first model specification - an explanation for the importance of British national debt was provided earlier on.

8.1.2.2.3 90% Confidence Interval

The variables found to be explanatory at the 90% confidence interval are very similar to those in Model 1: the Swiss Franc, the Canadian Dollar, the EURO STOXX 50, the VIX, and finally, the Euro Zone 10 year Government bond index. Interesting results are found for the Swiss Franc given that the country is a major trading center for platinum and palladium (Gold Field Mineral Services Ltd. (2015)). An explanation on why these variables are explanatory is provided in the earlier section on Model 1 results, but a brief discussion on the falling importance of the US Consumer Price Index from the 95% confidence level in the unconstrained model (Table O.3), to the 90% confidence level in Model 1 (Table 8.2) to outside the confidence band in Model 2 (Table 8.3) should briefly be provided. Indeed, the earlier chapter of this thesis presented and discussed the importance of US consumer price inflation on the price of gold. However, this relationship seems to vanish out when white precious metal prices are fixed across all regressions. This evidence shows that even though American inflationary pressure is an important variable to consider when understanding gold and silver prices, it shouldn't be considered as an explanatory variable in a model putting accentuated weight on the price of platinum and palladium as fixed regression elements. A reason behind it is the industrial importance of the two white precious metals. So even though their characteristic as a precious metal allows them to be considered value refuges during troublesome economic periods (see results for real estate), they are however not considered an *international currency* like gold and silver would be. It is noteworthy, that not only the US CPI fails to be an explanatory variable in Model 2, but indeed that no inflation measure or money supply series is.

8.1.2.2.4 Sign Shifts

Contrasting results in Figures 8.1 and 8.3, it can be observed that the following variables changed sign when fixing all white precious metals: palladium, the UK CPI, the Chinese CPI, the global CPI, the food price index, the US monetary base, the UK monetary base, the Euro Zone monetary base, the Indian monetary base, the Pound Sterling, the Australian Dollar, the FTSE100, the MSCI World, European economic uncertainty, Chinese economic uncertainty, Indian economic uncertainty, and finally, the Federal fund rate. The result section of Model 1 provided an explanation for the importance of British macroeconomic variables and economic uncertainty measures. Indeed, the reader should keep in mind both the importance that China and India play on all four precious metal markets (see Gold Field Mineral Services Ltd. (2016), The Silver Institute (2016) and Gold Field Mineral Services Ltd. (2015)) alongside the US and Europe, as well as the importance of precious metals as financial refuges during troublesome times. It is interesting that Model 2 suggests a negative relationship between the prices of gold and palladium: akin to a probable substitution effect of the white precious metal that gained increased investor attention not least with the creation of an ETF during the time window considered. Regarding inflation measures, the negative relationship with the price of gold when fixing white precious metals is an indication for their apparent failure to be used as an international currency. Indeed, only the American monetary base is positively associated with the price of gold in that setting: reflecting the importance that the US Dollar exercises on the gold price. An explanation could lie in the industrial nature of both platinum and palladium, where fixing the two variables decreases the exposure of the new model to monetary variables reflecting the currency aspect of gold. In that light, the negative relationship with the Federal fund rate can be explained by the positive effect that low interest rates have for the US economy: where a low interest rate is beneficial for industrial production and therefore leads to increasing demand for gold and to a similar effect to the three fixed white precious metals.

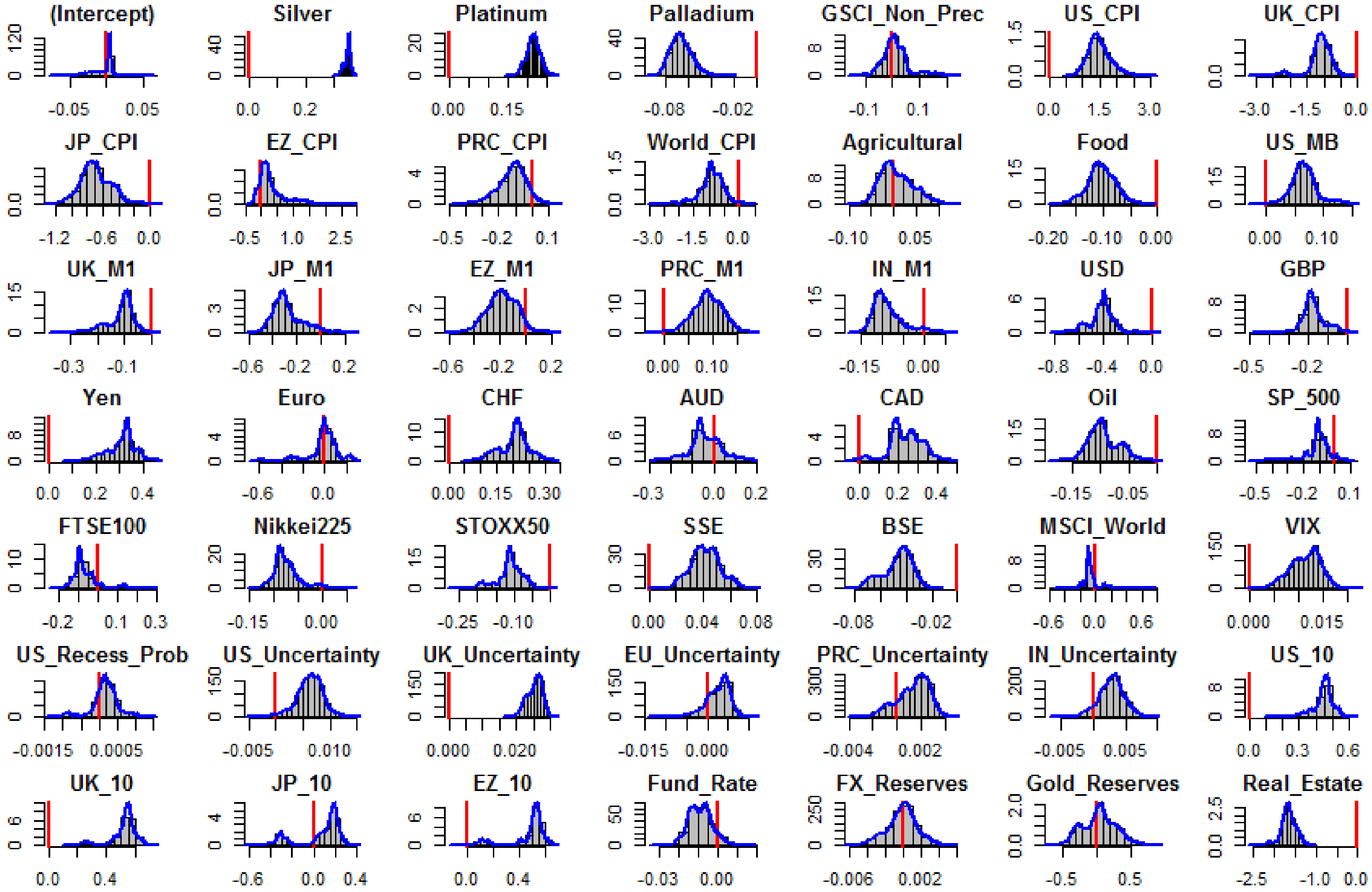
8.1.2.3 Model 3: Fixing Precious and Non-Precious Metals

The specifications in Model 2 have uncovered a pressure exercised on monetary variables when white precious metals are fixed in the system. The third model goes a step further and increases the industrial importance of the gold price by fixing all metals: precious and non-precious. The Sala-I-Martin (1997) regression results are displayed in Table 8.4 and Figure 8.4.

Table 8.4: Sophisticated Extreme Bounds Analysis Results for Gold - Model 3: Fixing Silver, Platinum, Palladium and Non-Precious Metals

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	33.648	66.352	Oil	focus	84.657	15.343
US_CPI	focus	12.548	87.452	GSCI_Non_Prec	fixed	45.159	54.841
UK_CPI	focus	89.082	10.918	S&P_500	focus	85.258	14.742
JP_CPI	focus	77.960	22.040	FTSE100	focus	76.106	23.894
EZ_CPI	focus	36.316	63.684	Nikkei225	focus	88.150	11.850
PRC_CPI	focus	60.471	39.529	STOXX50*	focus	94.131	5.869
World_CPI	focus	75.142	24.858	SSE	focus	10.364	89.636
Agricultural	focus	47.976	52.024	BSE	focus	88.509	11.491
Food	focus	86.284	13.716	MSCI_World	focus	76.044	23.956
US_MB	focus	22.974	77.026	VIX*	focus	9.628	90.372
UK_M1	focus	68.011	31.989	US_Recess_Prob	focus	44.132	55.868
JP_M1	focus	79.491	20.509	US_Uncertainty	focus	22.004	77.996
EZ_M1	focus	67.609	32.391	UK_Uncertainty***	focus	0.411	99.589
PRC_M1	focus	24.832	75.168	EU_Uncertainty	focus	36.209	63.791
IN_M1	focus	72.427	27.573	PRC_Uncertainty	focus	39.610	60.390
USD**	focus	98.950	1.050	IN_Uncertainty	focus	31.433	68.567
GBP	focus	86.970	13.030	US_10***	focus	0.769	99.231
Yen***	focus	0.716	99.284	UK_10**	focus	1.494	98.506
Euro	focus	47.803	52.197	JP_10	focus	39.446	60.554
CHF*	focus	6.903	93.097	EZ_10**	focus	4.785	95.215
AUD	focus	61.373	38.627	Fund_Rate	focus	67.702	32.298
CAD*	focus	5.506	94.494	FX_Reserves	focus	50.204	49.796
Silver***	fixed	0.000	100	Gold_Reserves	focus	48.410	51.590
Palladium*	fixed	94.876	5.124	Real_Estate***	focus	99.114	0.886
Platinum***	fixed	0.079	99.921				

Figure 8.4: Sophisticated Extreme Bounds Analysis Results for Gold - Model 3: Fixing Silver, Platinum, Palladium and Non-Precious Metals



8.1.2.3.1 99% Confidence Interval

In Model 3, all metals are fixed in the regressions with gold as a dependent variable. A striking observation, is that the same variable are explanatory at the 99% confidence interval as in Model 2; namely: silver, platinum, the Yen, the UK economic uncertainty index, the US 10 year Government bond index, and finally, the S&P Case-Shiller National Home Price Index. A discussion on all variables was provided earlier and shall not be repeated in this section. Fixing non-precious metals, in addition to fixing white precious metals, does not affect the 99% confidence level results - indicating that the *industrial demand* effect provided by Model 2 is not altered by adding an additional layer of exposure to industrial metals.

8.1.2.3.2 95% Confidence Interval

Slight changes are however observed at the 95% confidence level. Here, the following variables appear to be explanatory: the US Dollar, the UK 10 year Government bond index, and the Eurozone 10 year Government bond index. The effect of exposing the model to industrial demand leads to a decreasing importance of the American currency against an increasing importance of the Japanese currency and was discussed for Model 2. The positive correlation between debt prices and gold is however still a reflection of the investment aspect of gold. Indeed, despite an industrial calibration of the model, the financial asset aspects of gold still remain overwhelmingly important - findings very relevant in the ongoing discussion about the nature of gold as an asset: industrial versus financial.

8.1.2.3.3 90% Confidence Interval

With palladium, the Swiss Franc, the Canadian Dollar, the EURO STOXX 50 and the VIX being explanatory at the 90% confidence level, not a lot of movement is observed in switching from Model 2 to Model 3. However, two observations need to be made. First, fixing non-precious metals lead to a dropping importance of the price of palladium, the most industrial of the three white precious metals. Second, the non-precious metal price index falls from the 90% confidence interval in the unconstrained model (Table O.3) to outside any of the three confidence intervals when it is fixed in Model 3 (Table 8.4). This is an indication of the relative importance of the different metals on the price of gold. In a model fixing all metals, especially silver and platinum are found to be associated with the price of gold, while weaker evidence is given for palladium and non-precious metals. All this evidence is pointing towards the conclusion, that even if a model with high exposure to the industrial side of gold is computed, a strong importance for *investment side* variables is given; with silver and platinum having both a much stronger investment asset aspect than palladium and non-precious metals.

8.1.2.3.4 Sign Shifts

Considering a shift in the sign of the majority of the regressors of each variable, the results between Model 3 and Model 2 are again very similar. Indeed, following variables have switched sign going from an unconstrained model to a model fixing all metals in every regression: palladium, the GSCI non-precious metal index, the UK CPI, the Chinese CPI, the Global CPI, the Food price index, the US monetary base, the UK monetary base, the Eurozone monetary base, the Indian monetary base, the Pound Sterling, the Australian Dollar, the price of oil, the S&P 500, the FTSE 100, the MSCI World, EU economic uncertainty, Chinese economic uncertainty, Indian economic uncertainty, and finally, the Federal fund rate. The implications and a reasoning behind the change for most variables was provided earlier on, and this section will therefore only focus on one variable in particular: the price of oil. Indeed, in the unconstrained model (Figure 8.1), about 85% of the regressors for oil were positively associated with the price of gold. The amount of positive regressors declines steadily going from the unconstrained model to Model 3: from 51% positive regressors in Model 1 (Table 8.2), to 34% of positive regressors in Model 2 (Table 8.3), to 15% of positive regressors in Model 3 (Table 8.4). So in other words, the greater the exposure of gold's pricing model towards the metal's industrial aspects, the more negative the relationship between the price of oil and the price of gold becomes. This negative relationship should not be analysed in the light that the price of oil would reflect industrial activity and a higher price of oil should be linked to a higher price of gold when both are considered inputs of industrial activities. Much more, should oil be understood as a driver of inflation, which in turns drives the price of gold (O'Connor et al. (2015)). In that light, the negative relationship between oil and gold goes hand in hand with the observed negative relationship between gold and different inflation indices; namely the UK CPI, the Japanese CPI and the Global CPI (8.4).

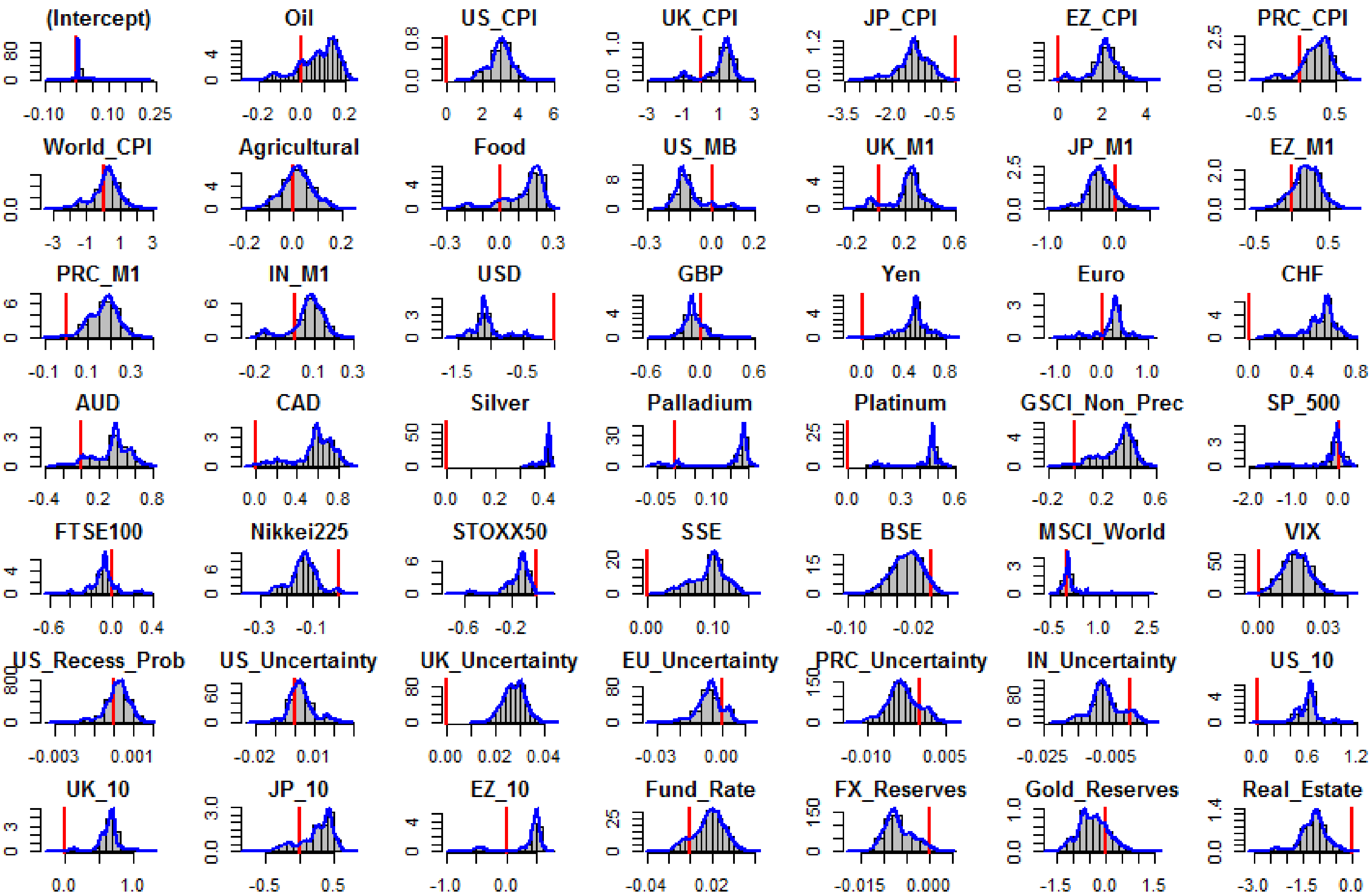
8.1.2.4 Model 4: Fixing Oil

Shifting from Model 1 to Model 3, or in other words increasing the model specifications towards industrial exposure has uncovered a gradual sign shift of the regressors of the oil price. This model specification is therefore fixing the price of oil in order to understand which variable appear to be explanatory in a model explaining gold price movements mainly via changes in the price of oil. Previous papers such as Narayan et al. (2010), Zhang and Wei (2010) or Reboredo (2013a) indeed focus on the relationship between oil and gold and the model proposed in the following section will be of interest to discuss their model specification. Model 4 regression results are displayed in Table 8.5 and Figure 8.5.

Table 8.5: Sophisticated Extreme Bounds Analysis Results for Gold - Model 4: Fixing Oil

Variable	**Type**	**CDF (beta** ≤ 0**)**	**CDF (beta** > 0**)**	**Variable**	**Type**	**CDF (beta** ≤ 0**)**	**CDF (beta** > 0**)**
(Intercept)	fixed	25.106	74.894	Oil	fixed	18.749	81.251
US_CPI**	focus	4.425	95.575	GSCI_Non_Prec*	focus	6.737	93.263
UK_CPI	focus	22.769	77.231	S&P_500	focus	68.820	31.180
JP_CPI	focus	83.385	16.615	FTSE100	focus	70.634	29.366
EZ_CPI**	focus	5.589	96.411	Nikkei225*	focus	92.099	7.901
PRC_CPI	focus	36.711	63.229	STOXX50*	focus	90.648	9.352
World_CPI	focus	46.716	53.284	SSE**	focus	3.718	96.282
Agricultural	focus	46.459	53.541	BSE	focus	69.473	30.527
Food	focus	20.961	79.039	MSCI_World	focus	40.165	59.835
US_MB	focus	77.147	22.853	VIX	focus	10.635	89.365
UK_M1	focus	29.010	70.990	US_Recess_Prob	focus	45.756	54.244
JP_M1	focus	67.566	32.434	US_Uncertainty	focus	40.443	59.557
EZ_M1	focus	37.299	62.701	UK_Uncertainty**	focus	3.089	96.911
PRC_M1	focus	19.329	80.671	EU_Uncertainty	focus	67.772	32.228
IN_M1	focus	38.006	61.994	PRC_Uncertainty	focus	64.984	35.016
USD***	focus	99.982	0.018	IN_Uncertainty	focus	76.772	23.228
GBP	focus	64.911	35.089	US_10***	focus	0.556	99.444
Yen***	focus	0.682	99.318	UK_10	focus	2.736	97.264
Euro	focus	21.262	78.738	JP_10	focus	28.700	71.300
CHF***	focus	0.809	99.191	EZ_10	focus	14.166	85.834
AUD*	focus	8.732	91.268	Fund_Rate	focus	28.738	71.262
CAD**	focus	1.935	98.065	FX_Reserves	focus	75.146	24.854
Silver***	focus	0.000	100	Gold_Reserves	focus	59.056	40.944
Palladium*	focus	7.855	92.145	Real_Estate	focus	85.815	14.185
Platinum***	focus	0.013	99.987				

Figure 8.5: Sophisticated Extreme Bounds Analysis Results for Gold - Model 4: Fixing Oil



8.1.2.4.1 99% Confidence Interval

Three currencies, two precious metals and one Government debt index are identified as explanatory at the 99% confidence interval in Model 4: the US Dollar, the Yen, the Swiss Franc, the price of silver, the price of platinum, and finally, the US 10 year Government bond index. Except for the US Dollar, all indicators are positively associated with the price of gold. The importance of the US Dollar for the price of gold was discussed earlier and the reader should keep in mind that the official oil price, like the official gold price, is quoted in US Dollars. The importance of the Yen is reflecting the strong effect that the Japanese currency has in a more *industrially* calibrated model. Indeed, Model 2 and Model 3 indicate that the Yen is explanatory at the 99% confidence interval (Tables 8.3 and 8.4). The results for the Swiss Franc deserve more attention as the currency is only indicated to be significant at the 99% level in the unconstrained model and in Model 4 (Tables O.3 and 8.5), but evidence is weaker for the three other models. Research results on the relationship between gold and the Swiss Franc were presented and discussed in the result section of the unconstrained model and it should be noticed, that the relative amount of demand from Switzerland on the gold market is more prominent than for silver (see Gold Field Mineral Services Ltd. (2016) and The Silver Institute (2016)). Furthermore, Reynard (2009) suggests that oil is a negative influencer of the Swiss Franc, indicating the systematic effect that oil exercised on gold through the Swiss currency in Model 4. A discussion about the positive relationship between silver, platinum, US Government debt and gold was provided earlier on and shall be omitted in this section.

8.1.2.4.2 95% Confidence Interval

At the 95% confidence interval, the significant variables are very similar with those in the unconstrained model specification. The following variables are identified: the US CPI, the Eurozone CPI, the Canadian Dollar, the SSE, the UK economic uncertainty index and the UK 10 year Government bond index. Two variables have switched from the 95% confidence level (Table O.3) to the 99% confidence level (Table 8.5): the Yen and the US 10 year Government bond index. A model fixing oil, the most important industrial commodity, increases the effect of the Yen level and the effect of US public debt; reflecting the two countries importance not only on the gold market but also on the market for oil.

8.1.2.4.3 90% Confidence Interval

The following variables are identified as significant at the 90% confidence interval: the Australian Dollar, the price of palladium, the GSCI non-precious metal index, the Nikkei 225 and the Euro Stoxx 50. In comparison to the unconstrained model (Table O.3), two new variables become significant when fixing oil across all regressions: the Japanese and the European equity indices. Unlike the three other variables significant at the 90% confidence interval, the Nikkei 225 and the Euro Stoxx 50 are negatively associated with the price of gold - when stock price indices are high, the price of gold is low. This is an indication for the hedging potential of gold in both markets (Baur and McDermott (2010)), where investors withdraw funds from the stock market to invest in gold for safe keeping. The fact this hedging ability is revealed in a model fixing the price of oil in every regression can be explained by the close movements of oil and the two mentioned equity indices against opposed movements of the gold price. Indeed, oil, the Nikkei 225 and the Euro Stoxx 50 proved to follow a similar pattern over the time-window considered, with a sharp drop in the price around the recent Financial Crisis for example, where else the price of gold was in a bullish channel between 2003 and 2015.

8.1.2.4.4 Sign Shifts

Comparing the sign of the majority of the regressors for each variable between the unconstrained model (Figure 8.1) and Model 4 (Figure 8.5), it can be asserted, that the effects of fixing oil are small. Indeed, the only variable that seems to change is the Global CPI rate, where nearly 75% of the regressors were positive in the unconstrained approach (Table O.3), the distribution is now evenly spread between positive and negative values (Table 8.5). The weaker effect of the Global CPI rate is to be explained by the fact that inflationary pressure is now channeled through oil in the model, hence diminishing the effect of official national inflation rates per se.

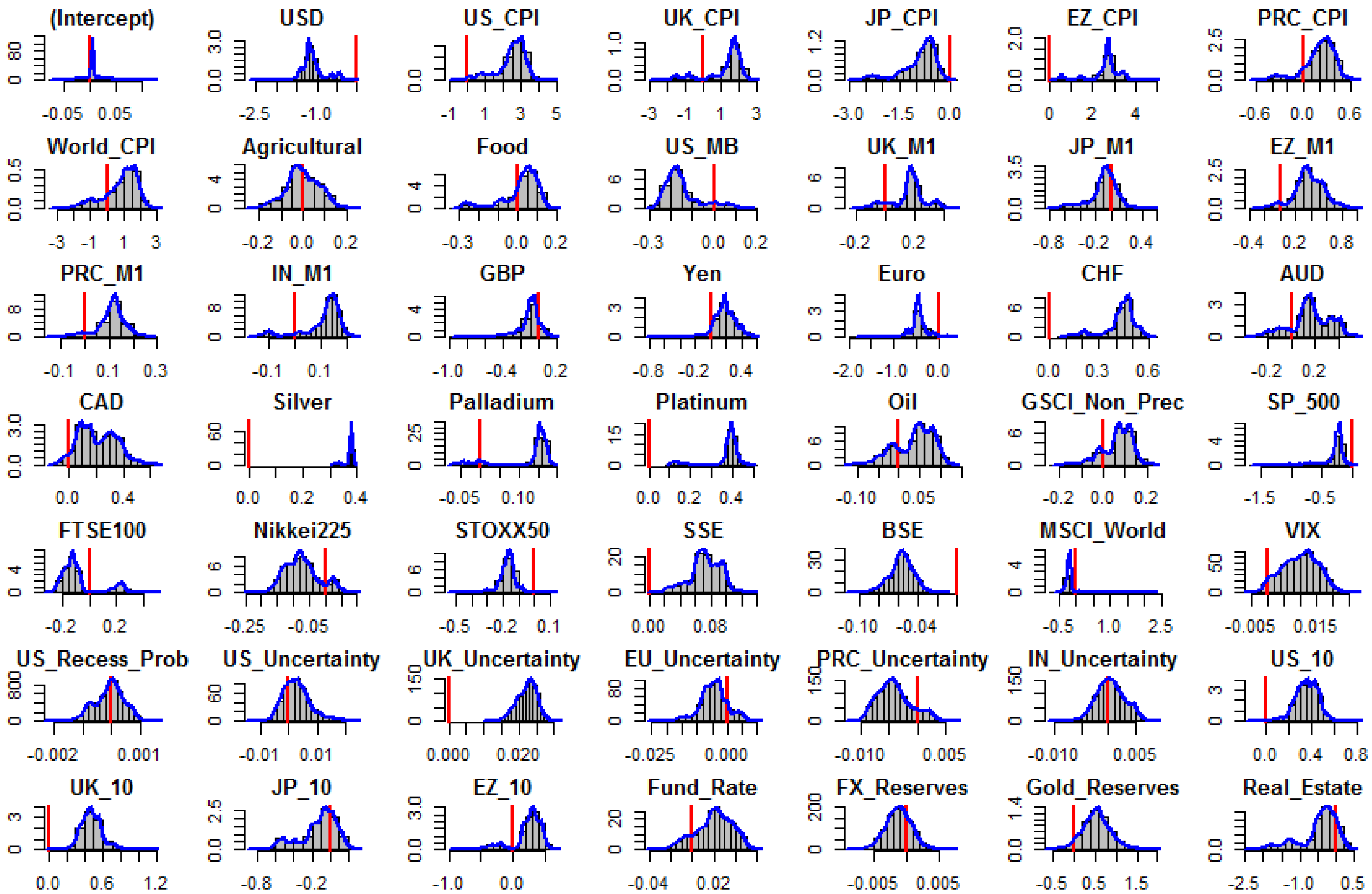
8.1.2.5 Model 5: Fixing the US Dollar

In the unconstrained approach, the US Dollar was the only significant variable to be negatively associated with the price of gold (Table O.3 and Figure 8.1). Previous research, such as Tully and Lucey (2007) finds evidence for the US Dollar to be the most significant variable to influence the gold price, results confirmed by Sjaastad (2008) and Sari et al. (2010). O'Connor et al. (2015) argue that a weak US Dollar makes it cheaper for the rest of the World to purchase gold, hence pushing the price of the precious metal upwards. Building upon previous research, and the results of the unconstrained Extreme Bounds Analysis, Model 5 fixes the US Dollar in every regression and considers all other variables as doubtful. The Sala-I-Martin (1997) regression results are displayed in Table 8.6 and Figure 8.6.

Table 8.6: Sophisticated Extreme Bounds Analysis Results for Gold - Model 5: Fixing the US Dollar

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	27.456	72.544	Oil	focus	26.660	73.340
US_CPI**	focus	4.976	95.024	GSCI_Non_Prec	focus	22.501	77.499
UK_CPI	focus	17.742	82.258	S&P_500**	focus	96.760	3.240
JP_CPI	focus	75.979	24.021	FTSE100	focus	75.159	24.841
EZ_CPI**	focus	1.325	98.675	Nikkei225	focus	80.210	19.790
PRC_CPI	focus	36.943	63.057	STOXX50**	focus	95.245	4.755
World_CPI	focus	32.173	67.827	SSE*	focus	5.932	94.068
Agricultural	focus	50.525	49.475	BSE	focus	86.092	13.908
Food	focus	42.143	57.857	MSCI_World	focus	87.962	12.038
US_MB	focus	85.787	14.213	VIX	focus	20.978	79.022
UK_M1	focus	31.279	68.721	US_Recess_Prob	focus	51.094	48.906
JP_M1	focus	57.438	42.562	US_Uncertainty	focus	40.593	59.407
EZ_M1	focus	24.985	75.015	UK_Uncertainty**	focus	4.485	95.515
PRC_M1	focus	26.761	73.239	EU_Uncertainty	focus	64.377	35.623
IN_M1	focus	29.659	70.341	PRC_Uncertainty	focus	69.216	30.784
USD***	fixed	99.965	0.035	IN_Uncertainty	focus	47.771	52.229
GBP	focus	66.500	33.500	US_10*	focus	5.018	94.982
Yen	focus	15.782	84.218	UK_10**	focus	3.170	96.830
Euro*	focus	93.782	6.218	JP_10	focus	59.928	40.072
CHF**	focus	1.173	98.827	EZ_10	focus	18.194	81.806
AUD	focus	22.432	77.568	Fund_Rate	focus	25.161	74.839
CAD	focus	19.301	80.699	FX_Reserves	focus	55.351	44.649
Silver***	focus	0.000	100	Gold_Reserves	focus	36.492	63.508
Palladium*	focus	7.818	92.182	Real_Estate	focus	65.712	34.288
Platinum***	focus	0.060	99.940				

Figure 8.6: Sophisticated Extreme Bounds Analysis Results for Gold - Model 5: Fixing the US Dollar



8.1.2.5.1 99% Confidence Interval

Three variables are identified as significant at the 99% confidence interval: the US Dollar, the price of silver, and the price of palladium. The important negative relationship between gold and the US Dollar was discussed earlier on and it is not surprising that it remains significant in the new model specification. In a fashion similar to the previous model specifications, the positive relationship between gold and both silver and platinum is akin to the aspects the three precious metals have in common. Because of the subjectively imposed weighting on the American currency alone, the Swiss Franc falls from the 99% confidence interval into the 95% confidence interval in Model 5 (Tables O.3 and 8.6). Furthermore, other currencies are falling out of the confidence bands, namely the Australian and the Canadian Dollar, indicating that the new model specification channels currency pressure through the US Dollar, alongside a few other currencies.

8.1.2.5.2 95% Confidence Interval

At the 95% confidence interval, the following variables are identified: the US CPI, the Eurozone CPI, the Swiss Franc, the S&P 500, the Euro Stoxx 50, the UK economic uncertainty index, and the UK 10 year Government bond index. Even though most identified variables are similar to those identified in the unconstrained model, two new variables appear to be significantly negatively associated with the price of gold: the American and the European equity index. The generally negative relationship between equity prices and gold is reflecting the safe haven qualities of gold (Baur and Lucey (2010)), where investors retrieve funds from equity markets and invest into the precious metal for it's alleged qualities to hold its value during troublesome times. The reason that the S&P 500 and the Euro Stoxx 50 appear in Model 5 fixing the US Dollar is because of the exposure of the two indices to the American legal tender. A further discussion on the importance of the American currency for the main American stock market is not necessary, but the importance of the US Dollar for Europen equity should be understood in the light of both, the importance of the American economy for European companies and the systematic exposure of European investors towards the globally most prominent currency of all.

8.1.2.5.3 90% Confidence Interval

Model 5 identifies four variables to be significant at the 90% confidence interval:

the Euro, the price of palladium, the Chinese equity price index, and finally, the US 10 year Government bond index. Both the SSE and the US Government debt index were identified as significant in the unconstrained model (Table O.3) but at the 95% confidence level. Interestingly, US debt is less significant in a model fixing the level of the US Dollar, indicating that a part of volatility arising from US debt and affecting gold is already channeled through the US Dollar. A very striking observation is the effect that fixing the US Dollar has on the Euro: not only does the Euro becomes significant under the new model specification (Table 8.6), but the distribution of regressors also becomes primarily negative (Figure 8.6) in comparison to the unconstrained model. Model 5 provides additional insights into the currency effects of gold by fixing the prime international currency: the US Dollar. The negative relationship between gold and the Euro is, parallel to the US Dollar, an indication of the flight to quality aspects of gold when the purchasing power of the European currency falls - akin to gold's role as an international currency.

8.1.2.5.4 Sign Shifts

The distribution of the following variables changed from the unconstrained model (Figure 8.1) to the specifications of Model 5 (Figure 8.6): the Euro, the S&P 500, the FTSE 100, the MSCI World and the global central bank gold reserves. The implications of the Euro have been discussed earlier and the predominantly negative relationship between the three identified stock indices is, once more, akin to gold's safe haven attributes during equity crises. The positive relationship between global central bank reserves and the price of gold in a model fixing the US Dollar reflects the exposure of central banks to the American currency, carrying indeed the highest weighting in the Special Drawing Rights (SDR) basket. So a weak US Dollar is associated with a higher demand for gold by central banks which in turn is associated to a higher price of gold.

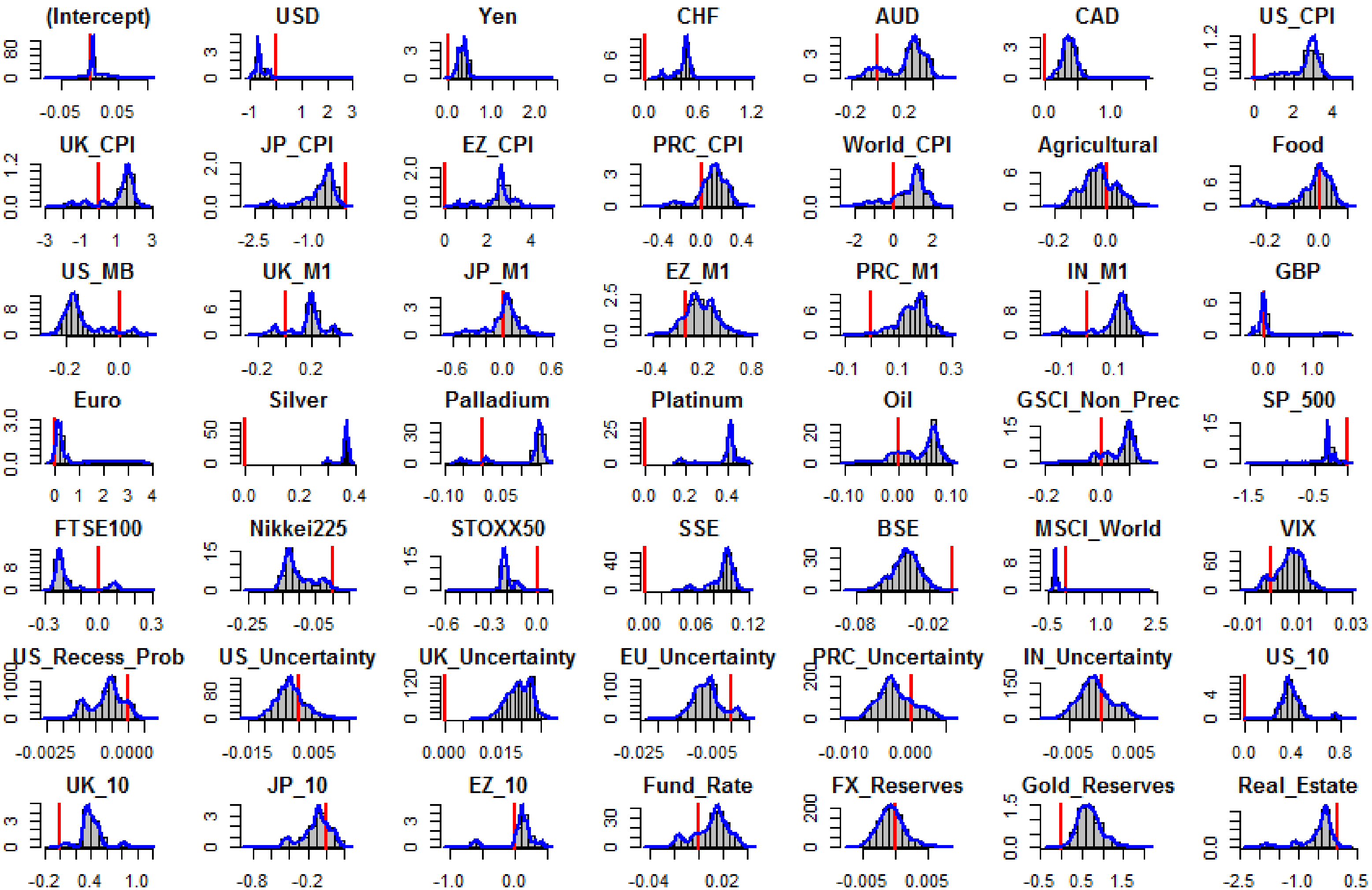
8.1.2.6 Model 6: Fixing Currencies Identified in the Unconstrained Model

The approach of Model 5 is taken a step further and all currencies are fixed in the following model. Regression results for Model 6 are displayed in Table 8.7 and Figure 8.7.

Table 8.7: Sophisticated Extreme Bounds Analysis Results for Gold - Model 6: Fixing Currencies Identified in the Unconstrained Model

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	28.927	71.073	Oil	focus	24.864	75.136
US_CPI**	focus	2.989	97.011	GSCI_Non_Prec	focus	22.510	77.490
UK_CPI	focus	20.037	79.963	S&P_500**	focus	97.434	2.566
JP_CPI	focus	71.526	28.474	FTSE100	focus	83.727	16.273
EZ_CPI**	focus	1.443	98.557	Nikkei225	focus	85.344	14.656
PRC_CPI	focus	42.687	57.313	STOXX50**	focus	95.982	4.018
World_CPI	focus	32.719	67.281	SSE**	focus	2.211	97.789
Agricultural	focus	58.106	41.894	BSE	focus	77.687	22.313
Food	focus	54.940	45.060	MSCI_World*	focus	91.361	8.639
US_MB	focus	86.159	13.841	VIX	focus	28.333	71.667
UK_M1	focus	31.344	68.656	US_Recess_Prob	focus	64.970	35.030
JP_M1	focus	48.458	51.542	US_Uncertainty	focus	58.438	41.562
EZ_M1	focus	37.715	62.285	UK_Uncertainty*	focus	6.766	93.234
PRC_M1	focus	19.877	80.123	EU_Uncertainty	focus	72.261	27.739
IN_M1	focus	30.932	69.068	PRC_Uncertainty	focus	62.034	37.966
USD*	fixed	94.805	5.195	IN_Uncertainty	focus	54.479	45.521
GBP	focus	50.758	49.242	US_10**	focus	3.512	96.488
Yen*	fixed	5.610	94.390	UK_10*	focus	6.728	93.272
Euro	focus	28.736	71.264	JP_10	focus	59.344	40.656
CHF**	fixed	1.396	98.604	EZ_10	focus	36.508	63.492
AUD	fixed	18.334	81.666	Fund_Rate	focus	35.483	64.517
CAD*	fixed	5.889	94.111	FX_Reserves	focus	52.948	47.052
Silver***	focus	0.000	100	Gold_Reserves	focus	32.114	67.886
Palladium*	focus	8.836	91.164	Real_Estate	focus	68.702	31.298
Platinum***	focus	0.007	99.993				

Figure 8.7: Sophisticated Extreme Bounds Analysis Results for Gold - Model 6: Fixing Currencies Identified in the Unconstrained Model



8.1.2.6.1 99% Confidence Interval

Fixing the currencies identified as significant in the unconstrained model specification (Table O.3) in Model 6 identifies two variables at the 99% confidence interval: the price of silver and the price of platinum. In comparison to Model 5 (Table 8.6), the US Dollar falls out of the 99% confidence interval into the 95% confidence interval (Table 8.7), making place for new appearing currencies. Like in all of the previous model specifications, 100% of the silver price regressors are positively associated with the price of gold, highlighting the strong relationship between the tow most prominent precious metals.

8.1.2.6.2 95% Confidence Interval

At the 95% confidence level, seven variables appear to be significant: the Swiss Franc, the US CPI, the Eurozone CPI, the S&P 500, the Euro Stoxx 50, the SSE and the US 10 year Government bond index. The importance of the Swiss Franc was identified and discussed in Model 5, but a more interesting observation is that fixing other currencies than the US Dollar is not detrimental to the relationship between gold and both the American and the European inflation rate. Indeed, a positive correlation between the series is observed in the unconstrained model (Table O.3) and both Model 5 (Table 8.6) and Model 6 (Table 8.7). The three equity indices identified were also pointed out as significant in Model 5, fixing only the US Dollar. Only the Chinese equity price index is positively associated with the price of gold, pointing towards gold's use as a luxury good in China rather than a safe haven asset during financial turmoils. Finally, the positive relationship with American public debt is pointing towards the resemblance of both assets, renown for their virtue during economic troubles.

8.1.2.6.3 90% Confidence Interval

The following variables are identified at the 90% confidence interval: the US Dollar, the Yen, the Canadian Dollar, the price of palladium, the MSCI World index, the UK economic uncertainty index, and finally, the UK 10 year Government bond index. The striking importance of British economic stability indicators was discussed in detail in previous sections as well as the observed negative relationship between gold and the MSCI global equity index. The relationship between gold and palladium remains significant at the 90% confident level, like in both the unconstrained model (Table O.3) and Model 5 (Table 8.6). However, in comparison to a model fixing only the US Dollar, two new currencies appear to be significant: the Yen and the Canadian Dollar. Interpreting this result in the light that the US Dollar falls from the 99% confidence interval (Table 8.6) into the 90% confidence interval (Table 8.7) it can be asserted that the currency effect of gold is far more international than sometimes believed. Indeed, approaches highlighted by Sjaastad and Scacciavillani (1996), Sjaastad (2008) and O'Connor and Lucey (2012) argue that other currencies than the US Dollar must be taken into account in explaining the price of gold. However, the positive relationship between gold and both the Yen and the Canadian Dollar is challenging the findings of Erb and Harvey (2013) who believe gold to be a hedge against the currencies mentioned.

8.1.2.6.4 Sign Shifts

Moving from an unconstrained approach (Figure 8.1) towards a more sophisticated model in which the significant currencies identified in Table O.3 are fixed across all regressions, affects the distribution of eight variables: the Japanese money supply, the S&P 500, the FTSE 100, the MSCI World, the US recession probability, the US economic uncertainty index, the Japanese 10 year Government bond index, and finally, the global central bank gold reserves. A reasoning for the effect on global gold reserves and equity indices was provided in an earlier section and the readers attention should be directed towards the new variables appearing: the macroeconomic indicators of the American and the Japanese economy. Interestingly, the two American variables identified to change sign were not identified by the pure USD model (Figure 8.6), indicating the effect that the US currency has on other currencies and on the price of gold itself. Indeed, a weakening American economy is linked to a weakening dollar and therefore a strengthening price of gold - as well as a strengthening of other international currencies. So when the US Dollar is fixed as a sole currency, the effects on the price of gold are all channeled through the currency itself, hence the 99% confidence level. However, a model treating multiple currencies as equally important weakens the importance of the US Dollar on the one hand, but provides more insights about the distribution of other American variables affecting the level of the US Dollar. Concerning the two Japanese variables identified to have changed sign from the unconstrained model (Figure 8.1) to Model 5 (Figure 8.6), they reflect the dominance of the Yen against other currencies in the basket of fixed variables, findings in line with Sjaastad (2008).

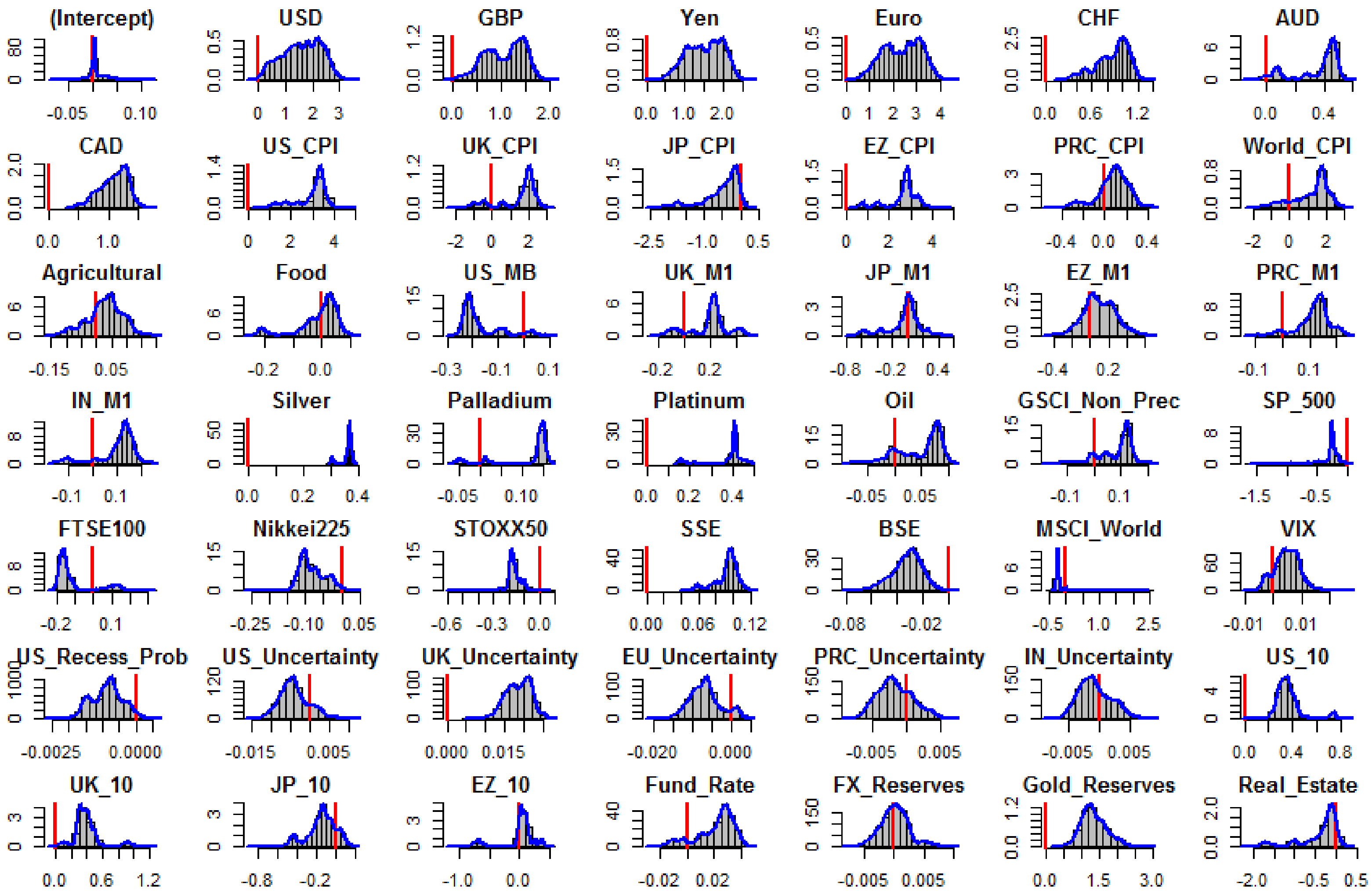
8.1.2.7 Model 7: Fixing all Currencies

The investigation of the previous two models is continued and all the currencies of the full set of variables are fixed. Offering a robustness analysis of Model 5 and 6, Model 7 will provide more insights into which currencies dominate in a model assigning equal importance to each of them. Regression results for Model 7 are displayed in Table 8.8 and in Figure 8.8.

Table 8.8: Sophisticated Extreme Bounds Analysis Results for Gold - Model 7: Fixing all Currencies

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	31.812	68.188	Oil	focus	21.078	78.922
US_CPI**	focus	1.895	98.105	GSCI_Non_Prec	focus	16.651	83.349
UK_CPI	focus	15.110	84.890	S&P_500*	focus	94.738	5.262
JP_CPI	focus	64.051	35.949	FTSE100	focus	77.870	22.130
EZ_CPI**	focus	1.057	98.943	Nikkei225	focus	80.802	19.198
PRC_CPI	focus	44.694	55.306	STOXX50*	focus	93.869	6.131
World_CPI	focus	24.890	75.110	SSE**	focus	1.897	98.103
Agricultural	focus	41.930	58.070	BSE	focus	73.293	26.707
Food	focus	50.799	49.201	MSCI_World	focus	86.866	13.134
US_MB*	focus	90.223	9.777	VIX	focus	34.448	65.552
UK_M1	focus	28.834	71.166	US_Recess_Prob	focus	69.733	30.267
JP_M1	focus	52.765	47.235	US_Uncertainty	focus	63.801	36.199
EZ_M1	focus	43.217	56.783	UK_Uncertainty*	focus	7.773	92.227
PRC_M1	focus	25.187	74.813	EU_Uncertainty	focus	73.094	26.906
IN_M1	focus	30.527	69.473	PRC_Uncertainty	focus	58.675	41.325
USD	fixed	15.211	84.789	IN_Uncertainty	focus	53.686	46.314
GBP*	fixed	9.531	90.469	US_10*	focus	5.399	94.601
Yen**	fixed	4.709	95.291	UK_10*	focus	7.919	92.081
Euro*	fixed	7.936	92.064	JP_10	focus	63.429	36.571
CHF**	fixed	1.162	98.838	EZ_10	focus	43.386	56.614
AUD*	fixed	9.140	90.860	Fund_Rate	focus	23.534	76.466
CAD**	fixed	2.215	97.785	FX_Reserves	focus	49.577	50.423
Silver***	focus	0.000	100	Gold_Reserves	focus	18.893	81.107
Palladium*	focus	8.653	91.347	Real_Estate	focus	63.531	36.469
Platinum***	focus	0.013	99.987				

Figure 8.8: Sophisticated Extreme Bounds Analysis Results for Gold - Model 7: Fixing all Currencies



8.1.2.7.1 99% Confidence Interval

The 99% confidence interval results are identical to the results in Model 6. The two variables identified are the price of silver and the price of platinum (Table 8.8), illustrating the detrimental effect that fixing multiple currencies has on the US Dollar. It should however be noted, that once more, 100% of the regressors of the silver price are positively associated with the price of gold.

8.1.2.7.2 95% Confidence Interval

Six variables are identified at the 95% confidence interval: the Yen, the Swiss Franc, the Canadian Dollar, the US CPI, the Eurozone CPI, and finally, the Shanghai stock index. In line with previous results of currency focused models, the American and European consumer price inflation index remains significant. Same goes for the Chinese stock market, where it is argued that the positive relationship reflects gold's role as a luxury good where the demand for the metal is higher during boom periods of the Chinese economy. Regarding the three variables that appear at the 95% confidence level, a rising importance is observed for the Yen and the Canadian Dollar, both being in a previous model significant at the 90% level only (Table 8.7). Indeed, the effect of fixing all currencies from the dataset reveals the relatively higher importance of some currencies against others.

8.1.2.7.3 90% Confidence Interval

At the 90% confidence level, the following variables appear to be significant: The Pound Sterling, the Euro, the Australian Dollar, the US monetary base, the price of palladium, the S&P 500, the Euro Stoxx 50, UK economic uncertainty index, the US 10 year Government bond index, and finally, the UK 10 year Government bond index. The importance of both Government debt indices and equity indices was discussed earlier and more attention should be directed towards the new currencies appearing in the 90% interval in comparison to Model 6: the Pound Sterling, the Euro and the Australian Dollar. The new model specification, fixing all currencies in the system seems to shift away the importance of the US Dollar in favour of other currencies. Indeed, the US Dollar vanishes out of the confidence intervals and becomes an insignificant variable in explaining the price of gold (Table 8.8). This result is in contrast to Tully and Lucey (2007) and Sari et al. (2010) who examine the effect of multiple currencies on gold and find the US Dollar to be the dominant currency of all. However, the effect of the Dollar doesn't disappear entirely as a new variable appears at the 90% significance level: the US monetary base. So the direct effect that the US Dollar has on the price of gold weakens, as more currencies are fixed in the system: the Dollar is significant at the 99% level in Model 5 (Table 8.6), at the 90% in Model 6 (Table 8.7), and insignificant in Model 7 (Table 8.8). The Dollar is however replaced by the monetary base which is negatively associated with the price of gold, suggesting that a higher amount of Dollars in the economy leads to a lower price of gold.

8.1.2.7.4 Sign Shifts

Switching from the unconstrained model (Figure 8.1) to the new specification in which all the currencies are fixed, the following variables appear to have changed signs: the US Dollar, the Pound Sterling, the Japanese money supply, the S&P 500, the FTSE 100, the MSCI global equity index, US recession probability, the US economic uncertainty index, the Japanese 10 year Government bond index, global foreign exchange currency reserves, and finally, global central bank gold reserves. Most of the variables changed signs in previous models and this section should therefore focus on three variables in particular: the US Dollar, the Pound Sterling, and global foreign exchange currency reserves. As mentioned earlier, the effect of the US Dollar is cooled down by adding further currencies as fixed variables in the system, channeling the effect of the American currency via money supply in the USA. However, when fixing all currencies in the regressions, it seems that the US Dollar simply becomes a regular currency, being positively associated with the price of gold. So a currency model indeed admits that a weak Dollar does not make it beneficial for other countries to invest in gold, but indeed strengthens the value of gold because the currency gold is quoted in becomes stronger. The change in sign of the Pound Sterling is due to the ubiquitous presence of the variable in Model 7. While the regressors seemed to be somehow evenly distributed between the two signs in the unconstrained model (Figure 8.1), the more sophisticated approach of Model 7 (Figure 8.8) suggests that most regressors are positively associated with the price of gold (Figure 8.8). Finally, the flattening distribution of the regressors of the foreign exchange currency reserve variable is due to presence of all the currencies across the entirety of the regressions, channeling the effect of the variable through the currencies themselves rather than through the currency reserve aggregate.

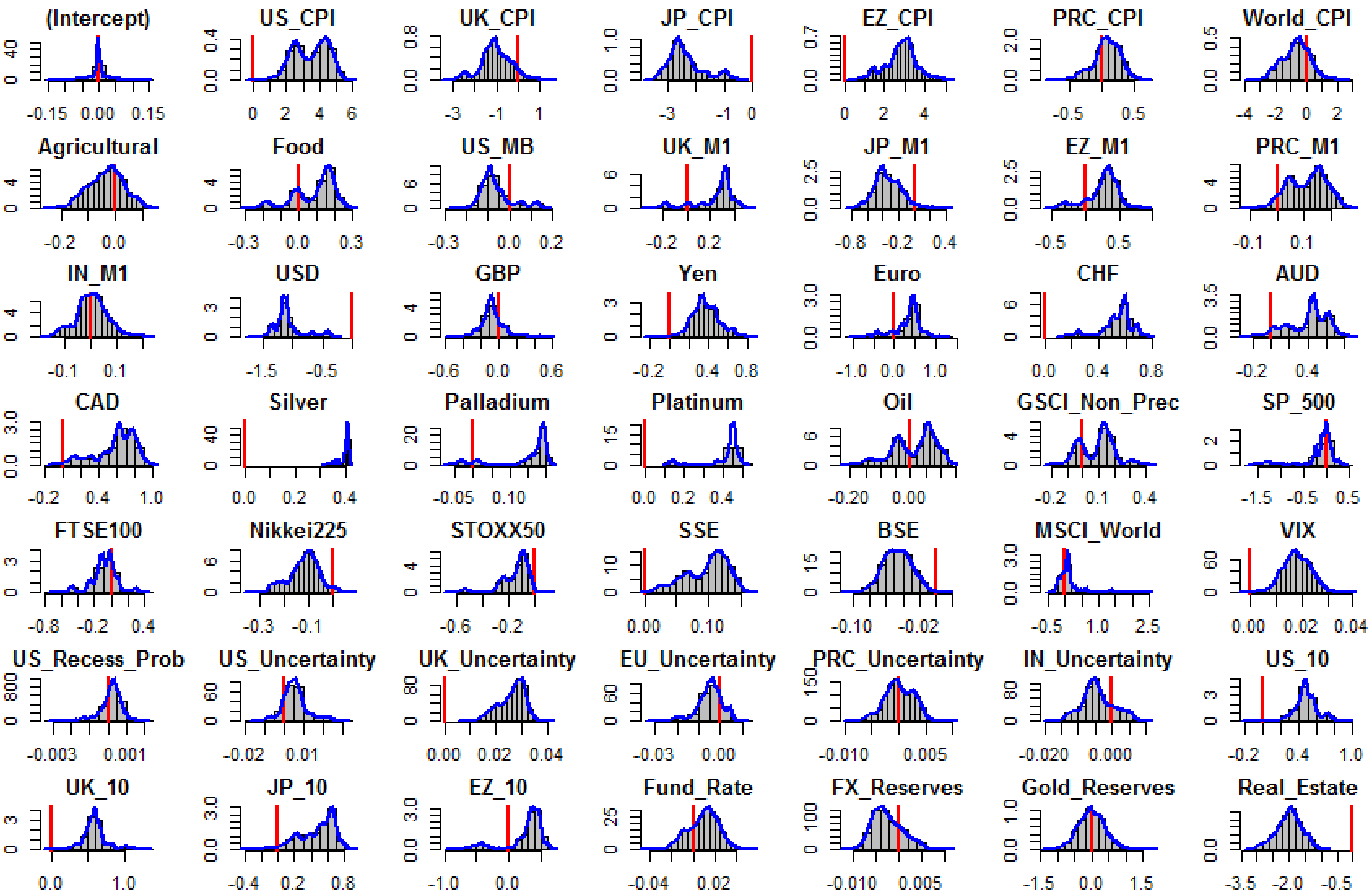
8.1.2.8 Model 8: Fixing Consumer Price Indices

The Literature Review uncovered the amount of work focused on the relationship between gold and inflation, which is a part of this very thesis as well. Model 8 fixes the US, the UK, the Japanese, the Eurozone, the Chinese, and the Global CPI rates to understand more about the relationship between gold and inflation in a multivariate system. The Sala-I-Martin (1997) regression results are displayed in Table 8.9 and Figure 8.9.

Table 8.9: Sophisticated Extreme Bounds Analysis Results for Gold - Model 8: Fixing Consumer Price Indices

Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)	Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)
(Intercept)	fixed	48.603	51.397	Oil	focus	41.766	58.234
US_CPI**	fixed	3.510	96.490	GSCI_Non_Prec	focus	27.314	72.686
UK_CPI	fixed	72.879	27.121	S&P_500	focus	58.629	41.371
JP_CPI**	fixed	95.069	4.931	FTSE100	focus	67.037	32.963
EZ_CPI**	fixed	2.502	97.498	Nikkei225	focus	88.565	11.435
PRC_CPI	fixed	45.655	54.345	STOXX50	focus	87.024	12.976
World_CPI	fixed	62.140	37.860	SSE**	focus	4.143	95.857
Agricultural	focus	57.988	42.012	BSE	focus	78.854	21.146
Food	focus	28.983	71.017	MSCI_World	focus	35.010	64.990
US_MB	focus	66.181	33.819	VIX*	focus	8.423	91.577
UK_M1	focus	26.663	73.337	US_Recess_Prob	focus	45.753	54.247
JP_M1	focus	73.868	26.132	US_Uncertainty	focus	33.613	66.387
EZ_M1	focus	33.363	66.637	UK_Uncertainty**	focus	3.406	96.594
PRC_M1	focus	29.919	70.081	EU_Uncertainty	focus	63.673	36.327
IN_M1	focus	49.691	50.309	PRC_Uncertainty	focus	48.585	51.415
USD***	focus	99.975	0.025	IN_Uncertainty	focus	65.896	34.104
GBP	focus	63.400	36.600	US_10**	focus	2.412	97.588
Yen**	focus	3.090	96.910	UK_10**	focus	2.484	97.516
Euro	focus	15.551	84.449	JP_10	focus	15.151	84.849
CHF***	focus	0.557	99.443	EZ_10	focus	18.837	81.163
AUD*	focus	7.181	92.819	Fund_Rate	focus	38.585	61.415
CAD**	focus	2.407	97.593	FX_Reserves	focus	59.337	40.663
Silver***	focus	0.000	100	Gold_Reserves	focus	50.100	49.900
Palladium*	focus	7.979	92.021	Real_Estate**	focus	95.283	4.717
Platinum***	focus	0.038	99.962				

Figure 8.9: Sophisticated Extreme Bounds Analysis Results for Gold - Model 8: Fixing Consumer Price Indices



8.1.2.8.1 99% Confidence Interval

A striking observation at the 99% confidence interval is that the same variables are identified in Model 8 (Table 8.9) then in the unconstrained approach (Table O.3): the US Dollar, the Swiss Franc, the price of silver, and the price of platinum. This is evidence for inflation as a key motor of gold price drivers, where indeed, the same variables appear to be significant in a free model and in a sophisticated model fixing multiple CPI measures. In the light of the previous chapter of this thesis, focused on the effects that CPI rates have on the price of gold, the results of Model 8 suggests the importance of four additional variables as explanatory for movements in the gold price. Of special interest, is the significant positive relationship between gold and both silver and platinum, indicating a very probable effect of inflationary pressure on the two white precious metals akin to their possible virtue as value holders during inflationary episodes, though a formal testing procedure would be required to assess such a conclusion. The reappearing Swiss Franc is further evidence of the important role of the European country on the gold market: far more important than often suggested in academic and practitioner research.

8.1.2.8.2 95% Confidence Interval

The variables identified at the 95% confidence interval (Table 8.9) are again very similar to those identified in the unconstrained approach (Table O.3): the US CPI rate, the Japanese CPI rate, the Eurozone CPI rate, the Yen, the Canadian Dollar, the SSE composite index, the UK economic uncertainty index, the US 10 year Government bond index, the UK 10 year Government bond index, and finally, the S&P Case-Shiller National Home Price Index. Two new variables appear in the 95% confidence interval that were previously not identified in the unconstrained approach: the Japanese CPI and the real estate index. The relationship between gold and the Japanese consumer price inflation is negative, indicating that the price of gold increases when the general Japanese price level decreases. This finding is in line with the development of the price of gold against the Japanese CPI rate during that period: the country was going through a deflationary episode while the price of gold was increasing. The importance of real estate, again negatively associated with gold, is found to express itself more strongly in a model specification exposed to inflation measures. While the negative relationship was explained earlier on in this chapter, the very fact that this relationship is uncovered when fixing different CPI rates is puzzling at first. It should be kept in mind that price changes in real estate are not taken into account when calculating CPI rates but fixing the CPI indices across every equation leads the variable in question to become significant - gold and real estate indeed had opposed trends over the sample period, mainly due to the drastic decline of housing prices in America during the recent Global Financial Crisis.

8.1.2.8.3 90% Confidence Interval

At the 90% confidence interval, only three variables are identified: the Australian Dollar, the price of palladium, and the VIX - a selection of variables again similar to those identified in the unconstrained approach (Table O.3). A change can however be observed: the disappearance of the GSCI non-precious metal index and the appearance of the stock market volatility index. The switch between the two variables indicates that fixing inflation indices in the system strengthens the *investment* aspects of gold and weakens the *industrial* aspects of the precious metal.

8.1.2.8.4 Sign Shifts

Two variables are identified to significantly change from a mainly positive distribution to a mainly negative distribution: the UK CPI and the Global CPI rate. The clustering around negative values of the two inflation indices indicates that gold might not have been an effective hedge against inflation during the period considered - it should be remembered however, that the relationship is not identified as statistically significant. Indeed, the evidence highlighted in the previous chapter suggested that gold and UK inflation were not cointegrated during the large part of the sample. A similar observation is made for global inflation, where it seems that gold is indeed not an effective inflation hedge. As to why the relationship is positive when the two variables are not fixed in every regression, the answer lies in the econometric logic of the procedure. When a variable is labeled as a *focus* variable, it only appears in a sub sample of the total regressions. On the other hand, the variables labeled as *fixed* appear in every regression; suggesting that the sub sample considered in Table O.3 was consisting mainly of positive regressors.

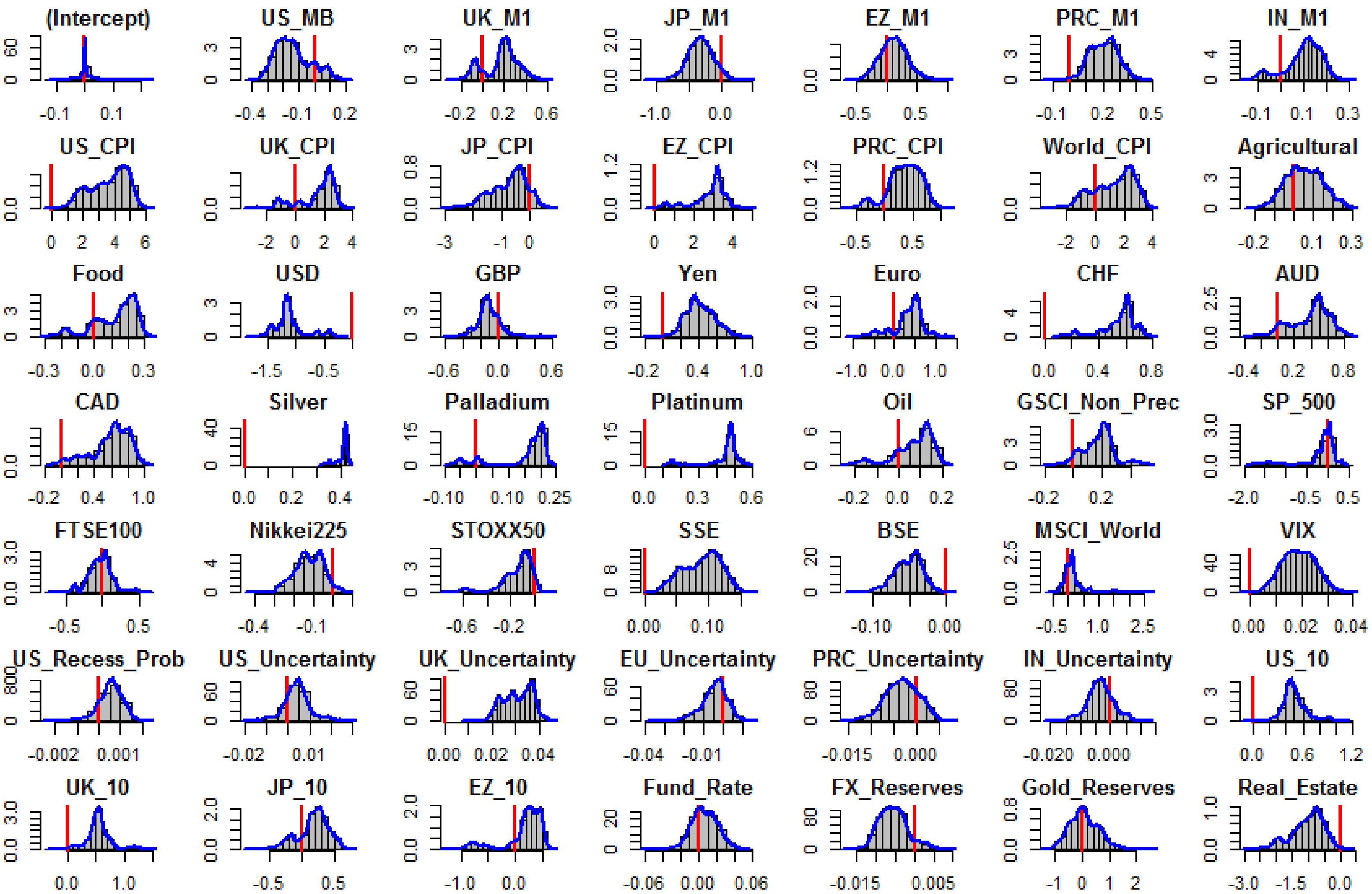
8.1.2.9 Model 9: Fixing Money Supply

The importance of money supply as the root of inflation was presented and discussed in previous sections of this thesis. The investigation into the importance of inflation indices is continued by fixing money supply indicators of the United States, the United Kingdom, Japan, the Eurozone, China and India. The Sala-I-Martin (1997) regression results can be found in Table 8.10 and Figure 8.10.

Table 8.10: Sophisticated Extreme Bounds Analysis Results for Gold - Model 9: Fixing Money Supply

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	42.215	57.785	Oil	focus	17.922	82.078
US_CPI**	focus	2.827	97.173	GSCI_Non_Prec*	focus	8.108	91.892
UK_CPI	focus	18.163	81.837	S&P_500	focus	57.722	42.278
JP_CPI	focus	69.347	30.653	FTSE100	focus	56.155	43.845
EZ_CPI**	focus	2.615	97.385	Nikkei225	focus	86.845	13.155
PRC_CPI	focus	31.229	68.771	STOXX50	focus	84.228	15.772
World_CPI	focus	28.837	71.163	SSE*	focus	5.187	94.813
Agricultural	focus	38.220	61.780	BSE	focus	80.547	19.453
Food	focus	23.252	76.748	MSCI_World	focus	32.276	67.724
US_MB	fixed	78.791	21.209	VIX*	focus	9.087	90.913
UK_M1	fixed	33.594	66.406	US_Recess_Prob	focus	39.119	60.881
JP_M1	fixed	71.830	28.170	US_Uncertainty	focus	37.762	62.238
EZ_M1	fixed	43.137	56.863	UK_Uncertainty**	focus	2.060	97.940
PRC_M1	fixed	16.746	83.254	EU_Uncertainty	focus	61.897	38.103
IN_M1	fixed	33.808	66.192	PRC_Uncertainty	focus	63.430	36.570
USD***	focus	99.957	0.043	IN_Uncertainty	focus	62.985	37.015
GBP	focus	67.267	32.733	US_10**	focus	2.119	97.881
Yen**	focus	2.545	97.455	UK_10**	focus	4.498	95.502
Euro	focus	16.807	83.193	JP_10	focus	34.436	65.564
CHF***	focus	0.728	99.272	EZ_10	focus	25.872	74.128
AUD*	focus	8.681	91.319	Fund_Rate	focus	43.663	56.337
CAD**	focus	2.722	97.278	FX_Reserves	focus	69.515	30.485
Silver***	focus	0.000	100	Gold_Reserves	focus	48.987	51.013
Palladium*	focus	8.983	91.017	Real_Estate	focus	79.237	20.763
Platinum***	focus	0.024	99.976				

Figure 8.10: Sophisticated Extreme Bounds Analysis Results for Gold - Model 9: Fixing Money Supply



8.1.2.9.1 99% Confidence Interval

At the 99% confidence interval, the exact same four variables are identified as significant as in the unconstrained model (Table O.3) and in Model 8 (Table 8.9), namely the US Dollar, the Swiss Franc, the price of silver and the price of platinum. In the light that the monetary base is the very root of inflation, it is not very surprising to see the same explanatory variable at the 1% significance level, and strengthens the argumentation used throughout this thesis, that money supply and inflation are indeed interlinked.

8.1.2.9.2 95% Confidence Interval

The following variables are identified as significant at the 95% confidence interval: the US CPI, the Eurozone CPI, the Yen, the Canadian Dollar, the UK economic uncertainty index, the US 10 year Government bond index, and finally, the UK 10 year Government bond index. So in comparison to the unconstrained model, all variables remain at the 95% confidence interval except for the SSE composite index, now significant at the 90% level. A further observation is that the two variables identified in Model 8, the Japanese CPI and the real estate index, do not appear as significant in the specifications of Model 9. It can be seen in Figure 8.10, that the relationship between gold and both the Japanese CPI and Japanese money supply is negative, results in line with those highlighted in the previous chapter.

8.1.2.9.3 90% Confidence Interval

Five variables are identified at the 90% confidence interval: the Australian Dollar, the price of palladium, the GSCI non-precious metal index, the SSE composite, and the VIX. The appearance of the VIX as an explanatory variable in a model specification exposed to inflationary variables was discussed in the result section of the previous model, with the difference that the GSCI remains an explanatory variable in Model 9. So both the *investment* and the *industrial* aspects of gold are identified in a model specification fixing money supply.

8.1.2.9.4 Sign Shifts

A striking observation of Model 9 (Figure 8.10) is that no variables are shifting signs in comparison to the unconstrained model (Figure 8.1). In other words: fixing international money supply indicators does not severely influence the distribution of the variables in the system.

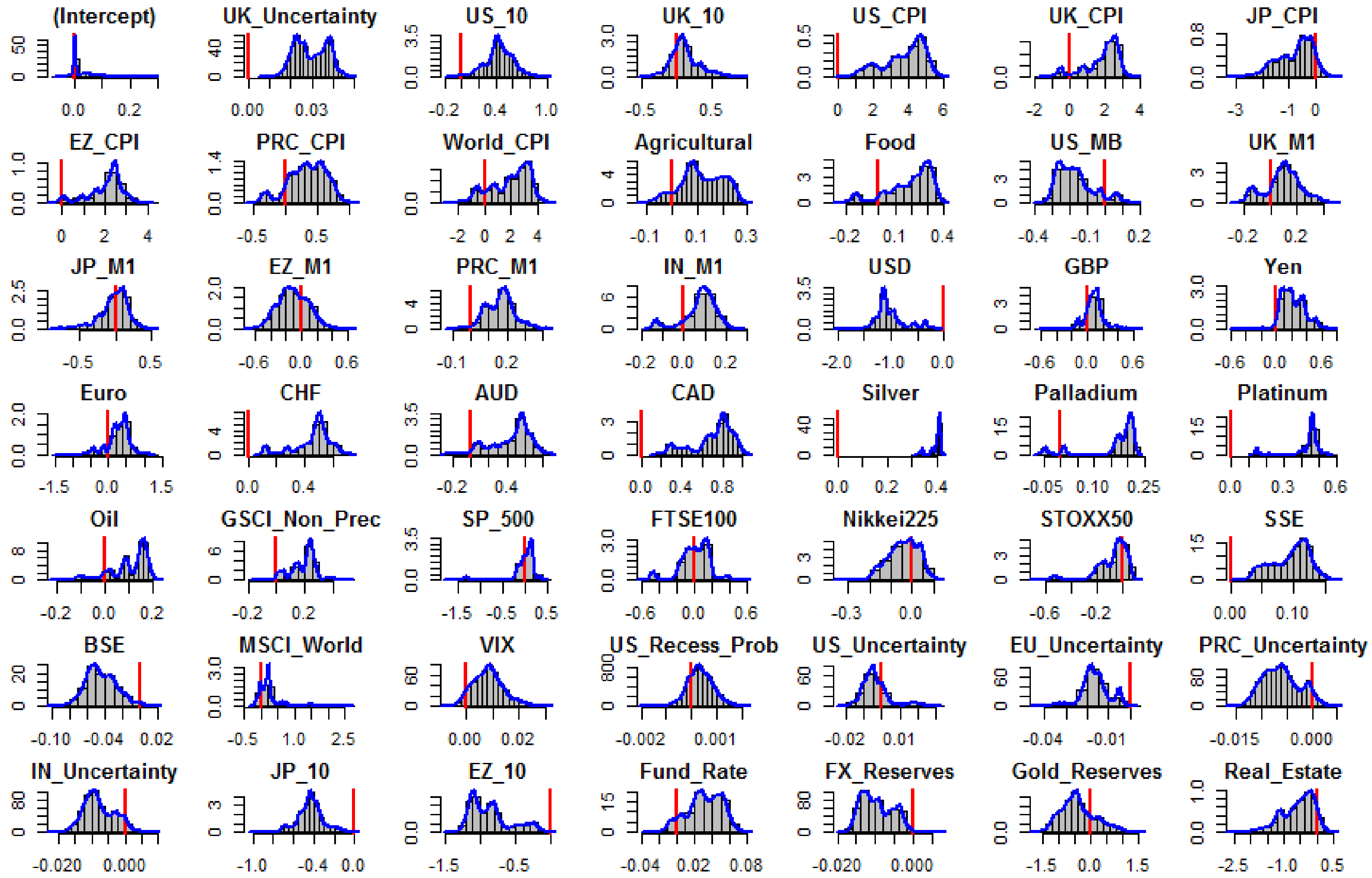
8.1.2.10 Model 10: Fixing Economic Indicators Identified in the Unconstrained Model

The unconstrained approach identified a significantly positive relationship between three economic indicators and the price of gold (Table O.3). Model 10 therefore fixes the UK economic uncertainty index, the US 10 year Government bond index and the UK 10 year Government bond index in order to get a better idea of the role and effect of the three economic indicators on the price of gold as the dependent variable and the bulk of other macroeconomic variables as the independent variables of the system. The regression results are displayed in Table 8.11 and in Figure 8.11.

Table 8.11: Sophisticated Extreme Bounds Analysis Results for Gold - Model 10: Fixing Economic Indicators Identified in the Unconstrained Model

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	21.563	78.437	Oil	focus	12.336	87.644
US_CPI**	focus	1.726	98.274	GSCI_Non_Prec*	focus	5.353	94.647
UK_CPI	focus	11.800	88.200	S&P_500	focus	39.705	60.295
JP_CPI	focus	70.618	29.382	FTSE100	focus	45.977	54.023
EZ_CPI*	focus	5.179	94.821	Nikkei225	focus	64.771	35.229
PRC_CPI	focus	31.515	68.485	STOXX50	focus	66.710	33.290
World_CPI	focus	19.084	80.916	SSE**	focus	3.543	96.457
Agricultural	focus	23.466	76.534	BSE	focus	77.811	22.189
Food	focus	14.172	85.828	MSCI_World	focus	20.358	79.642
US_MB	focus	85.545	14.455	VIX	focus	26.528	73.472
UK_M1	focus	40.899	59.101	US_Recess_Prob	focus	42.347	57.653
JP_M1	focus	51.130	48.870	US_Uncertainty	focus	62.777	37.223
EZ_M1	focus	57.657	42.346	UK_Uncertainty**	fixed	2.312	97.688
PRC_M1	focus	21.224	78.776	EU_Uncertainty*	focus	90.383	9.617
IN_M1	focus	36.523	63.477	PRC_Uncertainty	focus	75.618	24.382
USD***	focus	99.879	0.121	IN_Uncertainty	focus	79.267	20.733
GBP	focus	36.046	63.954	US_10	fixed	10.154	89.846
Yen	focus	15.476	84.524	UK_10	fixed	39.371	60.629
Euro	focus	19.941	80.059	JP_10	focus	82.811	17.189
CHF**	focus	2.105	97.895	EZ_10*	focus	94.232	5.768
AUD*	focus	5.023	94.977	Fund_Rate	focus	17.436	82.564
CAD***	focus	0.367	99.633	FX_Reserves	focus	82.948	17.052
Silver***	focus	0.000	100	Gold_Reserves	focus	60.012	39.988
Palladium*	focus	7.918	92.082	Real_Estate	focus	69.641	30.359
Platinum***	focus	0.011	99.989				

Figure 8.11: Sophisticated Extreme Bounds Analysis Results for Gold - Model 10: Fixing Economic Indicators Identified in the Unconstrained Model



8.1.2.10.1 99% Confidence Interval

An interesting result at the 99% confidence interval is the change in the second currency identified: the Swiss Franc was identified in the unconstrained model (Table O.3), while the Canadian Dollar is identified in Model 10 (Table 8.11). Several explanation can be brought forward from the switch observed between the two models; despite being an active and important player in both the demand and supply aspects of gold (Gold Field Mineral Services Ltd. (2016)), the effect of fixing US medium term debt increased the importance of the Canadian Dollar in the model because of the inter-linkages of the two economies. The other variables identified were the US Dollar, the price of silver and the price of platinum.

8.1.2.10.2 95% Confidence Interval

Both the US and the UK 10 year Government bond index drop out of the 95% confidence interval (Table O.3) and become insignificant in the new model specification (Table 8.11). This brings into question the true relationship between the series, as fixing the variables across all regressions uncovers a weaker relationship then discovered by a model assigning the same weight to each and every variable. In total, four variables are identified as significant at the 95% level in Model 10: the UK economic uncertainty index, the US CPI, the Swiss Franc, and the SSE composite index - all variables are positively associated with the price of gold.

8.1.2.10.3 90% Confidence Interval

At the 90% confidence interval, six variables are identified: the Eurozone CPI, the Australian Dollar, the price of palladium, the GSCI non-precious metal index, the EU economic uncertainty index, and finally, the Eurozone 10 year Government bond index. In comparison to the unconstrained model, two new significant variables are identified: the EU economic uncertainty index and the Eurozone 10 year Government bond index. So fixing a selection of three significant macroeconomic indicators for the state of the national economy in the US and the UK uncovers the importance of European indicators, previously deemed insignificant. The logical explanation is the strong linkage amongst the three economies, with the UK being part of Europe and therefore being a very component of the EU debt indicator. A conclusion to draw from fixing the three variables proposed is that the role of the European Union is indeed more important than initially believed, but also that Japan fails to be identified as an important player in a model exposed to

Government debt - the reader will note that even the usually very significant Yen index falls out of the significance window under the proposed model specifications.

8.1.2.10.4 Sign Shifts

Six variables switch signs moving from the unconstrained approach (Figure 8.1) to Model 10 (Figure 8.11): Japanese money supply, Eurozone money supply, the Pound Sterling, the US economic uncertainty index, the Japanese 10 year Government bond index, and finally, the Eurozone 10 year Government bond index. The effects on European and Japanese macroeconomic variables was previously discussed and a noteworthy observation is the negative relationship between gold and the two Government bond indices. Especially European countries were considered somehow unsafe investments during the time-window considered, explaining the hedging effect of gold against European and Japanese debt when fixing American and UK debt across all regressions. Fixing two UK specific economic uncertainty indicators leads to a positive relationship between gold and the Pound Sterling, underlining the safe haven aspects already channeled through the significant positive relationship with the UK economic uncertainty index. Interestingly, the relationship between the US economic uncertainty index and gold now seems to be mostly negative; however, economic uncertainty should weaken the Dollar which then strengthens the price of gold. The puzzling observation should however be seen in the light of a value far from statistical significance.

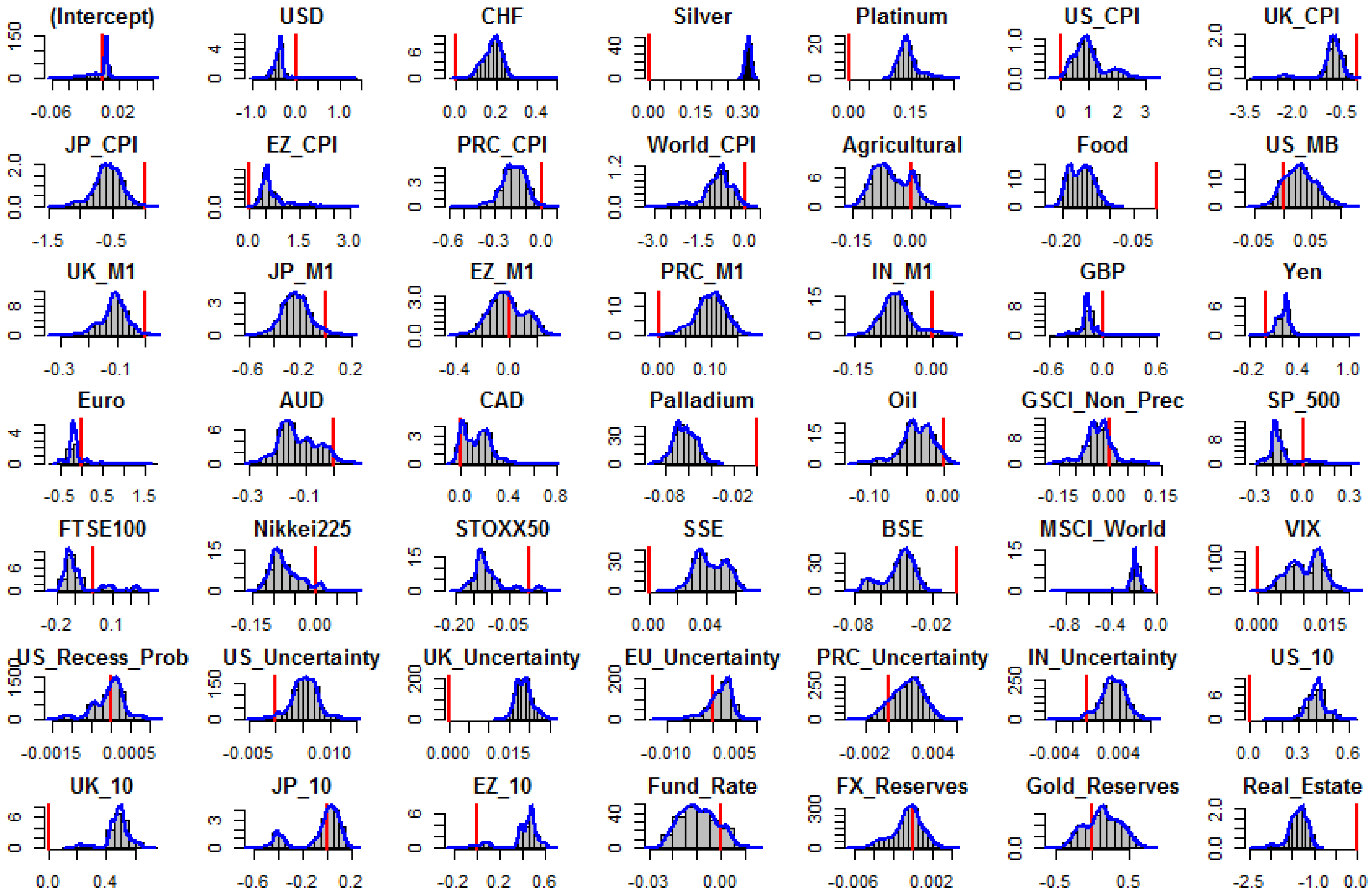
8.1.2.11 Model 11: Fixing the Variables Identified at the 99% Confidence Interval

In the last model, the variables identified as highly significant are fixed in order to run a robustness test on their true importance and see how it would affect the other variables in the system. In other words: the US Dollar, the Swiss Franc, the price of silver and the price of platinum are fixed in Model 11. Regression results are displayed in Table 8.12 and in Figure 8.12.

Table 8.12: Sophisticated Extreme Bounds Analysis Results for Gold - Model 11: Fixing the Variables Identified at the 99% Confidence Interval

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	33.575	66.425	Oil	focus	79.978	20.022
US_CPI	focus	17.381	82.619	GSCI_Non_Prec	focus	73.221	26.779
UK_CPI	focus	82.082	17.918	S&P_500*	focus	94.296	5.704
JP_CPI	focus	74.394	25.606	FTSE100	focus	80.059	19.941
EZ_CPI	focus	17.135	82.865	Nikkei225	focus	87.159	12.841
PRC_CPI	focus	65.921	34.079	STOXX50*	focus	91.803	8.197
World_CPI	focus	75.863	24.137	SSE*	focus	9.841	90.159
Agricultural	focus	68.141	31.859	BSE	focus	88.342	11.658
Food**	focus	95.903	4.097	MSCI_World**	focus	97.193	2.807
US_MB	focus	36.947	63.053	VIX	focus	11.597	88.403
UK_M1	focus	68.148	31.852	US_Recess_Prob	focus	50.996	49.004
JP_M1	focus	75.100	24.900	US_Uncertainty	focus	25.321	74.679
EZ_M1	focus	52.097	47.903	UK_Uncertainty**	focus	2.230	97.770
PRC_M1	focus	22.132	77.868	EU_Uncertainty	focus	39.875	60.125
IN_M1	focus	68.035	31.965	PRC_Uncertainty	focus	37.725	62.275
USD**	fixed	98.765	1.235	IN_Uncertainty	focus	28.027	71.973
GBP	focus	87.207	12.793	US_10**	focus	1.090	98.910
Yen	focus	5.442	94.558	UK_10**	focus	1.639	98.361
Euro	focus	79.497	20.503	JP_10	focus	54.466	45.534
CHF*	fixed	9.580	90.420	EZ_10*	focus	6.149	93.851
AUD	focus	82.815	17.185	Fund_Rate	focus	68.519	31.481
CAD	focus	24.061	75.939	FX_Reserves	focus	52.743	47.257
Silver***	fixed	0.000	100	Gold_Reserves	focus	44.664	55.336
Palladium*	focus	94.521	5.479	Real_Estate**	focus	97.503	2.497
Platinum***	fixed	0.613	99.387				

Figure 8.12: Sophisticated Extreme Bounds Analysis Results for Gold - Model 11: Fixing the Variables Identified at the 99% Confidence Interval



8.1.2.11.1 99% Confidence Interval

Fixing the variables previously identified as significant at the 99% level (Table O.3) allows to get a clearer picture of the variables believed to be explanatory. When fixing the four mentioned variables across all regressions, only the price of silver and the price of platinum appear to remain significant at the 99% confidence interval. A very valuable finding indicating that silver and platinum have a stronger association with the price of gold than the level of the US Dollar. A similar observation is made for the level of the Swiss Franc that is only significant at the 90% confidence interval in the new model. To conclude, given a set of four variables identified as explanatory in the unconstrained model, only the price of silver and the price of platinum remain significant when taking the four variables into account across all regressions. This is not exactly in line with Batten et al. (2015) who argue that gold and silver are relatively similar but are different from platinum and palladium. However, a formal examination of the drivers of silver, as provided later on in this chapter, will reveal how different gold and silver truly are from each other.

8.1.2.11.2 95% Confidence Interval

The US Dollar, the food price index, the MSCI World, the UK economic uncertainty index, the US 10 year Government bond index, the UK 10 year Government bond index, and finally, the S&P Case-Shiller National Home Price Index are identified by the 95% confidence interval. The negative relationship with global food prices is negative, akin to the luxury demand for gold, especially in countries like India or the Middle East, where indeed gold is used as a luxury good rather than as a bullion investment. It is however interesting to see that none of the official inflation indices is significant at any confidence level - inflationary pressure in the model seems to be channeled only through the food price index and nothing else. The UK economic uncertainty index and the American real estate index are more important influencers of the price of gold than suggested in peer academic literature. Arguments to explain this relationship were brought forward in this section, and to conclude, the most obvious reasons are the effect of the economic environment of the country that sets the official gold price on the one hand, and the plunge of real estate prices as the trigger of the recent financial crisis on the other. This finding opens new doors to large chunks of research, especially to what extent the price of gold is influenced by the sentiment in the United Kingdom rather than by international macroeconomic metrics.

8.1.2.11.3 90% Confidence Interval

Six variables are significant at the 90% confidence interval: the Swiss Franc, the price of palladium, the S&P 500 index, the Euro Stoxx 50, the SSE index, and finally, the Eurozone 10 year Government bond index. So in contrary to the unconstrained approach, which suggested that only the Chinese stock index would be significantly associated with the price of gold, the more sophisticated approach of Model 11 finds evidence for American and European equity prices to be negatively associated with the price of gold - akin to gold's hedging and safe haven capacities as formally presented in Baur and Lucey (2010) and Baur and McDermott (2010).

8.1.2.11.4 Sign Shifts

Comparing the unconstrained approach (Figure 8.1) with the new specifications in Model 11 (Figure 8.12) a sign shift for nearly all variables can be observed. The severe changes across the model can be explained by the complete different nature of the specifications, which indeed don't make a lot of sense *economically* but indeed *methodologically*. Previously presented model specifications were rooted in the *inflation* aspects of gold, or in gold's role as an *international currency*, fixing the respective variables. However, in Model 11, a completely different approach is taken and the variables identified as highly significant are fixed in order to understand their relationship with gold better. A robust result to take out of Model 11 is a stronger relationship between gold and both silver and platinum, rather than between gold and the US Dollar or the Swiss Franc. Offering a too thorough interpretation of the other results obtained in the specifications of Model 11 would likely make poor economic sense and lead to erroneous conclusions.

8.2 Silver

The literature review provided earlier on in this thesis uncovered that the studies undertook on silver are far greater in number than one might initially believe. However, an empirically agreed upon set of drivers and influencers of the silver price hasn't yet been provided. Furthermore, and in comparison to gold, while the investment side of silver is indeed important, the industrial nature of the white precious metal is undeniable. In light of the introduction of an ETF for silver in April 2006 (IShares (2016)) a shift in the drivers of silver is likely to have occurred over the years. In this section, millions of regressions are run following different model specifications, in order to understand which variables significantly influence the price of silver and which variables fail to do so.

8.2.1 An Unconstrained Extreme Bounds Analysis

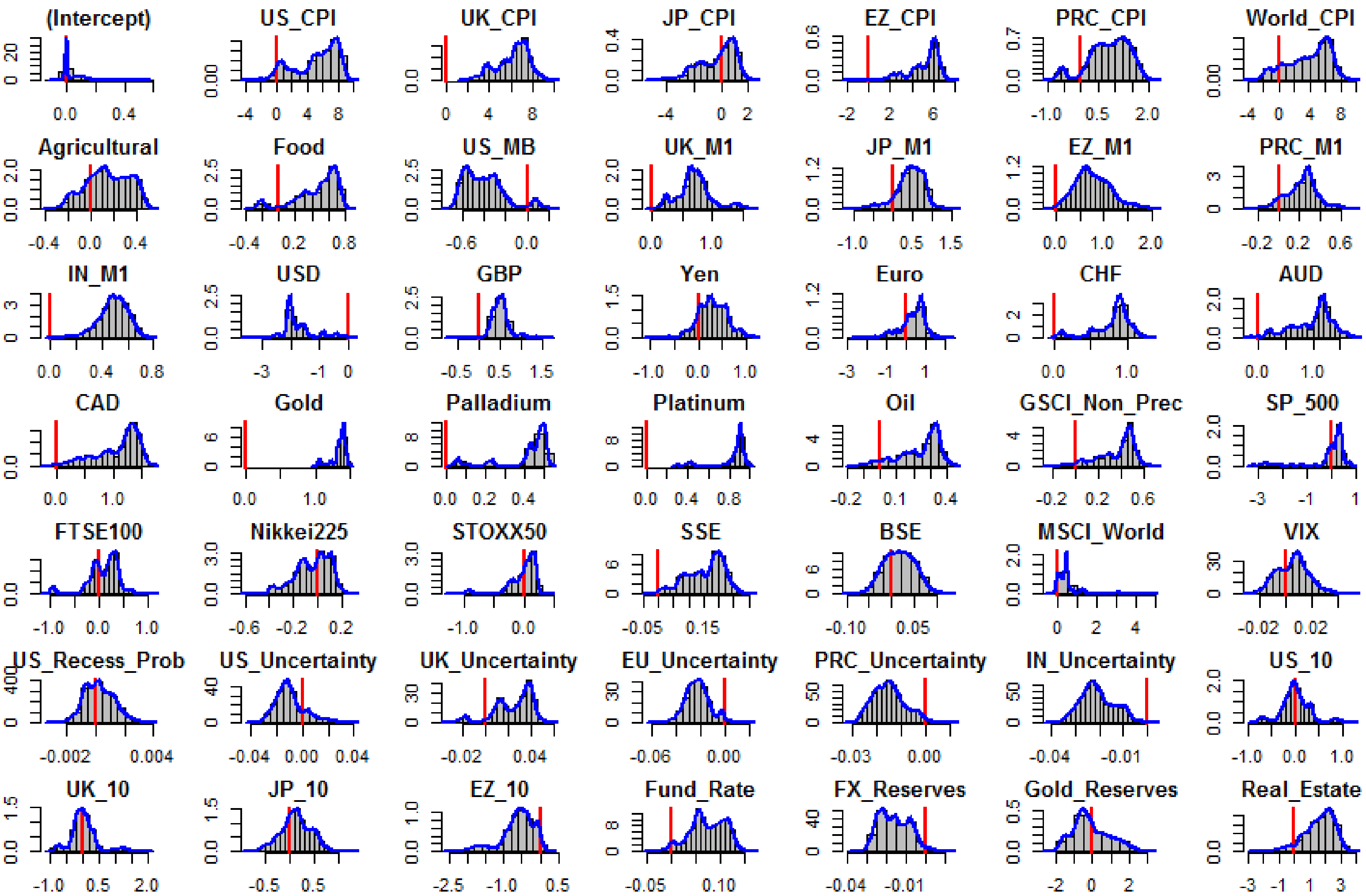
The first run follows a naive philosophical approach in which no variables are fixed and each macroeconomic indicator is allocated the same weighting as the others. Following the relevant literature in the Sala-I-Martin (1997) Extreme Bounds approach, the maximum amount of variables k per regression is fixed up to three.

The graphical results of the unconstrained model, underpinned by the formal Sala-I-Martin (1997) results can be found in Figure 8.13 and in Table 8.13.

Table 8.13: Naive Extreme Bounds Analysis Results for Silver

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	35.334	64.666	Oil*	focus	6.113	93.887
US_CPI*	focus	9.202	90.798	GSCI_Non_Prec**	focus	3.963	96.037
UK_CPI**	focus	1.123	98.877	S&P_500	focus	28.718	71.282
JP_CPI	focus	52.710	47.290	FTSE100	focus	35.699	64.301
EZ_CPI***	focus	0.988	99.012	Nikkei225	focus	55.740	44.260
PRC_CPI	focus	26.675	73.325	STOXX50	focus	45.487	54.513
World_CPI	focus	17.621	82.379	SSE*	focus	6.932	93.068
Agricultural	focus	31.920	68.080	BSE	focus	43.433	56.567
Food*	focus	8.823	91.177	MSCI_World	focus	10.621	89.379
US_MB	focus	91.250	8.750	VIX	focus	42.426	57.574
UK_M1	focus	15.585	84.415	US_Recess_Prob	focus	46.865	53.135
JP_M1	focus	31.753	68.247	US_Uncertainty	focus	67.407	32.593
EZ_M1	focus	23.973	76.027	UK_Uncertainty	focus	21.549	78.451
PRC_M1	focus	27.989	72.011	EU_Uncertainty	focus	84.118	15.882
IN_M1	focus	11.277	88.723	PRC_Uncertainty	focus	83.273	16.727
USD***	focus	99.157	0.843	IN_Uncertainty	focus	89.716	10.284
GBP	focus	11.388	88.612	US_10	focus	49.075	50.925
Yen	focus	22.985	77.015	UK_10	focus	49.887	50.113
Euro	focus	26.762	73.238	JP_10	focus	44.152	55.848
CHF**	focus	3.151	96.849	EZ_10	focus	82.201	17.799
AUD**	focus	1.680	98.320	Fund_Rate	focus	10.813	89.187
CAD**	focus	1.616	98.384	FX_Reserves	focus	80.282	19.718
Gold***	focus	0.000	100	Gold_Reserves	focus	51.750	48.250
Palladium**	focus	1.428	98.572	Real_Estate	focus	21.762	78.238
Platinum***	focus	0.001	99.999				

Figure 8.13: Naive Extreme Bounds Analysis Results for Silver



8.2.1.1 99% Confidence Interval

In light of the results provided in Table 8.13 and in Figure 8.13, mainly precious metals are found to be significantly associated with the price of silver. Indeed, all of the coefficients of gold are positively associated with the price of silver across all equation specifications computed. The exact same result was observed in the first part of this chapter, when fixing the price of gold as the dependent variable (Table O.3 and Figure 8.1). The very strong and significant positive relationship between a high price of silver and a high price of gold is in line with previous research. Using complex econometric specifications, Escribano and Granger (1998) argued for a positive long-run cointegration relationship between the two metals early on, though the data sample used by the authors dates back further than the data sample used in this study. Baur (2014) however extends the dataset considered and supports the findings of Escribano and Granger (1998), that a long-run positive relationship between the two metals exist. A positive relationship between gold and silver is also observed when considering futures intraday data, where Adrangi et al. (2000) find the relationship between the two metals to be bi-causal, while silver carries the burden for spread convergence. Trying to understand whether or not the positive relationship between gold and silver is stable through time, Lucey and Tully (2006a) consider a time-varying cointegration framework between January 1978 and November 2002 and find evidence that while the mentioned relationship is positive on average, there was a break in the relationship during the 1990's; hence explaining the results observed by Ciner (2001) who argues that gold and silver are not cointegrated while considering only a short time-window ranging from 1992 to 1998.

The relationship between silver and platinum is very strong, where 99.999% of the regressors are positively associated with the price of silver (Table 8.13). While the amount of research on the relationship between silver and platinum is not very high, previous research tends to agree with the finding, that silver and platinum have a positive long-run relationship. Charlot and Marimoutou (2014) consider data between 2005 and 2012, similar to our time window, and find that there is a high correlation of 0.74 between the returns of the two white precious metals. Considering daily convenience yields of all four precious metals between 1996 and 2010, Chng and Foster (2012) support the substantial interaction between silver and platinum, while providing formal evidence that these interactions changed over time.

The third most significant variable to be associated with silver is the US Dollar, where 99.157% of the regressors have a negative relationship with the price of silver; in other words, a strong US Dollar pushes down the price of silver. Given that the official price of silver is quoted in US Dollars, a significant relationship is expected; for the case of gold, Tully and Lucey (2007) argued that the Dollar is the single most important factor to determine the price of the yellow metal. O'Connor et al. (2015) argue that a weak Dollar makes it cheaper for other countries to purchase the metal which then drives up the price of the metal explaining the negative relationship - a similar argumentation could be drawn for silver. More formally, Sari et al. (2010) and Balcilar et al. (2015) investigate the relationship between the US Dollar/Euro exchange rate and find evidence for information transmission between the currencies and silver.

The last variable identified as significant at the 99% confidence level is the Eurozone CPI, where 99.012% of the regressors are positively associated with the price of silver: higher inflation in Europe is linked with a higher price of silver. A positive relationship between silver and inflation can be expected in the light of both, silver as an international currency and an industrial asset. If silver is considered to be international currency, which up until the 20^{th} century it was, then an increase in expected inflation should lead to investors driving down their cash holding to invest in silver, ultimately pushing the prices upwards. On the other hand, if silver is considered to be a regular commodity needed as an input for production, its price should rise alongside the prices of any other regular asset for that is the very definition of inflation (Jaffe (1989)). Culturally speaking, silver indeed has a record as a perceived attractive investment in Europe (The Silver Institute (2016)) while on the other hand, a strong and steady industrial demand for silver coming from Eurozone countries was recorded over the past years (The Silver Institute (2014)). More formally, Apergis (2014) is one of the few papers to offer an exposure into the relationship between silver prices and inflation rates of Eurozone countries by pooling together the inflation rates of G7 Nations. However, the authors observe a negative impact of inflation on silver prices - results contrary to our findings. The significant relationship between silver prices and inflation in the Eurrozone significantly contributes to the research on the drivers of silver as very few papers, if any, considered frameworks in which silver price movements were identified by considering CPI rates in Continental Europe.

8.2.1.2 95% Confidence Interval

Six variables are identified at the 95% confidence interval, amongst which an additional European inflation rate, three currencies and two metal price variables.

The positive relationship between the UK CPI and the price of silver should be considered in light of the framework provided earlier on for Eurozone inflation. While the demand for silver originating from the United Kingdom was falling over the past 12 years, the aggregated demand still remains relatively high in comparison to other countries (The Silver Institute (2014)). Bampinas and Panagiotidis (2015) formally investigate the relationship between silver prices and inflation in the United Kingdom by looking at annual data between 1791 and 2010 in a time-varying fashion. While a linear cointegration relationship fails to exist, a strong long-run relationship is identified between silver and the UK CPI in a time-varying framework.

Regarding the strong relationship identified between silver and non US Dollar currencies, the amount of research undertook in that field is fairly small. With 96.849% of all regressors positively associated with silver, the Swiss Franc is far from being a negligible macroeconomic influencer of the silver price. Within a VAR-framework consisting of multiple commodities and currencies, Antonakakis and Kizys (2015) identify the Swiss Franc as the largest volatility transmitter to commodities, amongst which silver. The positive relationship between silver and both the Australian and Canadian Dollar, with 98.320% and 98.384% of the regressors positively associated with the white precious metal respectively, need again be considered under the light of the two countries' importance as producers of silver (The Silver Institute (2014)). Indeed, Chen and Rogoff (2003) argue that the US Dollar price of commodity exports in Australia and Canada influence the Nations exchange rate, hence strengthening the currency when the silver price rises. Clements and Fry (2008) find that the opposite relationship also exists, whereby the exchange rate of metal exporting countries influence the price of the metal. Focusing on gold as a proxy for Australian precious metal exports, Cashin et al. (2004) strengthen the case of the Australian Dollar to be considered a *commodity currency* because real exchange rates are cointegrated with commodity prices; unfortunately, the authors don't formally test the relationship between precious metal prices and exchange rates in Canada.

Out of all precious metals, palladium has the weakest significant relationship with the price of silver: where 98.572% of the regressors are positively associated with silver. Being the most industrial of the four precious metals, the positive relationship is likely to be driven by the industrial nature of silver more than by silver's virtue as an international currency. Chng and Foster (2012) find palladium to have the least cross-market influences of all four precious metals, while still influencing the convenience yield of silver - results in line with the findings in Table 8.13, where the relationship for gold and platinum is found to be stronger. Batten et al. (2015) support this finding and argues that the spillovers of both return and volatility are the weakest coming from palladium in comparison to the other three precious metals.

In light of palladium exemplifying the industrial nature of the silver price, the positive relationship between silver and the GSCI Non-precious metal index is another argument for the importance of the white precious metal as an input for industrial production. A basic framework would be that a good economic environment would act beneficially on industrial production and hence push up both the demand for non-precious metals and for silver, therefore pushing up their prices.

8.2.1.3 90% Confidence Interval

At the 90% confidence interval, the following variables are identified as statistically significant: the US CPI, the food price index, the price of oil, and finally, the Shanghai Stock Exchange Index.

Early results about the relationship between silver and inflation in the United States of America are provided by Taylor (1998) who find that silver was both a long-run and a short-run inflation hedge between January 1914 and April 1996. Results supported by Adrangi et al. (2003) who apply a different methodology but come to the same conclusion: silver is a hedge against American inflation in both the long-run and the short-run. More recently however, Bampinas and Panagiotidis (2015) enlarge the dataset considered and work with annual inflation rates between 1791 and 2010 to conclude that silver failed to be an inflation hedge, independent of the model specification considered - results suggesting that silver only became an inflation hedge in more modern times.

The positive relationship between the food price index and silver prices is puzzling in the light that the two goods should have a negative relationship: where the demand for silver falls in a scenario in which more funds need to be allocated to food. A reasonable explanation can only be provided when considering the food price index a proxy for inflation - akin to an alleged inflation hedging potential of silver on a more global scale, though this relationship was not element of previous research.

93.887% of oil's regressors are positively associated with oil - further evidence of the industrial importance of the white precious metal. Surprisingly though, some previous researchers found the relationship between oil and silver to be positive, such as Bhar and Hammoudeh (2011) considering weekly data from January 1990 to May 2006; results somehow supported by Charlot and Marimoutou (2014) who find the relationship between oil and silver to be weak though it strengthened around 2009. Recently however, Bildirici and Türkmen (2015a) consider monthly data between 1973 and 2012 and find that indeed, a positive long-run relationship between silver and oil can be observed, where a 1% price increase in oil results in a 1.33% price increase in silver.

The last variable identified as statistically significant is the level of the SSE, China's most prominent stock price index. Considering the similarity between gold and silver, one might expect silver to be able to function as a hedge against equity prices (Baur and Lucey (2010) and Lucey and Li (2015)), though this would entail a negative relationship between the two variables. The positive relationship between silver prices and equity prices in China is more likely reflecting both the industrial importance of the metal, that saw its demand rise in the past decade, along a rising industry in China and rising equity prices. The consumer demand aspects of silver in China are also rising along a strengthening economy and an increase in national wealth, pushing upwards the demand for luxury assets containing silver.

8.2.2 More Sophisticated Extreme Bound Analyses

In light of the result of an open approach in Table 8.13 and Figure 8.13, new model specifications can be useful to shed more light on the importance of certain macroeconomic drivers in given scenarios. Sophisticated model specifications are especially useful in the light that there is an open debate, as well as a shift, about silver evolving from an industrial asset to an investment asset over the past decades. Furthermore, there is an ongoing debate about the philosophical aspects of silver: international currency or mere commodity? In this section, different model specifications are proposed based on previous academic work and argumentation in order to offer a robustness analysis of the findings of the unconstrained model provided above.

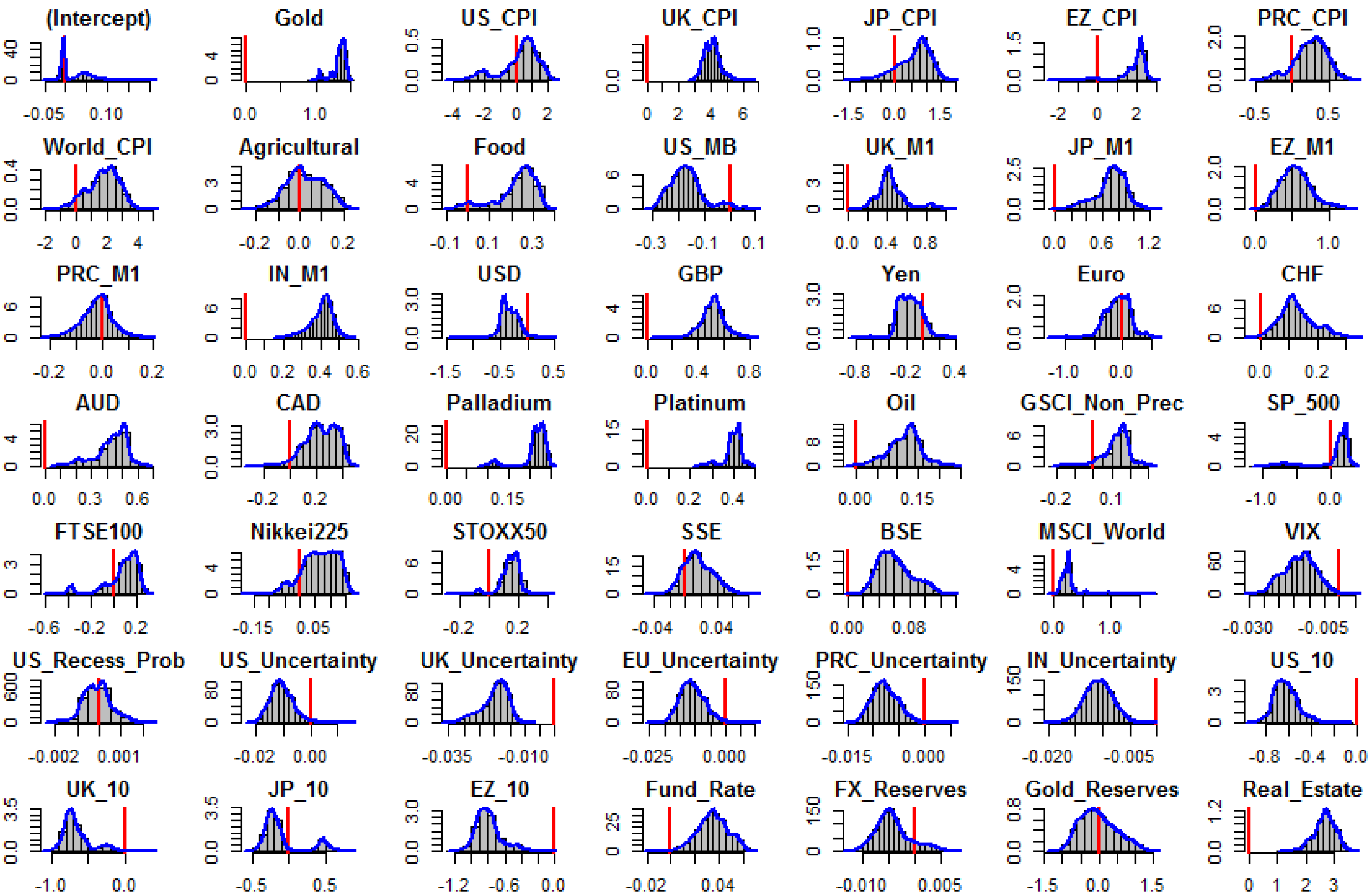
8.2.2.1 Model 1: Fixing Gold

The relationship between silver and gold was identified as highly significant, where 100% of the regressors have a positive relationship with the white precious metal. Building upon the argumentation of O'Connor et al. (2015) whereby the two metals can be considered substitutes for one another, the first model fixes the price of gold across every regression to identify which variables remain explanatory under the new specifications and which variables fail to be. Results of the density distribution are displayed in Table 8.14 and in Figure 8.14.

Table 8.14: Sophisticated Extreme Bounds Analysis Results for Silver - Model 1: Fixing Gold

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	54.698	45.302	Oil*	focus	6.005	93.995
US_CPI	focus	41.649	58.351	GSCI_Non_Prec	focus	10.487	89.513
UK_CPI***	focus	0.440	99.560	S&P_500	focus	16.443	83.557
JP_CPI	focus	35.314	64.686	FTSE100	focus	29.016	70.984
EZ_CPI*	focus	8.600	91.400	Nikkei225	focus	27.129	72.871
PRC_CPI	focus	37.924	62.076	STOXX50	focus	13.048	86.952
World_CPI	focus	22.719	77.281	SSE	focus	39.635	60.365
Agricultural	focus	44.549	55.451	BSE	focus	19.734	80.266
Food	focus	10.267	89.733	MSCI_World*	focus	5.278	94.722
US_MB	focus	84.583	15.417	VIX	focus	79.424	20.576
UK_M1	focus	16.437	83.563	US_Recess_Prob	focus	51.687	48.313
JP_M1	focus	12.904	87.096	US_Uncertainty	focus	76.374	23.626
EZ_M1	focus	22.641	77.359	UK_Uncertainty	focus	86.209	13.791
PRC_M1	focus	52.946	47.054	EU_Uncertainty	focus	77.922	22.078
IN_M1*	focus	6.727	93.273	PRC_Uncertainty	focus	78.307	21.693
USD	focus	84.261	15.739	IN_Uncertainty	focus	84.696	15.304
GBP**	focus	2.956	97.044	US_10**	focus	98.103	1.897
Yen	focus	73.525	26.475	UK_10**	focus	95.106	4.894
Euro	focus	58.026	41.974	JP_10	focus	58.287	41.713
CHF	focus	30.853	69.147	EZ_10**	focus	97.420	2.580
AUD**	focus	2.905	97.095	Fund_Rate	focus	16.653	83.347
CAD	focus	17.077	82.923	FX_Reserves	focus	64.380	35.620
Gold***	fixed	0.000	100	Gold_Reserves	focus	50.559	49.441
Palladium***	focus	0.328	99.672	Real_Estate**	focus	2.158	97.842
Platinum***	focus	0.034	99.966				

Figure 8.14: Sophisticated Extreme Bounds Analysis Results for Silver - Model 1: Fixing Gold



8.2.2.1.1 99% Confidence Interval

Results in Table 8.14 suggest that the following variables are associated with silver at the 99% confidence interval: the UK CPI and the prices of gold, platinum and palladium. In comparison to the naive approach in Table 8.13, the US Dollar drops out of the 99% confidence interval and becomes insignificant, while the UK CPI increases in significance. The positive relationship between silver and the UK CPI is in line with the findings of Bampinas and Panagiotidis (2015), who also argue that gold was an inflation hedge against British inflation between 1791 and 2010. Fixing gold as another variable positively associated with the UK CPI therefore increases the statistical significance of the British inflation index. Explanations for the positive relationship between silver and the other three precious metals were provided earlier and it is no surprise, that gold, platinum and palladium remain significant at the 99% confidence interval under the new model specifications. Very interestingly, the US Dollar drops out as a significant variable and becomes insignificant in a model fixing gold across all regressions. While previous argumentation discussed the importance of the American currency, it seems that fixing the two main precious metals is detrimental to the US Dollar; probably deleting out the *dollar effect* under multicollinearity issues around fixing silver and gold. However, in a previous sophisticated Extreme Bound analysis, where the price of silver was fixed while the price of gold was the dependent variable (see Table 8.2 and Figure 8.2) the US Dollar remained significant at the 99% confidence interval; an indication that the level of the American national currency is more important in making the price of gold then in making the price of silver.

8.2.2.1.2 95% Confidence Interval

At the 95% confidence level, the following variables are identified as statistically significant: the pound sterling, the Australian Dollar, the US 10 year Government bond index, the UK 10 year Government bond index, the Eurozone 10 year Government bond index, and finally, the S&P Case-Shiller National Home Price Index. Akin on the previous *commodity currency* discussion, only the Australian Dollar remains significant while the Canadian Dollar drops out of the significance interval. Indeed, Australia is by far the more important producer of both gold and silver[1], explaining why the currency remains significant while the Canadian currency

[1]For figures refer to Gold Field Mineral Services Ltd. (2016) and The Silver Institute (2016).

doesn't; not surprisingly, results in Figure 8.14 suggest a strong Australian Dollar in light of strong silver and gold prices. The appearance of the pound sterling is interesting and should be understood in the light of the importance of the country on both the silver and the gold market. As argued above, given that the LBMA fixes the official prices, a relationship with macroeconomic determinants in the country should not come as a big surprise. Furthermore, while the UK is not an important player on both the supply and demand market of silver, more than 60% of global silver ETFs are vaulted in the UK (The Silver Institute (2016)) probably explaining the relationship observed between the currency and the silver price. The negative relationship observed for three national debt measures, in the USA, the UK and the Eurozone, are pointing towards the somewhat more speculative nature of silver in comparison to gold. While a positive relationship usually exists between gold and debt (Figure 8.1), the negative relationship in Model 1 points towards the safe haven attributes of gold, rising alongside Government bond prices in periods of financial turmoil. Silver on the other hand, being the more speculative metal of the two, is ill-favoured during economic downturns to the benefit of gold, explaining the negative relationship observed. 97.842% of the *Real Estate* regressors are positively associated with the price of silver in a model fixing the price of gold across all regressions - results contrary to those in Table 8.2, fixing silver in a model explaining the price of gold, and where the relationship with American real estate prices was found to be negative. The argument here again is the more speculative nature of silver in direct comparison to gold, where the price of gold offered protection against falling house prices during the recent financial crisis. Silver on the other hand, as the more speculative asset of the two, saw it's price rise alongside house prices in the US, offering limited hedging potential against falling mortgage quality.

8.2.2.1.3 90% Confidence Interval

The following variables are identified at the 90% significance level: the Eurozone CPI, Indian money supply, the price of oil, and finally, the MSCI World equity index. In light of a less important Eurozone CPI rate for gold than for silver (Tables O.3 and 8.13), the weakening importance of the variable in a model fixing gold is not very suprising. More interestingly though, the appearance of Indian money supply as an explanatory variable is calling for an investigation into the relationship between silver and gold and the Indian currency. While only few articles, such as Jain and Ghosh (2013), consider Rupee/US Dollar exchange rates as a variable influencing the price of silver, no research was undertook on the formal relationship between the Rupee and silver, or gold, while India is by far one of the most important demanders of the two precious metals. The positive relationship between silver and oil remains in the new model specification and is akin, as previously argued, to the industrial aspects of silver. The MSCI Global equity index is positively associated with silver, meaning that the price of silver is high when global equity prices are high. This relationship should be understood in the light of silver as an industrial production factor and somehow questions the findings of Lucey and Li (2015) though the contrary relationship observed in Model 1 might be due to the law of averages and would be different if the precious metal is compared to individual equity indices.

8.2.2.1.4 Sign Shifts

Fixing the price of gold across all regressions led to a shift in the distribution of certain variables, namely: the Chinese monetary base, the Yen, the BSE, the VIX, and finally, the American, British and Japanese 10 year Government bond indices. The regressors of Chinese money supply seem evenly distributed under the new specifications, while the Yen is now mostly negatively associated with silver. While both countries are indeed important players on the demand side, an explanation for the distribution would be of limited use as the relationship is far from being significant. The positive relationship observed for the BSE is akin to the perception of both gold and silver as luxury assets in India, explaining why a higher demand would be linked to a higher value of national equity and therefore a greater level of national wealth. The negative relationship with the VIX is interesting in light of silver as a hedge and a safe haven during financial turmoils (Lucey and Li (2015)) - an explanation for the negative relationship between silver and national debt prices was provided above.

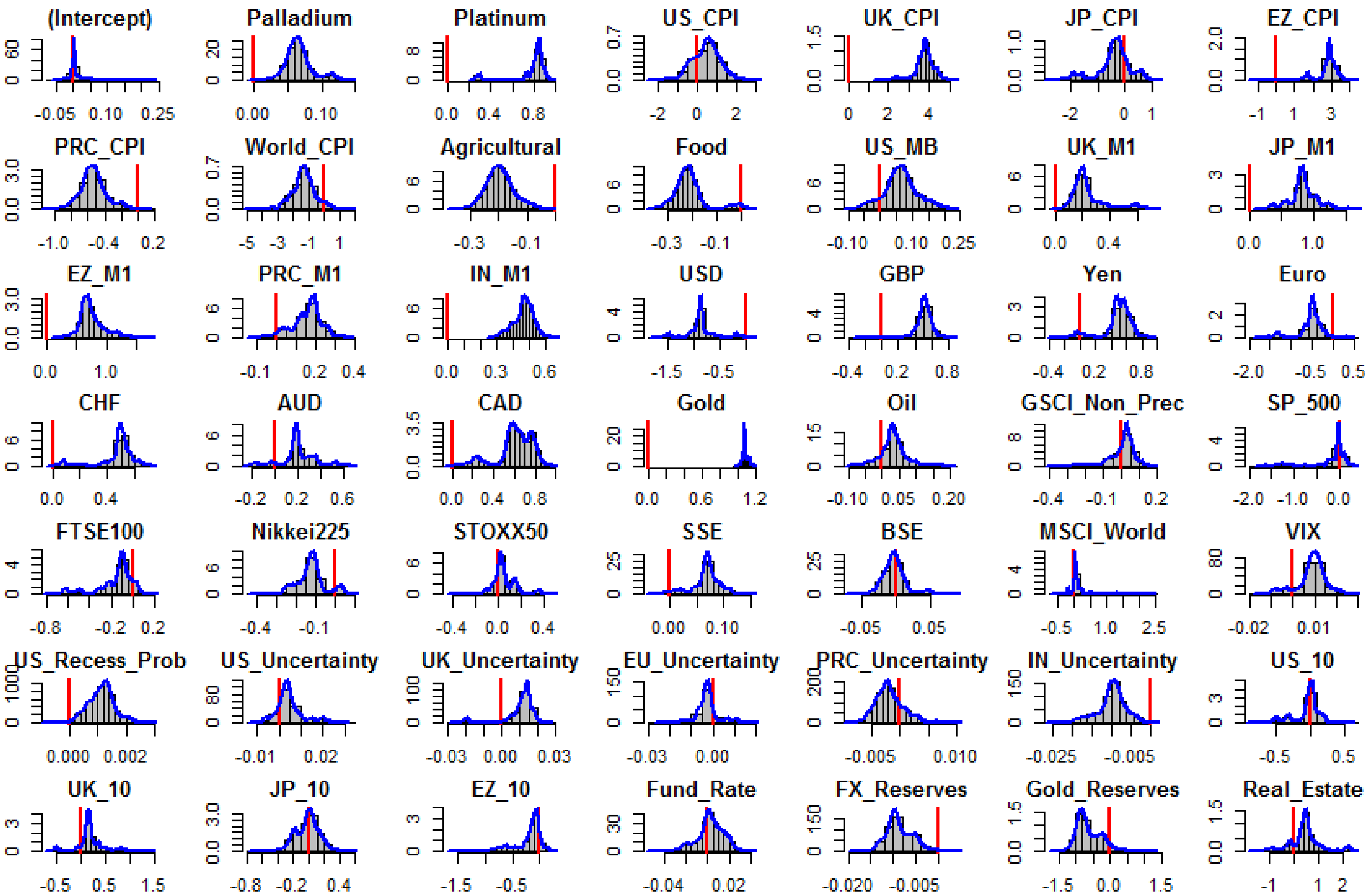
8.2.2.2 Model 2: Fixing White Precious Metals

In a fashion similar to Model 1, the prices of platinum and palladium are fixed across all regressions in order to give the model an exposure to white precious metals. Indeed, both Chng and Foster (2012) and Charlot and Marimoutou (2014) argue for the important linkages between silver and platinum while Batten et al. (2015) argue that even though return and volatility spillovers originate from palladium to silver, these spillovers are weaker than those originating from platinum. The Sala-I-Martin (1997) regression results for Model 2 are displayed in Table 8.15 and Figure 8.15.

Table 8.15: Sophisticated Extreme Bounds Analysis Results for Silver - Model 2: Fixing White Precious Metals

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	40.151	59.849	Oil	focus	36.181	63.819
US_CPI	focus	41.779	58.221	GSCI_Non_Prec	focus	43.156	56.844
UK_CPI**	focus	2.204	97.796	S&P_500	focus	58.665	41.335
JP_CPI	focus	57.678	42.322	FTSE100	focus	73.535	26.465
EZ_CPI**	focus	3.326	96.647	Nikkei225	focus	82.102	17.898
PRC_CPI	focus	70.882	29.118	STOXX50	focus	38.108	61.892
World_CPI	focus	68.460	31.540	SSE	focus	18.091	81.909
Agricultural	focus	82.123	17.877	BSE	focus	50.299	49.701
Food	focus	84.674	15.326	MSCI_World	focus	33.710	66.290
US_MB	focus	37.493	62.507	VIX	focus	32.690	67.310
UK_M1	focus	32.906	67.094	US_Recess_Prob	focus	33.338	66.662
JP_M1	focus	12.797	87.203	US_Uncertainty	focus	40.519	59.481
EZ_M1	focus	18.750	81.250	UK_Uncertainty	focus	31.842	68.158
PRC_M1	focus	29.753	70.247	EU_Uncertainty	focus	55.993	44.007
IN_M1*	focus	7.146	92.854	PRC_Uncertainty	focus	56.206	43.794
USD**	focus	97.733	2.267	IN_Uncertainty	focus	78.253	21.747
GBP*	focus	5.391	94.609	US_10	focus	53.993	46.007
Yen**	focus	4.686	95.314	UK_10	focus	33.514	66.486
Euro	focus	88.938	11.062	JP_10	focus	50.939	49.061
CHF*	focus	6.079	93.921	EZ_10	focus	64.969	35.031
AUD	focus	22.812	77.188	Fund_Rate	focus	47.282	52.718
CAD**	focus	2.589	97.411	FX_Reserves	focus	73.187	26.813
Gold***	focus	0.000	100	Gold_Reserves	focus	60.303	39.697
Palladium	fixed	22.181	77.819	Real_Estate	focus	38.595	61.405
Platinum***	fixed	0.056	99.944				

Figure 8.15: Sophisticated Extreme Bounds Analysis Results for Silver - Model 2: Fixing White Precious Metals



8.2.2.2.1 99% Confidence Interval

Under the new model specifications, only two variables are identified at the 99% confidence interval: gold and platinum. The fact that palladium dropped out of the confidence interval and now isn't a significant variable any longer is evidence for platinum's more important role in making the silver price than palladium; an argumentation in line with Batten et al. (2015). Indeed, results suggest that gold and platinum, in that order, are the most important influencers of the price of gold.

8.2.2.2.2 95% Confidence Interval

At the 95% confidence interval, the following variables are significant: the UK CPI, the Eurozone CPI, the US Dollar, the Yen, and finally, the Canadian Dollar. The two inflation measures identified were already discussed above and shall not be part of this analysis. Interestingly, the US Dollar remains significant in a model fixing platinum and palladium while it disappeared in a model fixing the price of gold (Table 8.14). This is evidence for gold being the main messenger of the *dollar effect*, hence deleting out the currency variable when the yellow metal is fixed across all regressions. So while the argumentation of Tully and Lucey (2007) holds for gold, that the US Dollar is the single most influencing variable of the price, this does not seem to be true for white precious metals. The Canadian Dollar is significant at the 95% confidence level while the Australian Dollar fails to be significant in the Model 2 specifications. The reason here is the importance of Canada as a producing country of platinum and palladium in contrary to Australia[2], arguments in favour of the *commodity currency* discussion provided earlier on. Furthermore, the Japanese Yen appears to be significant at the 95% confidence level, even though it failed to be so far. The reason here is the important demand for platinum and palladium coming from Japan in order to satisfy the extremely large automobile industry of the Asian country.

8.2.2.2.3 90% Confidence Interval

Only three variables are identified at the 90% confidence level: Indian money supply, the pound sterling and the Swiss Franc. While the importance of all variables has been discussed earlier, it should be noted that London and Zürich are the two most important markets for platinum and palladium, evidence in favour of the observed

[2]Facts and figures can be found in Gold Field Mineral Services Ltd. (2015).

positive relationship between silver and the two currencies in a model fixing white precious metals.

8.2.2.2.4 Sign Shifts

Nine variables change their distribution in Model 2 (Figure 8.15) compared to the unconstrained Model (Figure 8.13): the Japanese CPI, the Chinese CPI, the Global CPI, the Agricultural and Raw Material price Index, the Food price index, the Euro, the FTSE 100, and finally, the US Economic uncertainty index. The overwhelming amount of inflation indicators that changed signs is illustrating the new dynamics of the model that is now consisting of two very industrial metals: platinum and palladium. So while silver was positively influenced by inflation, it seems that the dynamics change following new parameters in which more industrial precious metals are added into the equation. However, just like what is observed for the Euro, the FTSE 100 and US Economic uncertainty, these results should be take with a grain of salt as none of the variables are identified as statistically significant; no empirical inferences should therefore be drawn from these observations.

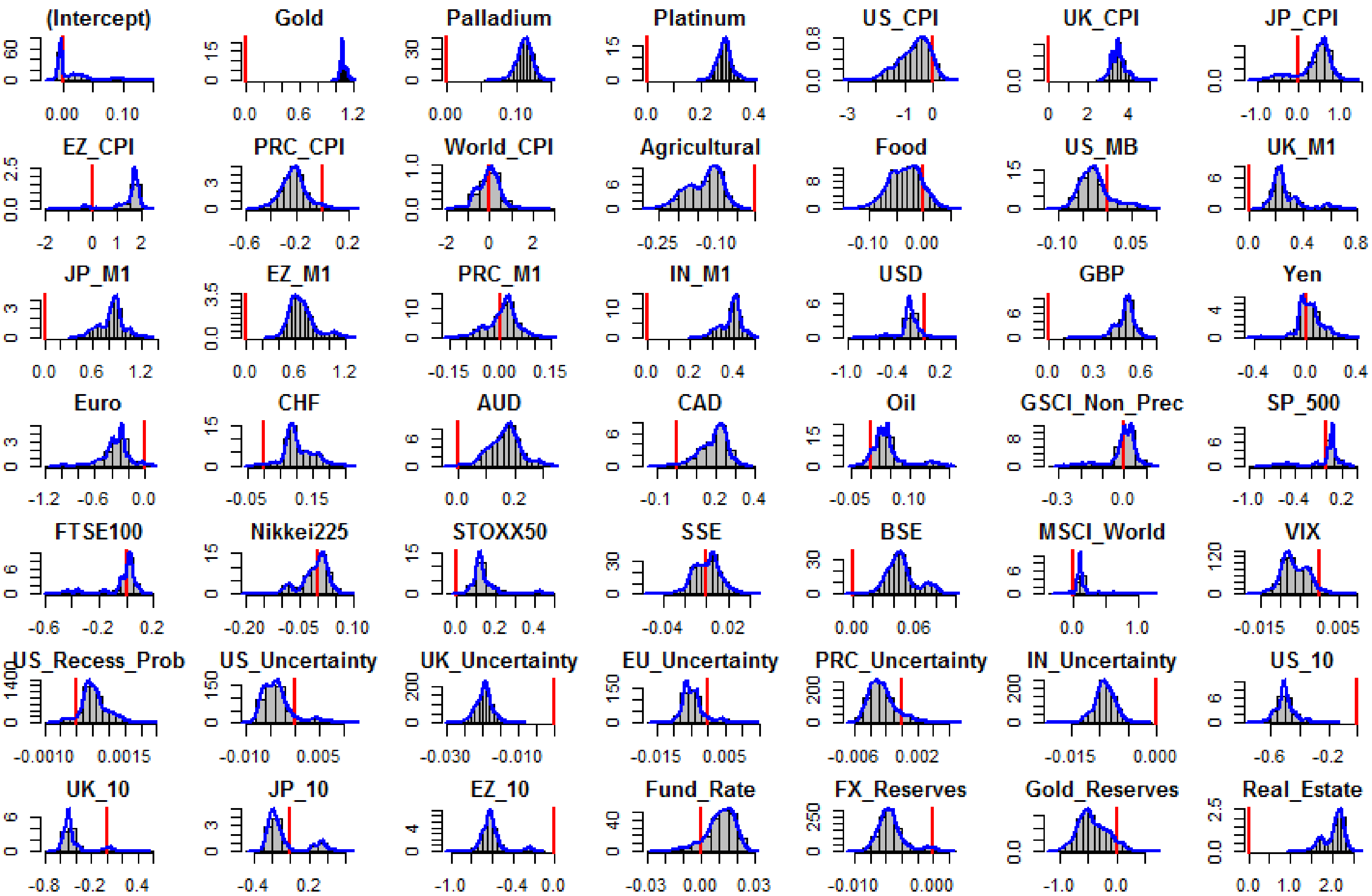
8.2.2.3 Model 3: Fixing all Precious Metals

This model specification is merely proposed to reconcile the findings of Model 1 and Model 2. In the specifications of Model 3, gold, platinum and palladium are fixed across all regressions and will therefore appear in each and every equation run by the system. Regression results are displayed in Table 8.16 and in Figure 8.16.

Table 8.16: Sophisticated Extreme Bounds Analysis Results for Silver - Model 3: Fixing all Precious Metals

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	55.206	44.794	Oil	focus	29.676	70.324
US_CPI	focus	64.163	35.837	GSCI_Non_Prec	focus	45.778	54.222
UK_CPI***	focus	0.816	99.184	S&P_500	focus	34.238	65.762
JP_CPI	focus	39.669	60.331	FTSE100	focus	52.740	47.260
EZ_CPI	focus	10.952	89.048	Nikkei225	focus	52.406	47.594
PRC_CPI	focus	61.342	38.658	STOXX50	focus	11.374	88.626
World_CPI	focus	50.617	49.383	SSE	focus	49.682	50.318
Agricultural	focus	77.742	22.258	BSE	focus	23.777	76.223
Food	focus	58.166	41.834	MSCI_World	focus	19.752	80.248
US_MB	focus	56.750	43.250	VIX	focus	66.083	33.917
UK_M1	focus	26.744	73.256	US_Recess_Prob	focus	39.914	60.086
JP_M1*	focus	7.895	92.105	US_Uncertainty	focus	60.590	39.410
EZ_M1	focus	16.161	83.839	UK_Uncertainty	focus	87.565	12.435
PRC_M1	focus	48.758	51.242	EU_Uncertainty	focus	63.213	36.787
IN_M1*	focus	6.423	93.577	PRC_Uncertainty	focus	60.858	39.142
USD	focus	74.391	25.609	IN_Uncertainty	focus	82.267	17.733
GBP**	focus	2.411	97.589	US_10**	focus	97.135	2.865
Yen	focus	44.284	55.716	UK_10	focus	89.407	10.593
Euro	focus	85.827	14.173	JP_10	focus	57.081	42.919
CHF	focus	32.794	67.206	EZ_10**	focus	95.742	4.258
AUD	focus	20.896	79.104	Fund_Rate	focus	37.348	62.652
CAD	focus	19.687	80.313	FX_Reserves	focus	68.644	31.356
Gold***	fixed	0.000	100	Gold_Reserves	focus	58.787	41.213
Palladium*	fixed	5.567	94.433	Real_Estate**	focus	4.918	95.082
Platinum***	fixed	0.788	99.212				

Figure 8.16: Sophisticated Extreme Bounds Analysis Results for Silver - Model 3: Fixing all Precious Metals



8.2.2.3.1 99% Confidence Interval

The price of gold and platinum as well as the UK CPI are identified as significant at the 99% confidence interval. The weaker significance level identified for palladium in comparison to gold and platinum is in line with the argumentation of Batten et al. (2015) discussed above. The UK CPI being associated with silver at the 99% confidence interval is further evidence for the importance exercised by British inflation on the silver price and so far the inflation series was always identified as statistically significant, while a discussion and explanation on why that is was provided in earlier parts of this chapter.

8.2.2.3.2 95% Confidence Interval

The pound sterling and the S&P Case-Shiller National Home Price Index, as well as the American and the Eurozone 10 year Government bond index are identified as significant at the 95% confidence interval. The importance exercised by the United Kingdom on the silver market, not only originating the price series but also holding 60% of global silver ETFs, is channeled through the level of the British currency, findings in line with Models 1 and 2 (Tables 8.14 and 8.15). The three other variables seem to reappear because gold was fixed across all equations (see Tables 8.14 and 8.16), akin to the more speculative nature of silver in comparison to gold when the yellow metal is fixed as an explanatory variable in the model.

8.2.2.3.3 90% Confidence Interval

The last three variables identified as significant are the price of palladium and both the Japanese and Indian monetary base. It is interesting to see that the Japanese monetary base appears to be significant in a model specification in which all the three precious metals are fixed. While a more formal investigation provided in the previous chapter of this thesis suggested that silver was cointegrated with the Japanese monetary base throughout the sample period considered, it seems that this positive relationship only blossoms when gold, platinum and palladium are fixed across all equations - calling for a more formal investigation into the relationship between platinum and palladium with Japanese money supply.

8.2.2.3.4 Sign Shifts

The following variables change distribution when switching from the unconstrained model (Figure 8.13) to Model 3 (Figure 8.16): the US CPI, the Chinese CPI, the

Agricultural and Raw Material price Index, the Food price index, the Euro, the VIX, and finally, the UK Economic Uncertainty Index. The effects of fixing white precious metals across every equation was discussed for Model 2, a similar effect is observed for the Euro. The change in distribution of the VIX, being mainly positively distributed (Figure 8.13) and now negatively distributed (Figure 8.16) is reflecting the effects of adding gold in the equation (8.14). Though not statistically significant, the negative relationship between silver and the VIX uncovered when gold is added, is another reflection of silver's more speculative nature that comes to light when directly compared to gold. The sign change for the UK Economic Uncertainty index is a direct consequence of fixing gold, where previous results indeed uncovered the importance that the macroeconomic indicator exercised on the price of gold.

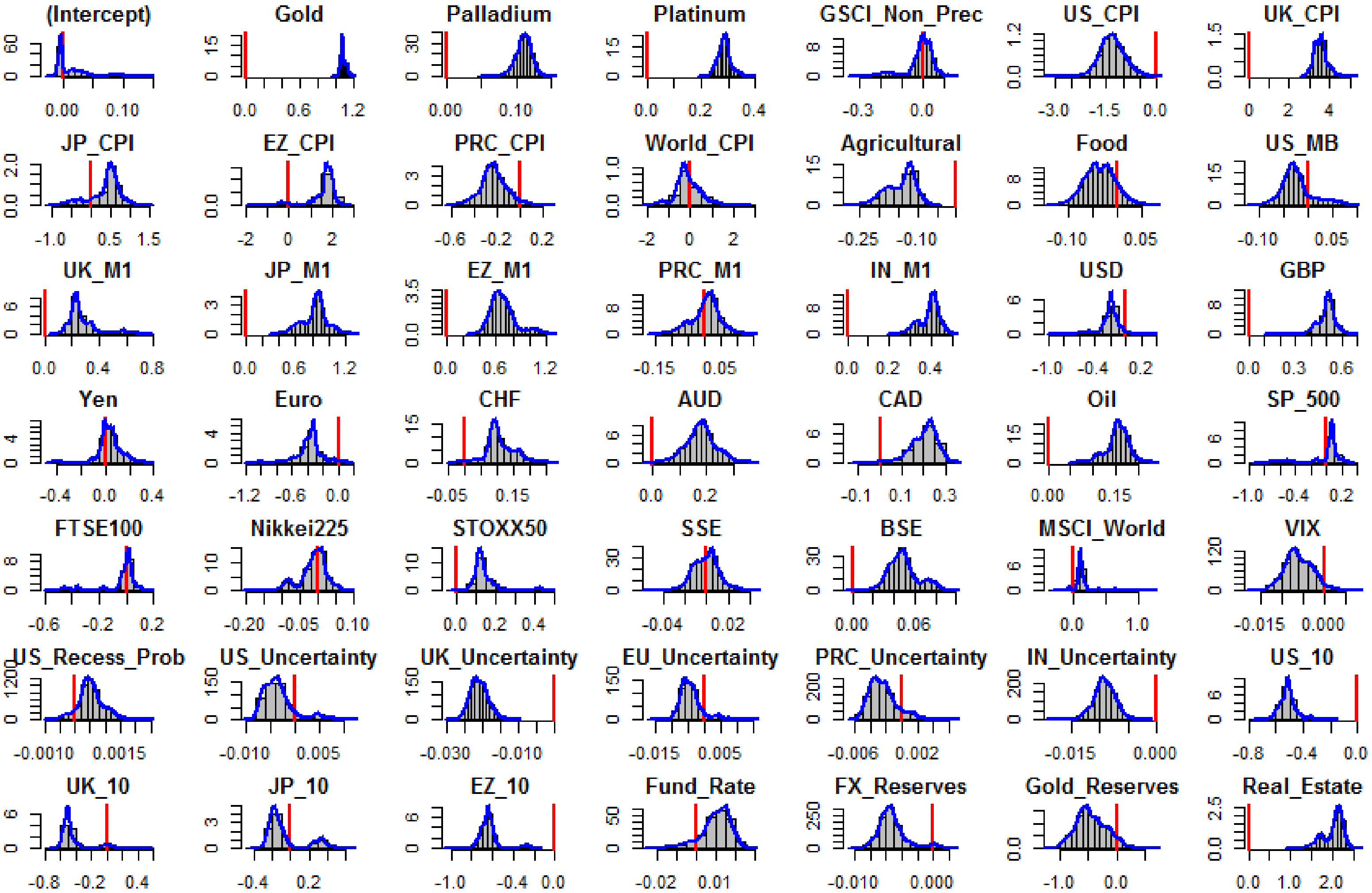
8.2.2.4 Model 4: Fixing Precious and Non-Precious Metals

In this final metal-specific model, the three precious metals previously fixed still remain in the system, while non-precious metals are added in order to gain an even bigger exposure to the industrial aspects of silver, previously provided by palladium only. Regression results are displayed in Table 8.17 and in Figure 8.17.

Table 8.17: Sophisticated Extreme Bounds Analysis Results for Silver - Model 4: Fixing Precious and Non-Precious Metals

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	54.875	45.125	Oil	focus	16.633	83.367
US_CPI	focus	71.944	28.056	GSCI_Non_Prec	fixed	49.141	50.859
UK_CPI***	focus	0.798	99.202	S&P_500	focus	35.089	64.911
JP_CPI	focus	40.544	59.456	FTSE100	focus	54.533	45.467
EZ_CPI	focus	10.966	89.034	Nikkei225	focus	54.091	45.909
PRC_CPI	focus	61.689	38.311	STOXX50	focus	11.414	88.586
World_CPI	focus	51.955	48.045	SSE	focus	50.489	49.511
Agricultural	focus	79.146	20.854	BSE	focus	23.376	76.624
Food	focus	58.371	41.629	MSCI_World	focus	19.632	80.368
US_MB	focus	56.081	43.919	VIX	focus	65.693	34.307
UK_M1	focus	26.103	73.897	US_Recess_Prob	focus	40.157	59.843
JP_M1*	focus	8.120	91.880	US_Uncertainty	focus	60.028	39.972
EZ_M1	focus	16.091	83.909	UK_Uncertainty	focus	88.487	11.513
PRC_M1	focus	49.211	50.789	EU_Uncertainty	focus	62.776	37.224
IN_M1*	focus	6.345	93.655	PRC_Uncertainty	focus	60.401	39.599
USD	focus	74.073	25.927	IN_Uncertainty	focus	82.194	17.806
GBP**	focus	2.470	97.530	US_10**	focus	97.138	2.862
Yen	focus	41.923	58.077	UK_10	focus	89.296	10.704
Euro	focus	86.742	13.258	JP_10	focus	56.171	43.829
CHF	focus	32.194	67.806	EZ_10**	focus	95.829	4.171
AUD	focus	20.947	79.053	Fund_Rate	focus	38.120	61.880
CAD	focus	19.561	80.439	FX_Reserves	focus	68.037	31.963
Gold***	fixed	0.000	100	Gold_Reserves	focus	59.181	40.819
Palladium*	fixed	6.000	94.000	Real_Estate*	focus	5.187	94.813
Platinum***	fixed	0.888	99.112				

Figure 8.17: Sophisticated Extreme Bounds Analysis Results for Silver - Model 4: Fixing Precious and Non-Precious Metals



8.2.2.4.1 99% Confidence Interval

Three variables are identified at the 99% confidence interval: the price of gold, the price of platinum and the UK CPI index. Having fixed the GSCI Non-precious metal index which fails to appear in any of the confidence intervals, the results of the final *metal exposed* model indicate that gold and platinum are more closely related to silver than palladium and non-precious metals, findings in line with Batten et al. (2015). Discussed earlier on, the importance of the UK CPI exercised on the silver price is truly revealed when gold is fixed across all equations (see results in Tables 8.14 and 8.16 for a comparison). This is a vital finding for researchers focused on explaining the simultaneous movements of gold and silver prices, as it is the United Kingdom, not the United States, that seems to reveal more information about price movements.

8.2.2.4.2 95% Confidence Interval

Considering the 95% confidence interval, three additional variables appear: the pound sterling, the US 10 year Government bond index, and finally, the Eurozone 10 year Government bond index. The importance of the pound sterling exercised on the price of silver is only revealed when fixing precious metals across all equations, akin to the importance of the originating market, but also to a possible reverse effect where a strong pound is linked to a weak US Dollar and therefore higher precious metal prices - do note however, that the US Dollar doesn't appear at any significance level. The effect of fixing the gold price in the system is illustrated by the appearance of the two sovereign debt indices at the 95% confidence interval. As argued above, the negative relationship with the two macroeconomic indicators is akin to the more speculative nature of gold in comparison to silver.

8.2.2.4.3 90% Confidence Interval

The following four variables are identified at the 90% confidence interval: the price of palladium, the Japanese and Indian monetary base, as well as the S&P Case-Shiller Real Estate index. The weaker importance of palladium in comparison to silver and platinum was previously discussed and is in line with previous findings such as Batten et al. (2015) who argue that palladium is different in many aspects to the three other precious metals. The importance of Indian money supply is revealed when gold is fixed (Table 8.14) and calls for a more formal investigation into the importance of Indian macroeconomic drivers; on the other hand, Japan only appears at the 90% confidence interval in a system that fixes all three precious metals across every equation (Table 8.16), result in line with previous findings in this thesis and that should be more formally investigated in light of the relationship between platinum and palladium with Japanese money supply. Finally, the effect of fixing gold is once more revealed in light of the statistical significance of the real estate index, where the positive relationship is akin to silver's more speculative nature in comparison to gold, that was found to act as a hedge against falling American house prices.

8.2.2.4.4 Sign Shifts

In a model fixing precious and non-precious metals, the industrial aspects of silver are underlined by the changing distribution of certain inflation series, namely: the US CPI, the Chinese CPI, the Global CPI, as well as the agricultural price index and the food price index. The effects of fixing white precious metals can also be observed on the Euro, where a similar change was observed in previous model specifications. The GSCI non-precious metal index drops out of the 95% confidence level and is now more evenly distributed - questioning the importance that industrial metals have in making the silver price. The change in distribution for the VIX and the UK Economic Uncertainty index is further evidence in favour of the revealed industrial aspects of silver in the specifications of Model 4, where the price of silver is higher when uncertainty on the markets is low. Finally, the changes observed for the US, the UK and the Japanese 10 year Government bond indices are suggesting that in Model 4, the price of silver is on average higher when the yields of the mentioned countries are lower - pointing towards an industrial success leading to a more stable economy and higher silver prices; further evidence that Model 4 focuses significantly on the industrial aspects of silver.

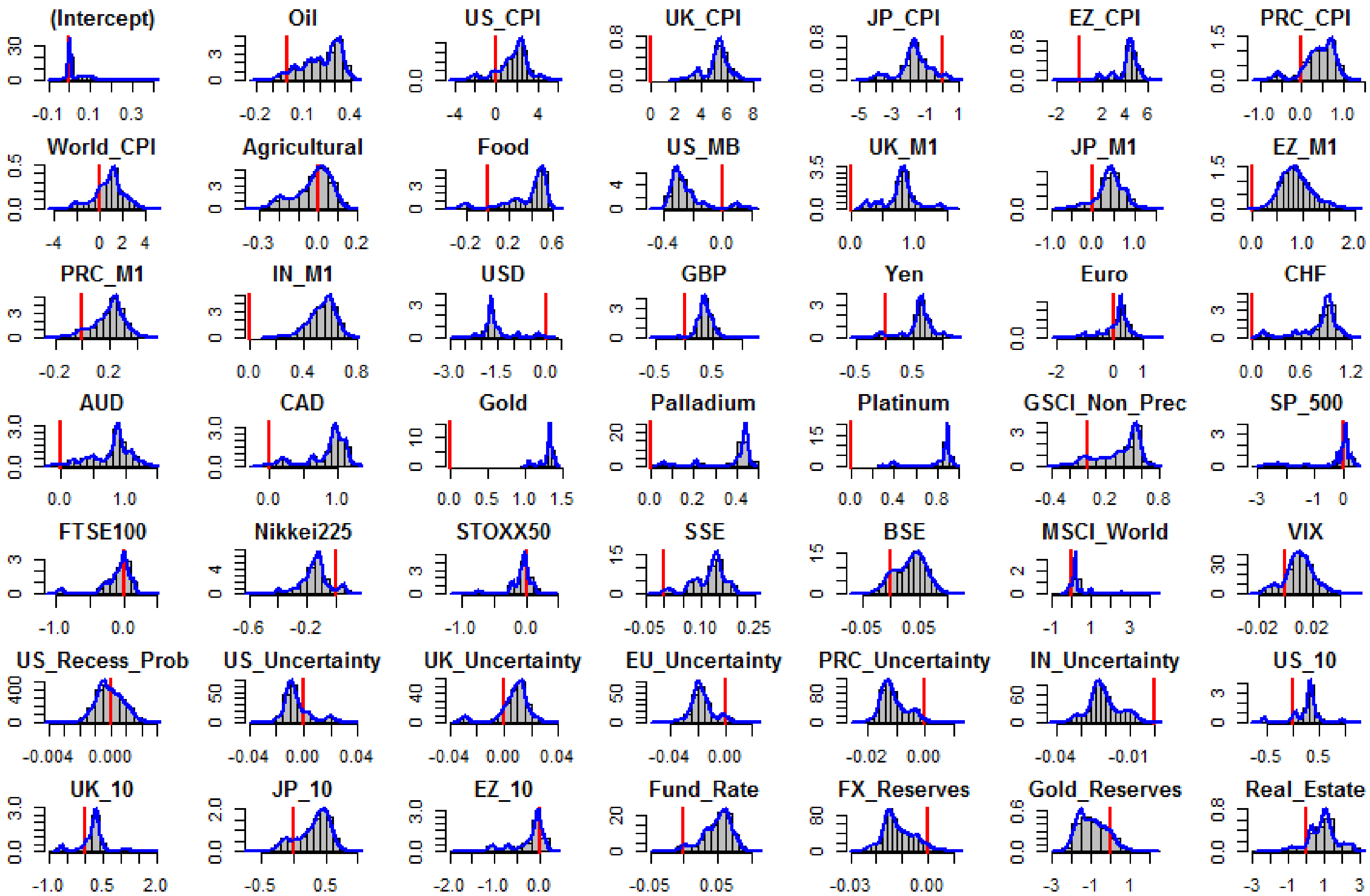
8.2.2.5 Model 5: Fixing Oil

In a philosophical approach similar to Model 4, this model only fixes the prices of oil across all regressions. While certain papers such as Bhar and Hammoudeh (2011), fail to find a significant relationship between silver and oil, others like Charlot and Marimoutou (2014) find a weak but existing correlation between silver and oil returns. Indeed, the unconstrained model proposed in this chapter (Figure 8.13) found evidence for a significant relationship between the two variables (Table 8.13), inviting a deeper investigation into the matter. The Sala-I-Martin (1997) regression results can be found in Table 8.18 and Figure 8.18.

Table 8.18: Sophisticated Extreme Bounds Analysis Results for Silver - Model 5: Fixing Oil

Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)	Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)
(Intercept)	fixed	35.701	64.299	Oil*	fixed	8.290	91.710
US_CPI	focus	31.751	68.249	GSCI_Non_Prec	focus	17.556	82.444
UK_CPI**	focus	1.532	98.468	S&P_500	focus	44.032	55.968
JP_CPI	focus	74.120	25.880	FTSE100	focus	58.927	41.073
EZ_CPI**	focus	2.167	97.833	Nikkei225	focus	79.558	20.442
PRC_CPI	focus	36.792	63.208	STOXX50	focus	60.330	39.670
World_CPI	focus	41.469	58.531	SSE*	focus	9.998	90.002
Agricultural	focus	54.091	45.909	BSE	focus	36.865	63.135
Food	focus	10.369	89.631	MSCI_World	focus	17.925	82.075
US_MB	focus	84.775	15.225	VIX	focus	34.605	65.395
UK_M1	focus	11.834	88.166	US_Recess_Prob	focus	50.502	49.498
JP_M1	focus	31.832	68.168	US_Uncertainty	focus	59.860	40.140
EZ_M1	focus	20.452	79.548	UK_Uncertainty	focus	39.647	60.353
PRC_M1	focus	29.847	70.153	EU_Uncertainty	focus	78.814	21.186
IN_M1*	focus	8.249	91.751	PRC_Uncertainty	focus	77.432	22.568
USD**	focus	98.497	1.503	IN_Uncertainty*	focus	90.558	9.442
GBP	focus	17.879	82.121	US_10	focus	27.606	72.394
Yen*	focus	6.508	93.492	UK_10	focus	31.784	68.216
Euro	focus	40.043	59.957	JP_10	focus	34.829	65.171
CHF**	focus	2.663	97.337	EZ_10	focus	63.512	36.488
AUD**	focus	2.695	97.305	Fund_Rate	focus	17.708	82.292
CAD**	focus	3.625	96.375	FX_Reserves	focus	74.362	25.638
Gold***	focus	0.000	100	Gold_Reserves	focus	62.162	37.838
Palladium**	focus	1.564	98.436	Real_Estate	focus	31.969	68.031
Platinum***	focus	0.002	99.998				

Figure 8.18: Sophisticated Extreme Bounds Analysis Results for Silver - Model 5: Fixing Oil



8.2.2.5.1 99% Confidence Interval

Only two variables appear in the 99% confidence interval under the Model 5 specifications: gold and platinum. For both variables, a thorough discussion was provided earlier on and shall not be part of this analysis.

8.2.2.5.2 95% Confidence Interval

Interestingly however, palladium gains in importance and appears at the 95% confidence interval, where 98.436% of the regressors are positively associated with the price of silver. In light of another model exposed to the industrial aspects of silver, by fixing the price of oil, this finding is not too surprising. The two inflation rates identified, for the UK and the Eurozone, is in line with previous model specifications and indicates that oil doesn't exercise a meaningful effect on the importance of those variables. Finally, four currencies are identified as significant at the 95% confidence interval: the US Dollar, the Swiss Franc, the Australian Dollar, and finally, the Canadian Dollar. While a reason was provided above for the different currencies identified, an explanation for the appearance of so many currencies (similar to the findings in the unconstrained model displayed in Table 8.13), is that oil doesn't affect the *currency effect* of silver. In other words, while fixing other precious metals channeled out the effect of certain currencies such as the US Dollar when fixing gold (Table 8.14), oil being not considered an *international currency* doesn't act detrimental on the important effect of certain currencies.

8.2.2.5.3 90% Confidence Interval

Fixing a variable across all equations in the system allows to get a better understanding of the distribution of the regressors for that particular variable. Fixing oil, the variable remains at the 90% confidence interval, results identical to the unconstrained approach (Table 8.13). However, two new variables appear: the Indian monetary base and the Indian economic uncertainty index, suggesting a greater importance of the Asian economy than initially suggested. Fixing oil reveals that the relationship between the Indian economic uncertainty index and silver is negative. This is a suggestion that the price of silver is higher in a fruitful economic environment and points towards silvers use as both an industrial input in India (where greater economic activity leads to a higher silver demand) and a luxury asset (where consumers have a demand for silver in cases where they can truly afford such expenses). So in contrary to other countries, and especially in contrary to gold, silver has no role as a safe haven during economic turmoils in India. Another currency appears as significant: the Yen. The reasoning here is purely industrial, where fixing an industry proxy reveals the true relationship between silver and the level of the Japanese currency. China took over a very large amount of the global industrial production that had a demand for silver as an input over the past decades (The Silver Institute (2016)). The appearing positive relationship with the SSE in an industrially calibrated model points towards a higher price of silver when the Chinese economy is roaring, suggesting a far greater importance of China than one could initially believe.

8.2.2.5.4 Sign Shifts

In the specifications of Model 5, fixing the price of oil across all regressions, only two variables appear to have changed distributions: the Japanese CPI and the Nikkei 225. The demand for silver in Japan stems from industry rather than from private investors which could explain the negative relationship with the CPI rate, suggesting higher silver prices when inflation is low. As to why the relationship changes when the price of oil is fixed, an explanation could only be that the specifications of Model 5 are trimmed to uncover the industrial production aspects of silver, where oil is indeed a vital input of production. While the unconstrained model suggested a somewhat positive relationship (Figure 8.13) and Model 5 suggests a somewhat negative relationship (Figure 8.18) between silver prices and the Japanese CPI, the formal investigation between the two series in the previous chapter uncovered the complexity between the two series, that used to be cointegrated but stopped to be in later parts of the observation period. Interestingly however, the negative relationship with the Nikkei 225 would indicate equity hedging qualities of silver in Japan that would originate from investor demand rather than from industrial demand. While the results are not statistically significant (Table 8.18) and should therefore be handled carefully, the change in signs of Japanese variables highlight once more the complexity of the relationship between the white precious metal and macroeconomic series of the Asian economy due to Japan's period of deflation and disinflation.

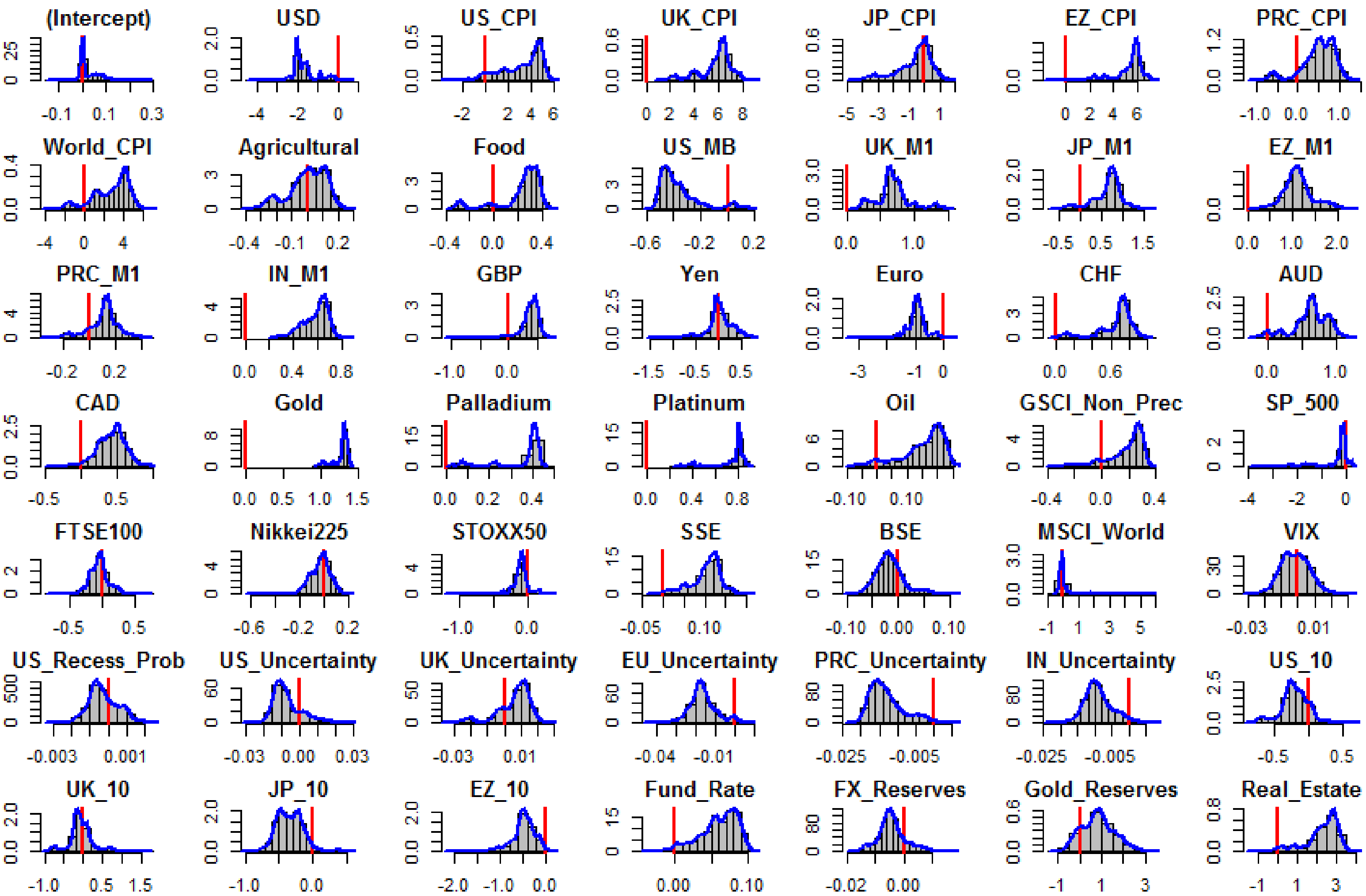
8.2.2.6 Model 6: Fixing the US Dollar

In the unconstrained model, the US Dollar was found to be significantly associated with silver at the 99% confidence level (Table 8.13), not surprising results given that silver is officially quoted in US Dollars. Focused on gold, precious findings suggest that the US Dollar is the single most important determinant of the gold price (Tully and Lucey (2007)), a similar argumentation could hold for silver in light of the similarities between the two precious metals. In order to understand more about currency effects on the price of silver, Model 6 is starting by fixing the US Dollar across every regression. Sala-I-Martin (1997) regression results are displayed in Table 8.19 and Figure 8.19.

Table 8.19: Sophisticated Extreme Bounds Analysis Results for Silver - Model 6: Fixing the US Dollar

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	37.268	62.732	Oil*	focus	8.610	91.390
US_CPI	focus	13.649	86.351	GSCI_Non_Prec	focus	11.281	88.719
UK_CPI**	focus	1.391	98.609	S&P_500	focus	74.747	25.253
JP_CPI	focus	58.430	41.570	FTSE100	focus	57.851	42.149
EZ_CPI***	focus	0.551	99.449	Nikkei225	focus	56.699	43.301
PRC_CPI	focus	33.596	66.404	STOXX50	focus	67.136	32.864
World_CPI	focus	20.619	79.381	SSE	focus	11.864	88.136
Agricultural	focus	49.052	50.948	BSE	focus	55.993	44.007
Food	focus	17.933	82.067	MSCI_World	focus	51.075	48.925
US_MB*	focus	92.393	7.607	VIX	focus	53.027	46.973
UK_M1	focus	14.149	85.851	US_Recess_Prob	focus	53.273	46.727
JP_M1	focus	22.740	77.260	US_Uncertainty	focus	63.928	36.072
EZ_M1	focus	13.476	86.524	UK_Uncertainty	focus	40.939	59.061
PRC_M1	focus	37.396	62.604	EU_Uncertainty	focus	79.244	20.756
IN_M1*	focus	5.813	94.187	PRC_Uncertainty	focus	82.510	17.490
USD**	fixed	98.623	1.377	IN_Uncertainty	focus	73.273	26.727
GBP	focus	15.236	84.764	US_10	focus	69.959	30.041
Yen	focus	45.385	54.615	UK_10	focus	55.594	44.406
Euro**	focus	95.628	4.372	JP_10	focus	68.034	31.966
CHF**	focus	4.002	95.998	EZ_10	focus	81.579	18.421
AUD*	focus	5.256	94.744	Fund_Rate	focus	12.633	87.367
CAD	focus	14.431	85.569	FX_Reserves	focus	60.508	39.492
Gold***	focus	0.000	100	Gold_Reserves	focus	39.054	60.946
Palladium**	focus	1.177	98.823	Real_Estate	focus	11.912	88.088
Platinum***	focus	0.002	99.998				

Figure 8.19: Sophisticated Extreme Bounds Analysis Results for Silver - Model 6: Fixing the US Dollar



8.2.2.6.1 99% Confidence Interval

Three variables appear at the 99% confidence interval: the Eurozone CPI, the price of gold and the price of platinum. A discussion on the importance of gold and platinum was provided above, it is however interesting to note that fixing the US Dollar did not affect the significance level of gold while fixing gold in Model 1 channeled out the US Dollar effect. The Eurozone CPI appears to be the strongest inflation measure when the US Dollar is fixed across all regressions; akin to the importance of inflation in the Eurozone, a very important economic market heavily linked with both exports and imports with the US therefore directly influenced and influencing the level of the American currency. It should be noted that in previous models the UK CPI was identified as more important, except for the unconstrained model (Table 8.13), where a short discussion was provided on why the Eurozone CPI is identified at the 99% confidence level.

8.2.2.6.2 95% Confidence Interval

Alongside the UK CPI, the Euro, the Swiss Franc and the price of palladium, the US Dollar appears to be significant at the 95% confidence interval. In line with previous results and argumentation, the level of the US Dollar is therefore less important for the price of silver than it is for the price of gold, where the Dollar constantly appeared at the 99% confidence level. Results underlying the international aspects of silver whos' price depends on international macroeconomic variables rather than on US American indicators alone.

8.2.2.6.3 90% Confidence Interval

Four variables appear at the 90% confidence interval: the US monetary base, Indian money supply, the Australian Dollar, and finally, the price of oil. Indian money supply was previously identified as significant and is akin to the important demand for silver coming from the Asian economy. It can be observed, that the US monetary base only appears to be significant at the 90% confidence interval when the level of the US Dollar is fixed, reflecting the importance of monetary supply on the purchasing power of the American currency. The negative relationship suggests that a higher monetary base leads to a lower price of silver; a finding that could be considered somewhat opposed to the negative relationship observed between silver and the level of the US Dollar if believed that a greater monetary base should lower the purchasing power of the Dollar. The observed relationship should therefore be considered in the light of a *money flooding* effect reducing the price of the white precious metal. Finally, the *commodity currency* effect of the Australian Dollar reappears in Model 6 as well as the *industrial aspect* of silver, where a strong price of oil is related to a strong price of silver (Table 8.19)

8.2.2.6.4 Sign Shifts

Five variables change distribution when the US Dollar is fixed across all equations: the Euro, the S&P 500, the Euro Stoxx 50, the BSE, and finally, the global central bank gold reserves. The effects that fixing the US Dollar has on other currencies was discussed earlier in light of the international aspects of silver, where the US Dollar is a less important single determinant than it is for gold. A *dollar effect* is also exercised on the S&P 500, where silver seems to abandon hedging potential and is now negatively associated with US equities. While a strong US Dollar is detrimental for the price of silver, it could also be detrimental for the S&P 500 due to export complications in light of more expensive American goods for non-US consumers. Similar observations are made for the Euro Stoxx 50 and the BSE, indicating the industrial importance of silver in these markets rather than inflation hedging potential. The change observed for central bank gold reserves is a direct reflection of the effects of fixing the US Dollar; indeed, when the gold reserves are higher, the price of silver rises. While this can be considered in the light of the close relationship between gold and silver, as well as keeping in mind that the official silver price is quoted in US Dollars, the far from statistically significant relationship urges to be considered carefully when attempting any empirical interpretation.

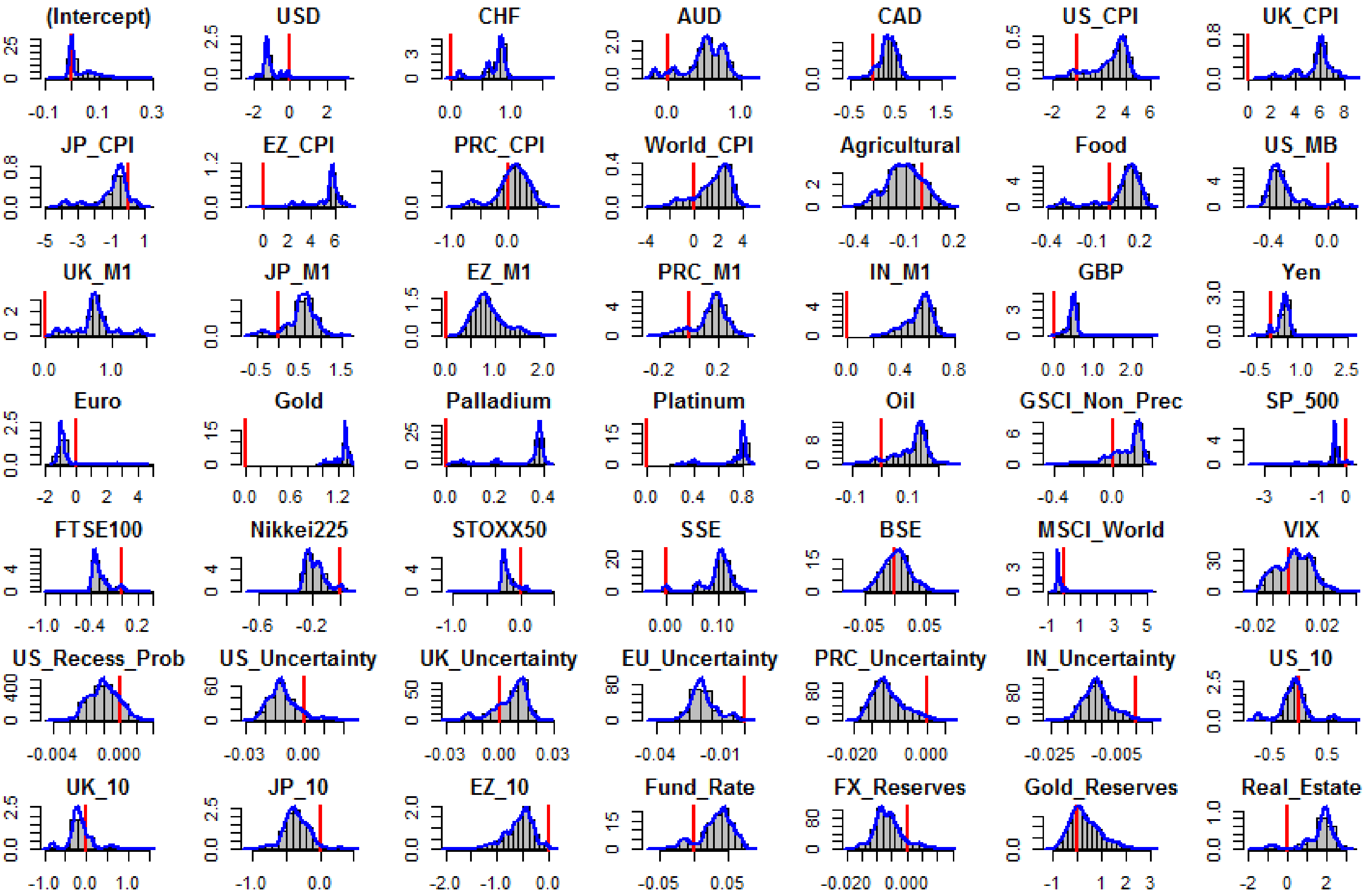
8.2.2.7 Model 7: Fixing Currencies Identified in the Unconstrained Model

The investigation into the monetary aspects of silver is continued by fixing all the currencies identified as statistically significant in the unconstrained model (Table 8.13). The results displayed in Table 8.20 and Figure 8.20 provide clearer information on the relationship between selected currencies and the price of silver.

Table 8.20: Sophisticated Extreme Bounds Analysis Results for Silver - Model 7: Fixing Currencies Identified in the Unconstrained Model

Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)	Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)
(Intercept)	fixed	39.691	60.309	Oil	focus	16.599	83.401
US_CPI	focus	16.378	83.622	GSCI_Non_Prec	focus	22.941	77.059
UK_CPI**	focus	1.523	98.477	S&P_500*	focus	91.165	8.835
JP_CPI	focus	64.102	35.898	FTSE100	focus	85.291	14.709
EZ_CPI***	focus	0.539	99.461	Nikkei225	focus	86.168	13.832
PRC_CPI	focus	47.414	52.586	STOXX50	focus	79.831	20.169
World_CPI	focus	30.315	69.685	SSE	focus	14.021	85.979
Agricultural	focus	65.830	34.170	BSE	focus	48.114	51.886
Food	focus	35.065	64.935	MSCI_World	focus	78.489	21.511
US_MB	focus	89.058	10.942	VIX	focus	45.388	54.612
UK_M1	focus	12.009	87.991	US_Recess_Prob	focus	61.801	38.199
JP_M1	focus	26.313	73.687	US_Uncertainty	focus	70.330	29.670
EZ_M1	focus	19.671	80.329	UK_Uncertainty	focus	41.831	58.169
PRC_M1	focus	33.073	66.927	EU_Uncertainty	focus	83.058	16.942
IN_M1*	focus	7.139	92.861	PRC_Uncertainty	focus	78.141	21.859
USD**	fixed	95.580	4.420	IN_Uncertainty	focus	78.190	21.810
GBP	focus	11.126	88.874	US_10	focus	59.135	40.865
Yen	focus	14.999	85.001	UK_10	focus	62.218	37.782
Euro*	focus	93.695	6.305	JP_10	focus	67.950	32.050
CHF**	fixed	4.036	95.964	EZ_10	focus	86.080	13.920
AUD	fixed	10.768	89.232	Fund_Rate	focus	25.869	74.131
CAD	fixed	23.192	76.808	FX_Reserves	focus	65.023	34.977
Gold***	focus	0.000	100	Gold_Reserves	focus	45.679	54.321
Palladium**	focus	1.517	98.483	Real_Estate	focus	18.954	81.046
Platinum***	focus	0.003	99.997				

Figure 8.20: Sophisticated Extreme Bounds Analysis Results for Silver - Model 7: Fixing Currencies Identified in the Unconstrained Model



8.2.2.7.1 99% Confidence Interval

Three variables are identified at the 99% confidence interval: the Eurozone CPI, the price of gold and the price of platinum. The results identified for the 99% confidence level are therefore identical to those observed at the same confidence for Model 6 (Table 8.19), fixing only the US Dollar. The similarity across the two models is an argument in favour of the US Dollar as the most important of the currencies considered across the system.

8.2.2.7.2 95% Confidence Interval

At the 95% confidence interval, the following variables are identified as relevant: the US Dollar, the Swiss Franc, the UK CPI, and the price of palladium. The only difference to Model 6 is that the Euro is not identified as significant at the 95% confidence level, but indeed at the 90% confidence interval. So fixing multiple currencies weakens the effect of the Euro while it doesn't strengthen the effect of the other currencies, an indication that the effect of the Euro is not as strong as suggested in Model 6.

8.2.2.7.3 90% Confidence Interval

Indian money supply, the Euro and the S&P 500 are identified at the 90% confidence interval. It should be noted that the Australian Dollar drops out as a significant variable, alongside a weakening statistical significance of the Euro - indications that no one single currency drives silver but that the currency effects on silver are complex and depend on model specification. Indian money supply indicates the importance of the Asian economy in a system fixing currencies across the model; results similar to previous findings. In contrary to Model 6 however (Table 8.19), fixing a bigger basket of currencies is detrimental to the importance of oil as a statistically significant variable, while it leads to the emergence of the S&P 500 at the 90% confidence interval. Indeed, results in Table 8.20 indicate that the price of silver is high when American equity prices are low - results in line with Lucey and Li (2015) arguing for the hedging and safe haven abilities of silver against equity.

8.2.2.7.4 Sign Shifts

Fixing the four currencies specified in Model 7 leads to a change in the distribution of the following variables: the Japanese CPI, the Agricultural and Raw Material price index, the Euro, the S&P 500, the FTSE100, the Nikkei 225, the Euro Stoxx 50, the MSCI Global stock price index, and finally, the Japanese 10 year Government debt index. The effect that fixing the US Dollar has on the Euro was discussed for Model 6. Furthermore, as already mentioned, fixing currency exchange rates across the system leads to a negative relationship between silver and equity indices, due to the importance of exports, directly linked to the strength of the individual national currency. A brief discussion on the Japanese CPI rate was provided earlier, while the negative relationship between silver and Japanese Government debt yields are a further indication of silvers' overwhelmingly industrial importance in Japan.

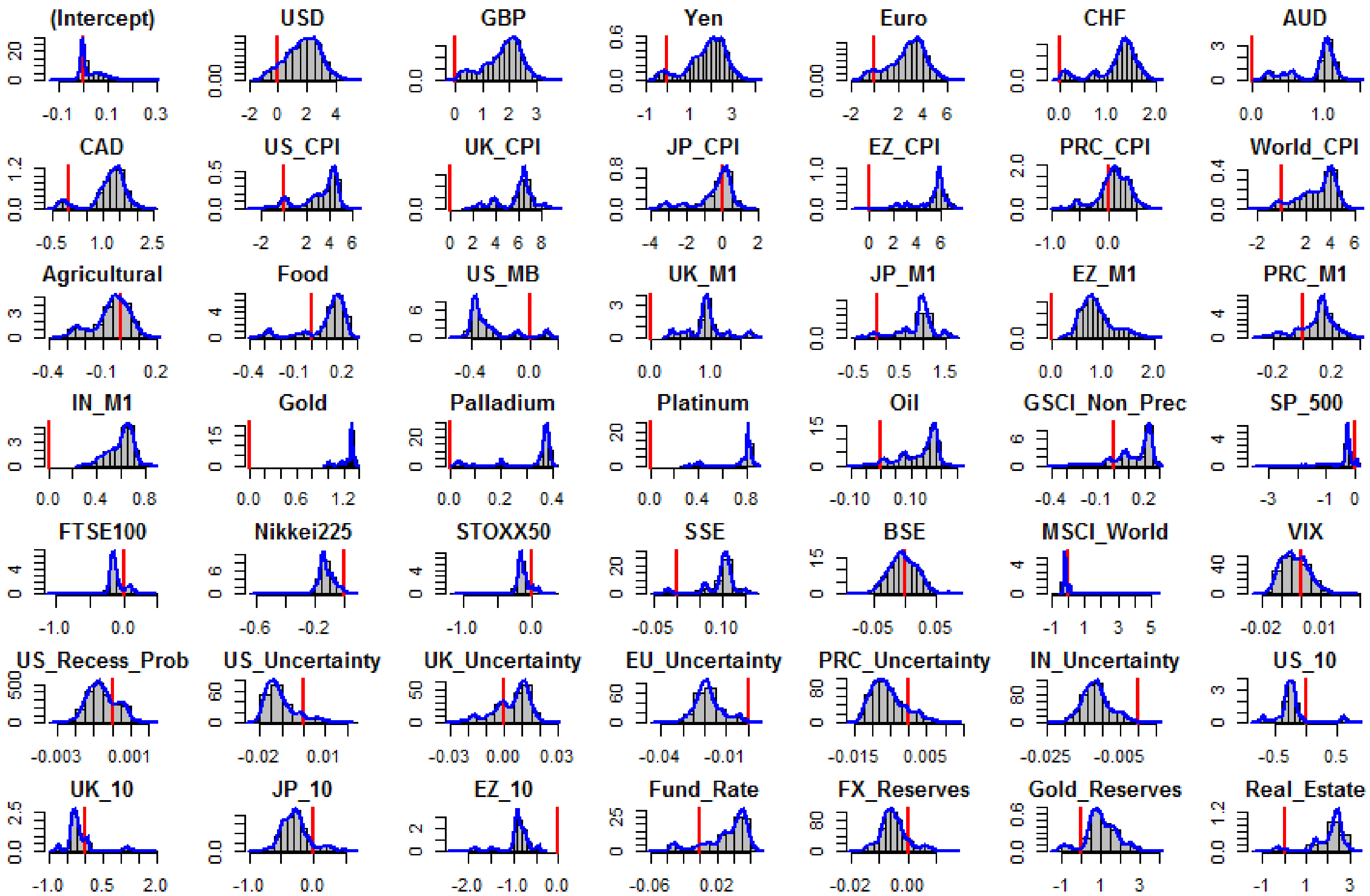
8.2.2.8 Model 8: Fixing all Currencies

In the last *currency* model, all of the seven currencies are fixed across the system and hence appear in every regression. Previous results from Model 6 and Model 7 have revealed a more complex silver-currency relationship than intuitively expected. This final model will shed additional light on the relationship by treating each and every currency equally. The Sala-I-Martin (1997) regression results are displayed in Table 8.21 and Figure 8.21.

Table 8.21: Sophisticated Extreme Bounds Analysis Results for Silver - Model 8: Fixing all Currencies

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	42.622	57.378	Oil	focus	12.649	87.351
US_CPI	focus	13.965	86.035	GSCI_Non_Prec	focus	18.678	81.322
UK_CPI**	focus	1.308	98.692	S&P_500	focus	80.395	19.605
JP_CPI	focus	55.303	44.697	FTSE100	focus	64.209	35.791
EZ_CPI***	focus	0.701	99.299	Nikkei225	focus	74.943	25.057
PRC_CPI	focus	46.630	53.370	STOXX50	focus	69.029	30.971
World_CPI	focus	18.721	81.279	SSE	focus	15.272	84.728
Agricultural	focus	57.545	42.455	BSE	focus	50.673	49.327
Food	focus	32.339	67.661	MSCI_World	focus	60.846	39.154
US_MB	focus	87.060	12.940	VIX	focus	55.868	44.132
UK_M1*	focus	7.239	92.761	US_Recess_Prob	focus	56.460	43.540
JP_M1	focus	16.253	83.747	US_Uncertainty	focus	70.175	29.825
EZ_M1	focus	19.441	80.559	UK_Uncertainty	focus	43.568	56.432
PRC_M1	focus	37.975	62.025	EU_Uncertainty	focus	82.106	17.894
IN_M1**	focus	4.988	95.012	PRC_Uncertainty	focus	66.138	33.862
USD	fixed	28.041	71.959	IN_Uncertainty	focus	78.953	21.047
GBP	fixed	11.980	88.020	US_10	focus	71.886	28.114
Yen	fixed	14.227	85.773	UK_10	focus	64.293	35.707
Euro	fixed	19.974	80.026	JP_10	focus	64.512	35.488
CHF*	fixed	6.231	93.769	EZ_10**	focus	95.764	4.236
AUD**	fixed	3.812	96.188	Fund_Rate	focus	27.937	72.063
CAD	fixed	13.784	86.216	FX_Reserves	focus	62.228	37.772
Gold***	focus	0.000	100	Gold_Reserves	focus	36.451	63.549
Palladium**	focus	2.407	97.593	Real_Estate	focus	13.985	86.015
Platinum***	focus	0.002	99.998				

Figure 8.21: Sophisticated Extreme Bounds Analysis Results for Silver - Model 8: Fixing all Currencies



8.2.2.8.1 99% Confidence Interval

For Model 6 (Table 8.19), Model 7 (Table 8.20) and Model 8 (Table 8.21), the identical three variables are identified as significant at the 99% confidence interval: the Eurozone CPI and the price of gold and platinum. The evidence derived from the currency models is therefore pointing towards the importance of the two other main precious metals in making the price of silver, but also at the importance of the Eurozone CPI: where the silver price rises with the level of European inflation, suggesting good inflation hedging abilities.

8.2.2.8.2 95% Confidence Interval

Five variables are identified at the 95% confidence interval: the Australian Dollar, the UK CPI, Indian money supply, the price of palladium, and finally, the Eurozone 10 year Government debt index. Some of the variables were already identified in previous model specifications and the implications have been discussed in earlier parts of this chapter. However, some new variables appear; such as the Eurozone debt index. Interestingly, the Eurozone debt index only appeared when gold was fixed across all regressions in the previous model specifications (Table 8.14) and is now appearing again in light of fixing the Euro, amongst other currencies (Table 8.21). A possible explanation for the negative relationship between silver and debt yields in the Eurozone would be that silver seems to have a speculative element in comparison to debt levels, where indeed the silver price drops when investors favour putting their money into National debt. A likely explanation of the appearance of the variable at the 95% confidence interval is the fixing of the Euro, where a possible hedging potential against dollar fluctuations is channeled through the two currencies directly in opposition to the bias of the white precious metal - results very different to those observed for gold. The complexity of the relationship between the Australian Dollar and gold is once more highlighted by it's appearance at the 95% confidence level in Model 8 (Table 8.21), results in line with the unconstrained model (Table 8.13), but in conflict with the appearance of the Oceanian currency at the 90% confidence interval when fixing the US Dollar (Table 8.19) and it's disappearance out of the confidence band when adding other currencies as fixed variables (Table 8.20). So while the Australian Dollar remains an important currency influencing the price of silver, its relative weakness against other currencies, amongst which the US Dollar alongside the Swiss Franc and the Canadian Dollar, is calling for more formal tests which would however be outside the scope of this investigation.

8.2.2.8.3 90% Confidence Interval

A similar argumentation could be used for the Swiss Franc falling from the 95% confidence interval (Tables 8.13, 8.19 and 8.20) into the 90% confidence interval (Table 8.21) - once more awaking the need for a formal investigation into the relative importance and effect of individual currencies on the price of silver. British money supply appears at the 90% confidence interval for the first time as it failed to do so in previous model specifications. Interestingly, the pound sterling doesn't appear to be statistically significant, indicating that the effects exercised by the British currency on the price of silver is channeled through money supply rather than through the exchange rate against a basket of other international currencies.

8.2.2.8.4 Sign Shifts

Fixing all currencies in the sample has an effect on equity indicators, where the S&P 500, the FTSE100, the Nikkei 225, the Euro Stoxx 50 and the MSCI World are all found to change distribution. Implications and explanations have already been provided for Models 6 and 7 and shall be omitted here. More interestingly however, is the change in distribution observed for the US Dollar, where the positive relationship with the price of silver suggests that the Dollar is *just another currency* in Model 8 - underlying the international aspects of silver in comparison to gold, where the US Dollar is a far more influential variable.

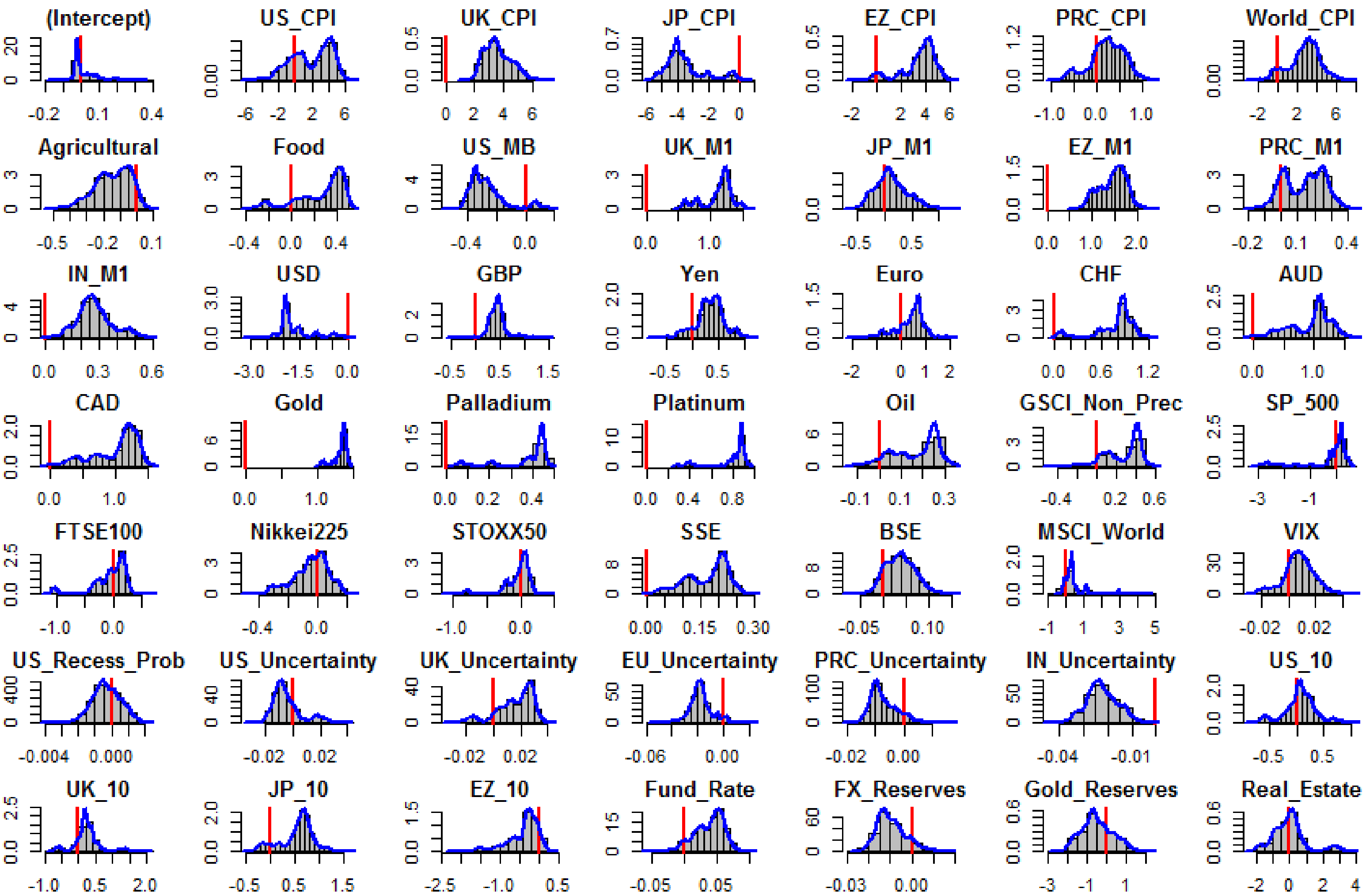
8.2.2.9 Model 9: Fixing Consumer Price Indices

In the unconstrained model three inflation measures were identified as significant at different significance levels: the US CPI, the UK CPI and the Eurozone CPI. While an argumentation for a relationship between inflation indices and the price of silver was provided on multiple occasions in earlier parts of this thesis, Model 9 is fixing the US, the UK, the Japanese, the Eurozone, the Chinese and the Global CPI indices in order to gain more insights into the relationship between silver and inflation. The Sala-I-Martin (1997) regression results are displayed in Table 8.22 and in Figure 8.22.

Table 8.22: Sophisticated Extreme Bounds Analysis Results for Silver - Model 9: Fixing Consumer Price Indices

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	63.513	36.487	Oil	focus	13.165	86.835
US_CPI	fixed	31.599	68.401	GSCI_Non_Prec	focus	12.064	87.936
UK_CPI	fixed	11.671	88.329	S&P_500	focus	35.545	64.455
JP_CPI*	fixed	90.213	9.787	FTSE100	focus	49.944	50.056
EZ_CPI	fixed	10.306	89.694	Nikkei225	focus	58.099	41.901
PRC_CPI	fixed	43.015	56.985	STOXX50	focus	50.071	49.929
World_CPI	fixed	24.551	75.449	SSE**	focus	4.754	95.246
Agricultural	focus	69.052	30.948	BSE	focus	35.690	64.310
Food	focus	18.250	81.750	MSCI_World	focus	13.648	86.352
US_MB	focus	84.680	15.320	VIX	focus	39.229	60.771
UK_M1**	focus	4.457	95.543	US_Recess_Prob	focus	53.458	46.542
JP_M1	focus	44.624	55.376	US_Uncertainty	focus	59.368	40.632
EZ_M1*	focus	8.460	91.540	UK_Uncertainty	focus	28.780	71.220
PRC_M1	focus	36.461	63.539	EU_Uncertainty	focus	79.136	20.864
IN_M1	focus	25.259	74.741	PRC_Uncertainty	focus	68.796	31.204
USD***	focus	99.179	0.821	IN_Uncertainty*	focus	91.882	8.118
GBP	focus	13.587	86.413	US_10	focus	43.575	56.425
Yen	focus	19.593	80.407	UK_10	focus	33.694	66.306
Euro	focus	24.488	75.512	JP_10	focus	25.659	74.341
CHF**	focus	3.513	96.487	EZ_10	focus	72.267	27.733
AUD**	focus	1.298	98.702	Fund_Rate	focus	23.798	76.202
CAD**	focus	1.822	98.178	FX_Reserves	focus	70.457	29.543
Gold***	focus	0.000	100	Gold_Reserves	focus	56.741	43.259
Palladium**	focus	1.476	98.524	Real_Estate	focus	50.350	49.650
Platinum***	focus	0.003	99.997				

Figure 8.22: Sophisticated Extreme Bounds Analysis Results for Silver - Model 9: Fixing Consumer Price Indices



8.2.2.9.1 99% Confidence Interval

The following three variables are identified at the 99% confidence interval: the US Dollar, the price of gold and the price of platinum. The three variables have already been identified in previous models, mainly the unconstrained approach in Table 8.13, but it should be noted that a difference between Model 9 and the naive model is the disappearance of the Eurozone CPI index from the 99% confidence interval. Indeed, fixing multiple CPI rates to appear across every regression is detrimental to the identified relationship between silver and European inflation. While it should be noted that about 89.69% of the regressors are positive, fixing multiple CPI rates decreases the impact exercised from Eurozone inflation on the price of silver.

8.2.2.9.2 95% Confidence Interval

At the 95% confidence level, the Sala-I-Martin (1997) regression results point towards the following variables: British money supply, the Swiss Franc, the Australian Dollar, the Canadian Dollar, the price of palladium, and finally, the Chinese equity index. While all variables were identified in previous models and discussed in earlier parts of this chapter, a special explnation should be provided as to why the UK monetary base appears to be significant at the 95% level under the specifications of Model 9. The only other model in which UK M1 was already identified is Model 8, fixing all currencies in the sample. The reason provided was that while the pound sterling disappeared from the set of explanatory variables, the effects exercised from the British currency on silver were channeled through the UK monetary base in a currency focused system specification. A similar argument can be made for Model 9, fixing all the CPI rates of the sample. While the UK CPI was previously identified as explanatory at the 95% confidence level in the unconstrained model (Table 8.13), the UK CPI is not identified under the new model specifications of Model 9 (Table 8.22). While this thesis previously argued for the interdependence between inflation and money supply series, it seems that the UK monetary base channels the inflation effects of Great Britain and Northern Ireland when the official CPI rate is fixed across all regressions.

8.2.2.9.3 90% Confidence Interval

Finally, at the 90% confidence level the following three variables are identified: the Japanese CPI, Eurozone money supply and the Indian Economic Uncertainty index.

Not only is the Japanese CPI rate the only inflation series identified in Model 9, but it is also negatively associated with the price of silver, hence suggesting the opposite to a hedging instrument; results in line with the more formal investigation in the previous chapter. The monetary index for the Eurozone was never identified as an explanatory variable in any of the previous model specifications - but similar to UK money supply, it appears in Model 9 to counterbalance the disappearance of the Eurozone CPI, hence channeling the effect through the monetary base directly. While data availability restrictions prevent adding the Indian CPI into the datasample, a role of the country is identified through the economic uncertainty indicator, where the negative relationship indicates that silver is considered more of a luxury asset where it's price is high when Indias' economic situation is considered stable.

8.2.2.9.4 Sign Shifts

Fixing the nominal inflation indices contained in the data sample doesn't have a significant effect on the distribution of most variables except for two: the Japanese CPI and the Agricultural and Raw Material price index. Indeed, the regressors of both variables were positive on average in the unconstrained model (Figure 8.13) and are now negative in Model 9 (Figure 8.22). While a discussion for the Japanese CPI has been provided in the above section, the change in signs of the regressors for the agricultural price index should be considered with caution as the relationship is not statistically significant and could simply be due to econometric implications of fixing other inflation series rather than due to underlying economic arguments.

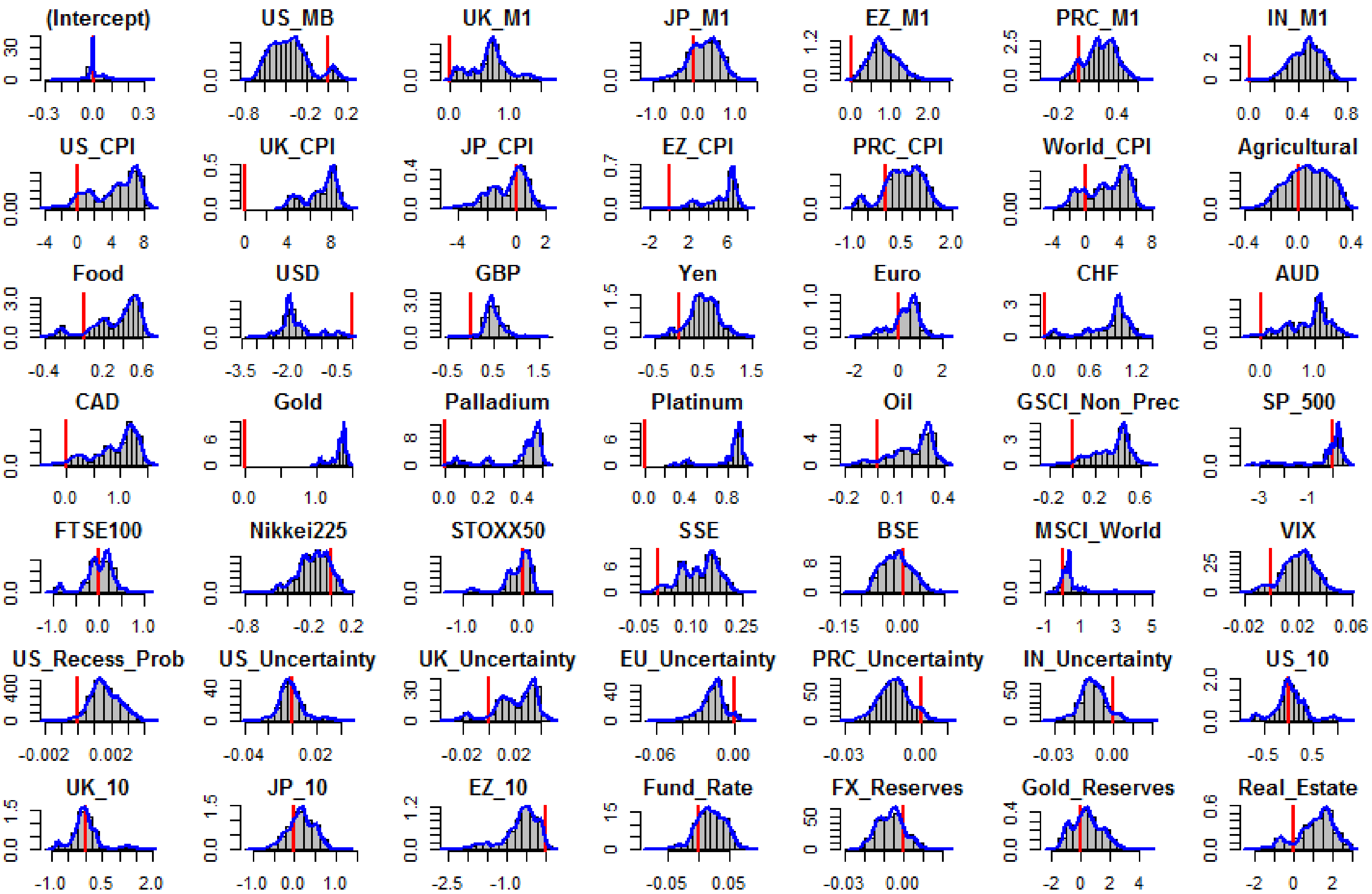
8.2.2.10 Model 10: Fixing Money Supply

This model offers an investigation similar to Model 9, where money supply is fixed instead of inflation indices. Regression results in the Sala-I-Martin (1997) fashion are displayed in Table 8.23 and in Figure 8.23.

Table 8.23: Sophisticated Extreme Bounds Analysis Results for Silver - Model 10: Fixing Money Supply

Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)	Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)
(Intercept)	fixed	62.328	37.672	Oil*	focus	7.645	92.355
US_CPI	focus	12.629	87.371	GSCI_Non_Prec**	focus	4.761	95.239
UK_CPI***	focus	0.585	99.415	S&P_500	focus	38.883	61.117
JP_CPI	focus	57.725	42.275	FTSE100	focus	44.565	55.435
EZ_CPI**	focus	1.711	98.289	Nikkei225	focus	77.535	22.465
PRC_CPI	focus	34.328	65.672	STOXX50	focus	54.787	45.213
World_CPI	focus	27.314	72.686	SSE	focus	11.572	88.428
Agricultural	focus	41.617	58.383	BSE	focus	54.452	45.548
Food	focus	14.437	85.563	MSCI_World	focus	16.127	83.873
US_MB	fixed	88.834	11.166	VIX	focus	23.139	76.861
UK_M1	fixed	17.253	82.747	US_Recess_Prob	focus	31.645	68.355
JP_M1	fixed	39.477	60.523	US_Uncertainty	focus	53.226	46.774
EZ_M1	fixed	22.541	77.459	UK_Uncertainty	focus	25.477	74.523
PRC_M1	fixed	28.966	71.034	EU_Uncertainty	focus	76.260	23.740
IN_M1	fixed	13.216	86.784	PRC_Uncertainty	focus	75.257	24.743
USD***	focus	99.340	0.660	IN_Uncertainty	focus	72.719	27.281
GBP	focus	13.143	86.857	US_10	focus	48.088	51.912
Yen	focus	11.640	88.360	UK_10	focus	50.655	49.345
Euro	focus	29.288	70.712	JP_10	focus	42.765	57.235
CHF**	focus	2.870	97.130	EZ_10	focus	82.937	17.063
AUD**	focus	2.551	97.449	Fund_Rate	focus	38.400	61.600
CAD**	focus	3.898	96.102	FX_Reserves	focus	63.158	36.842
Gold***	focus	0.000	100	Gold_Reserves	focus	44.999	55.001
Palladium**	focus	1.767	98.233	Real_Estate	focus	30.423	69.577
Platinum***	focus	0.003	99.997				

Figure 8.23: Sophisticated Extreme Bounds Analysis Results for Silver - Model 10: Fixing Money Supply



8.2.2.10.1 99% Confidence Interval

At the 99% confidence level, four variables are identified in Model 10: the UK CPI, the US Dollar, the price of gold, and finally, the price of platinum. So in comparison to the unconstrained model (Table 8.13), a difference is only observed for the UK CPI which swaps from the 95% confidence interval into the 99% confidence interval. These results are in line with the formal investigation provided in the previous chapter, where silver was proven to be a hedge against nominal inflation in the United Kingdom, but failed to be a hedge against money supply - indeed, UK M1 is not identified as a significant variable in Table 8.23.

8.2.2.10.2 95% Confidence Interval

At the 95% confidence level, the difference between the results identified in Table 8.23 in comparison to regression results in Table 8.13 is minimal. The same variables are identified at the 95% level with the little difference, that the Eurozone CPI falls from the 99% confidence interval into the 95% confidence interval under the specifications of Model 10. Interestingly, the opposite change is observed for the UK CPI, swapping from the 95% confidence interval (Table 8.13) into the 99% confidence interval (Table 8.23). So fixing money supply strengthen the importance of the UK CPI at the burden of the Eurozone CPI; a consequence of the hedging potential of silver against nominal British inflation directly rather than against British money supply.

8.2.2.10.3 90% Confidence Interval

At the 90% confidence level, only oil is identified, where the positive relationship between the two variables is pointing towards the industrial aspects of silver. The Chinese stock market index however vanished away from the 90% confidence level in the unconstrained model (Table 8.13) and is not significant any longer in Model 10. It should be noted, that the Model 10 specifications provided, all in all, very similar results to the unconstrained model - findings suggesting that the monetary aspects of silver were already accounted for in the naive model.

8.2.2.10.4 Sign Shifts

In accordance with the above findings, that fixing money supply indices has no significant effect on the basket of variables identified by the Sala-I-Martin (1997) procedure, none of the variables are found to significantly change distributions when comparing the results of the unconstrained model (Figure 8.13) to those of Model 10 (Figure 8.23).

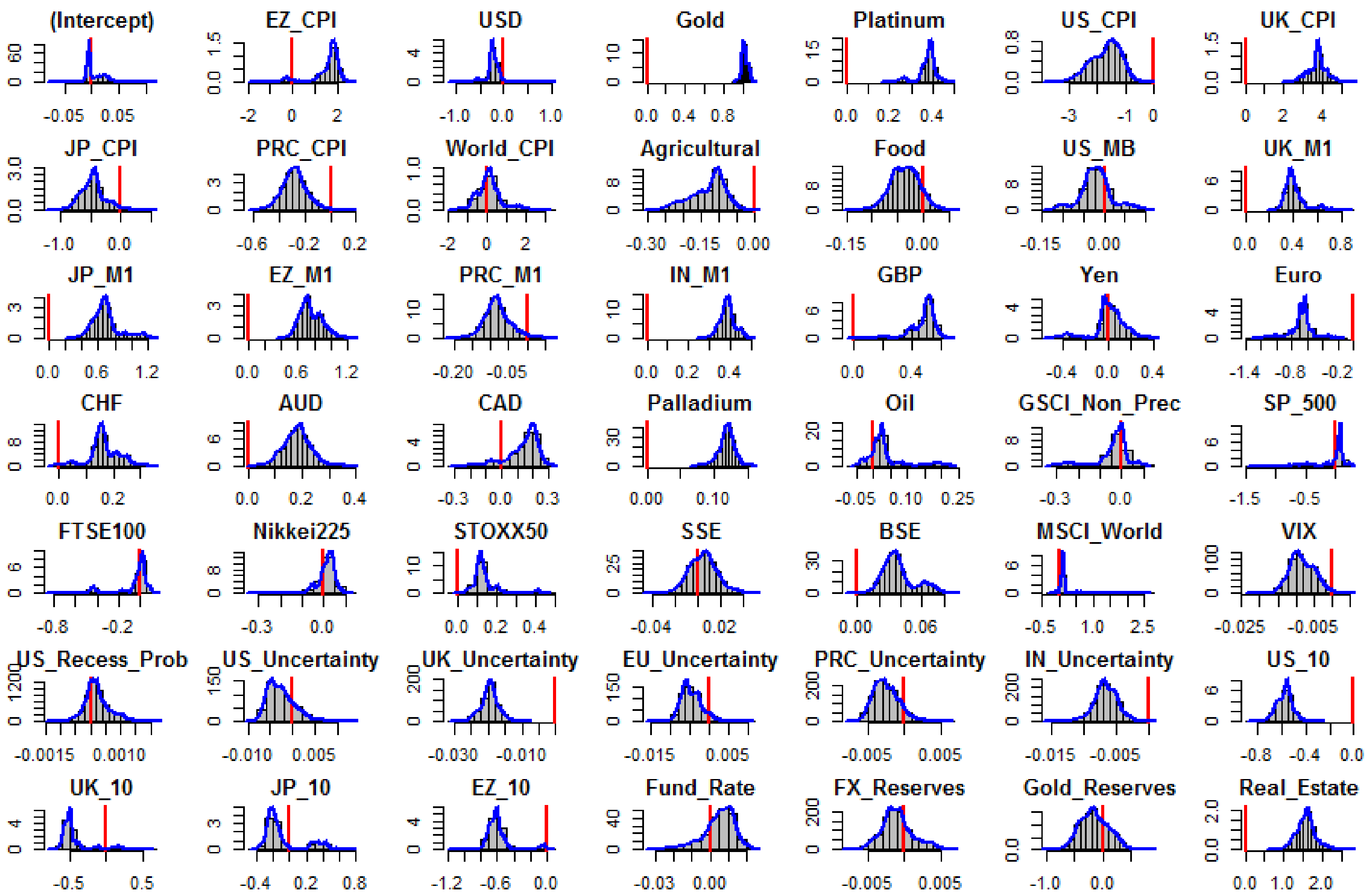
8.2.2.11 Model 11: Fixing the Variables identified at the 99% Confidence Interval

In the last of the 11 sophisticated models, the four variables identified at the 99% confidence level in the unconstrained approach are fixed in order to test their robustness. More specifically, the Eurozone CPI, the US Dollar, the price of gold and the price of platinum are fixed across every regression. Regression results are displayed in Table 8.24 and Figure 8.24.

Table 8.24: Sophisticated Extreme Bounds Analysis Results for Silver - Model 11: Fixing the Variables identified at the 99% Confidence Interval

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	60.674	39.326	Oil	focus	38.132	61.868
US_CPI	focus	82.730	17.270	GSCI_Non_Prec	focus	59.460	40.540
UK_CPI**	focus	2.912	97.088	S&P_500	focus	36.832	63.168
JP_CPI	focus	61.321	38.679	FTSE100	focus	55.114	44.886
EZ_CPI	fixed	12.071	87.929	Nikkei225	focus	42.879	57.121
PRC_CPI	focus	64.186	35.814	STOXX50	focus	12.716	87.284
World_CPI	focus	47.979	52.021	SSE	focus	47.014	52.986
Agricultural	focus	77.037	22.963	BSE	focus	28.620	71.380
Food	focus	58.688	41.312	MSCI_World	focus	22.558	77.442
US_MB	focus	54.763	45.237	VIX	focus	70.982	29.018
UK_M1	focus	16.810	83.190	US_Recess_Prob	focus	45.980	54.020
JP_M1	focus	13.650	86.350	US_Uncertainty	focus	58.106	41.894
EZ_M1	focus	13.440	86.560	UK_Uncertainty	focus	87.335	12.665
PRC_M1	focus	63.455	36.545	EU_Uncertainty	focus	63.217	36.783
IN_M1*	focus	6.721	93.279	PRC_Uncertainty	focus	60.631	39.369
USD	fixed	77.129	22.871	IN_Uncertainty	focus	74.533	25.467
GBP**	focus	3.036	96.964	US_10**	focus	98.563	1.437
Yen	focus	46.224	53.776	UK_10	focus	89.714	10.286
Euro**	focus	96.496	3.504	JP_10	focus	57.691	42.309
CHF	focus	24.278	75.722	EZ_10*	focus	94.340	5.660
AUD	focus	19.963	80.037	Fund_Rate	focus	43.902	56.098
CAD	focus	28.860	71.140	FX_Reserves	focus	53.780	46.220
Gold***	fixed	0.000	100	Gold_Reserves	focus	53.130	46.870
Palladium**	focus	4.545	95.455	Real_Estate	focus	12.250	87.750
Platinum***	fixed	0.125	99.875				

Figure 8.24: Sophisticated Extreme Bounds Analysis Results for Silver - Model 11: Fixing the Variables identified at the 99% Confidence Interval



8.2.2.11.1 99% Confidence Interval

Only two variables remain significant at the 99% confidence interval in Model 11: the price of gold and the price of platinum. Interestingly, the US Dollar drops out entirely, with only about 77% of the regressors being negatively associated with the price of silver (Table 8.24). This is in line with Model 1 where we discuss the detrimental effects that fixing gold has on the US Dollar.

8.2.2.11.2 95% Confidence Interval

At the 95% confidence interval, the following variables are identified: the UK CPI, the pound sterling, the Euro, the price of palladium, and finally, the US Dollar 10 year Government debt index. While no substantial difference is observed between the unconstrained approach in Table 8.13 for both the UK CPI and the price of palladium that both remain significant at the 95% confidence level, the pound sterling, the Euro and US national debt all appear in Model 11. Previous model specifications revealed that fixing precious metals, gold especially, revealed a co-movement between the British currency and silver. Indeed, given the importance of the United Kingdom, more so as a price maker than as an important player on either the demand or the offer market, the appearance of the British currency when other precious metals are fixed is less surprising than it could initially be believed. The importance of the Euro was so far only relieved when other currencies were fixed across all equations, mainly the US Dollar (Table 8.19). So while a negative relationship between the price of silver and the US Dollar can be observed, the overwhelming negative relationship between the price of silver and the Euro is an indication for a certain hedging capacity of silver against the main European currency - exercised via the bi-lateral relationship between the American and the European currency and revealed in a model fixing the US Dollar. The effects of fixing gold are also observed through the appearance of the US 10 year Government bond index - see Table 8.14 for a comparison. With the relationship being negative between US debt and the price of silver, this can be understood as an indication of the more speculative aspects of silver in comparison to gold, which usually offers protection in times of financial turmoils and acts as a hedge and safe haven against debt instruments as well (Baur and Lucey (2010)).

8.2.2.11.3 90% Confidence Interval

Finally, two variables appear to be significant at the 90% confidence level: Indian money supply and the Eurozone 10 year Government bond index. So far, the Indian monetary base index appeared in every model specification, except in the *inflationary* models 9 and 10 (Tables 8.22 and 8.23). While most papers don't consider working with Indian macroeconomic indicators to explain the price of silver, the results highlighted in this chapter offer further evidence for the importance of the Asian economy in affecting the price of silver. The appearance of the Eurozone Debt index is a direct consequence of fixing the price of gold in the model (Table 8.14). Similar to what is observed for US American debt, the negative relationship indicates the more speculative nature of silver, where prices seem to fall when debt yields rise.

8.2.2.11.4 Sign Shifts

The following set of variables changes sign when comparing the unconstrained model (Figure 8.13) to Model 11 (Figure 8.24): the US CPI, the Japanese CPI, the Chinese CPI, the Agricultural and Raw Material price index, the Food price index, Chinese money supply, the Euro, the VIX, the UK Economic Uncertainty index, and finally, the Japanese 10 year Government debt index. The shifts in distribution of the regressors are due to individual variables being fixed, such as the Chinese monetary base and the VIX as a direct result of fixing gold. This chapter already uncovered the effects on nominal inflation series when fixing white precious metal prices across all equations. Indeed, the sign changes for all series mentioned can be attributed to one of the four variables fixed in the system.

8.3 Conclusion

Building upon the vast majority of variables found to influence the price of gold (O'Connor et al. (2015)) and silver (Chapter 3), I have re-coded the Extreme Bound Analysis of Hlavac (2016) to uncover which variables are associated with changes in the price of the two precious metals.

Results for gold uncover the importance of *classic* variables, namely the US Dollar, inflation, international currencies, other metals, and bond indices. More interestingly, however, results uncover the importance of two new variables: British economic uncertainty and the S&P Case-Shiller National Home Price Index. Important insights for market actors and researchers who now know that gold prices are more strongly associated with the state of the British economy, where the price of gold originates, and the movements of American real estate prices, a determining factor of the recent Global Financial Crisis. Other crucial insights obtained in this chapter and of importance to investors and traders is the role played by gold in the Chinese economy, where it acts as a luxury good rather than a financial asset.

Regarding silver, currency movements, international inflation rates, and commodities are identified as the main variables associated with changes in the price of the precious metal. Important results for market actors are that British macroeconomic indicators are more important than suggested by the related literature; more specifically, the relationship between silver and the UK CPI is stronger than between silver and the US CPI. Also, sophisticated system specifications indicate that the US Dollar is not a stand-alone currency associated with movements in the price of silver, but that a wider set of international currencies plays a role in the price of silver. At last, weaker relationships between the price of silver and international debt and equity measures indicate that silver is the more speculative asset in comparison to gold.

CHAPTER 9

A Panel Approach on the Physical Demand Drivers of Gold and Silver

Which factors drive the price of gold and silver? Many papers have addressed this question from different angles; the answer depends on the researchers' view and definition of precious metals: investment asset, industrial asset, or a mixture of both? While the previous Chapters focused on the influence of macroeconomic variables on the price of gold and silver, this Chapter investigates the relationship between a set of macroeconomic variables and the physical demand for gold and silver across a multitude of countries. Different panel and non-panel models are used and tested for goodness of fit in order to derive empirical insights into the drivers of physical demand for precious metals. This chapter contributes to the economic literature by identifying the drivers of physical gold and silver demand and differentiates between different types of demand.

Results for total gold demand indicate a positive relationship with short-term yields and economic uncertainty, suggesting an increase in demand when the economic climate is bad. The exact opposite is observed for industrial gold demand, where a positive relationship with economic activity is observed. Furthermore, results indicate a rising luxury demand linked to increases in national wealth, and towards a positive relationship between investment demand for gold and both inflation and economic uncertainty.

Considering silver, results are found to be more country-specific, pointing towards the greater complexity of the nature of silver: investment asset or industrial asset. Indeed, considering total physical demand for silver, only money supply seems to be significantly associated with changes in demand, while increases in luxury demand seem to occur in fruitful economic climates. Results for investment demand are somewhat puzzling, where a positive relationship with money supply might be suggesting possible inflation hedging abilities, though the negative relationship with the CPI is rejecting such a conclusion. Finally, clearer results are obtained for production demand, where a positive relationship with the GDP, alongside a negative relationship with economic uncertainty points towards the importance of a fruitful economic climate in determining the level of physical silver demand as a production input.

9.1 Gold

While a large amount of research exists on the implications and the effects of certain macroeconomic variables on the price of gold, only one formal investigation exists on the drivers of physical demand for gold. In this section the total amount of physical gold demanded in 17 different countries was calculated manually and multiple models are applied to investigate the importance of certain macroeconomic indicators on the amount of physical gold purchased. The seventeen countries considered are: Australia, Canada, China, Egypt, Germany, India, Italy, Japan, Mexico, Russia, Saudi Arabia, South Korea, Switzerland, Thailand, Turkey, the United Kingdom of Great Britain and Northern Ireland, and finally, the United States of America.

9.1.1 Total Demand

The total demand is the aggregated sum of gold demand required for jewellery production, gold demanded for investment purposes, and gold required for industrial production, mainly in electronics.

9.1.1.1 General-to-Specific Model Prediction

The General-to-Specific (GenSpec) procedure is used to detect the best model specification taking into account 17 different panels and individuals macroeconomic values for each countries. Results of linear regression analyses are displayed in Table 9.1.

Table 9.1: General-to-Specific Modelling Algorithm: Total Demand for Gold

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.19283	0.01953	9.87	0.000	0.15430	0.23137
lngdp	-0.31872	0.02637	-12.09	0.000	-0.37074	-0.26671
lnexchange	0.12768	0.01729	7.39	0.000	0.09358	0.16177
lyield	-0.14002	0.04439	-3.15	0.002	-0.22757	-0.05247
syield	0.14304	0.03718	3.85	0.000	0.06970	0.21638
lnuncertainty	0.31900	0.06969	4.58	0.000	0.18153	0.45646
_cons	10.1564	0.56309	18.04	0.000	9.0458	11.26705

The results of the GenSpec procedure suggest that the best model explaining changes in the physical demand for gold when taking data of 17 countries into consideration consists of the following variables: money supply, the GDP, the exchange rate to the US Dollar, long term and short term interest rates, and finally, the country's Economic Uncertainty index. In other words, Table 9.1 suggests that the national CPI rate and the level of the national equity index are not relevant in modelling the demand for physical gold across the set of countries considered. While the results for both the CPI rate and the equity index are consistent with previous research on physical gold, by Starr and Tran (2008), they are surprising in the light of the numerous results suggesting that the two variables should indeed have a relationship with gold. Keeping in mind the initial results provided by the GenSpec model in Table 9.1, the R^2 value of 0.5798 as well as the adjusted R^2 of 0.5667 suggest that the model is by far not optimal and requires further investigation.

9.1.1.2 Optimising Linear Regression Models

The investigation is continued by running a simple pooled Ordinary Least Squares (OLS) regression specifying the standard errors as robust to model misspecification.

Table 9.2: Pooled OLS Regression: Total Demand for Gold

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.17292	0.01881	9.19	0.000	0.13582	0.21001
lncpi	0.10177	0.23351	0.44	0.663	-0.35884	0.56237
lngdp	-0.29987	0.02423	-12.37	0.000	-0.34768	-0.25207
lnexchange	0.11639	0.02206	5.28	0.000	0.07288	0.15990
lyield	-0.16751	0.06223	-2.69	0.008	-0.29025	-0.04477
syield	0.14435	0.05836	2.47	0.014	0.02923	0.25946
lnequity	-0.09475	0.05912	-1.60	0.111	-0.21136	0.02185
lnuncertainty	0.27217	0.09070	3.00	0.003	0.09327	0.45107
_cons	10.69103	1.98452	5.39	0.000	6.7765	14.60555

Results in Table 9.2 support the findings of the GenSpec procedure in Table 9.1, namely that the CPI and stock market indices have no significant relationship with the price of gold in the panel data model proposed. Again, the same results are found in Starr and Tran (2008) taking into account physical gold demand between 1992 and 2003, a much shorter sample than the 25 years sample taken into account in the investigation presented here. However, the model presented in Table 9.2 only has an R^2 value of 0.5883, therefore challenging the quality of linear regression models in regard to the panel data on hand.

An important question to raise in the light of the previous results is to understand if it properly fits the data. The Lagrange Multiplier test by Breusch and Pagan (1979) is used to test for misspecification in the model proposed in Table 9.2.

Table 9.3: Breusch and Pagan Lagrangian Multiplier Test for Random Effects: Total Demand for Gold

	Var	sd = sqrt (Var)
lngdemand	1.255042	1.120286
e	0.116359	0.3411144
u	2.017151	1.420264
	$\bar{\chi}^2$ (1)	168.64
	Prob $>\bar{\chi}^2$	0.0000

The test results displayed in Table 9.3 advice to reject the null hypothesis and suggest that the variance of the unobserved fixed effects is different than 0 - a pooled OLS regression might therefore not be the appropriate model to use.

In order to build a good model to fit the physical gold demand data of the 17 countries in the system, an essential question is to understand if the data should be fitted in a random effect or a fixed effect model. The Hausman Specification Test (Hausman (1978)) is used to determine whether or not the coefficients should be determined by a random or a fixed effect model.

Table 9.4: Hausman Specification Test: Total Demand for Gold

	(b) Fixed	**(B) Random**	**(b-B) Difference**	**sqrt(diag($V_b - V_B$)) S.E.**
lnmoney	-0.43509	-0.24014	-0.19495	0.06363
lncpi	-1.59667	-0.99779	-0.59888	0.34198
lngdp	1.18667	0.02337	1.16330	0.43084
lnexchange	-0.33014	-0.05041	-0.27973	0.14255
lyield	-0.06516	-0.09073	0.02557	0.00521
syield	0.04523	0.05944	-0.01422	0.00000
lnequity	0.37140	0.34840	0.02300	0.02690
lnuncertainty	0.34916	0.33627	0.01289	0.00000
			χ^2 (8)	43.13
			Prob $>\chi^2$	0.0000

Results in Table 9.4 suggest rejecting the null hypothesis and that a fixed effect specification should be used in modelling the total physical demand for gold across countries.

In a final step, a linear panel data model is run in which the coefficients are approximated by a fixed effects estimator.

Table 9.5: Fixed Effects Linear Regression Model: Total Demand for Gold

	Coef.	**Std.**	**Err.**	**t**	**P>|t|**	**95% Confidence Interval**
lnmoney	-0.43509	0.12102	-3.60	0.000	-0.67390	-0.19628
lncpi	-1.59667	0.51600	-3.09	0.002	-2.61489	-0.57844
lngdp	1.18667	0.46942	2.53	0.012	0.26036	2.11297
lnexchange	-0.33014	0.18348	-1.80	0.074	-0.69219	0.03192
lyield	-0.06516	0.03093	-2.11	0.037	-0.12618	-0.00413
syield	0.04523	0.01981	2.28	0.024	0.00614	0.08431
lnequity	0.37140	0.10066	3.69	0.000	0.17276	0.57003
lnuncertainty	0.34916	0.07995	4.37	0.000	0.19140	0.50692
_cons	11.97691	4.57720	2.62	0.010	2.94469	21.00912
σ_u	3.89851					
σ_e	0.34111					
ρ	0.99240					

The results in Table 9.5 are very interesting as they seem to identify every variable as being significant at the 90% confidence level. In the fixed effects model specification of Starr and Tran (2008), both inflation and equity indices also appear to be significant. It should furthermore be noted, that the exchange rate fails to be significant at the 95% confidence level, results in conflict with previous model specification. Furthermore, with an R^2 value of 0.4664, the model in Table 9.5 is far from being optimal, suggesting to consider a more sophisticated approach rather than a simple linear regression.

9.1.1.3 Dynamic Regression Models

In light of the results highlighted in the previous section and the failure of linear regression models to fully capture the effects of different macroeconomic variables on the amount of physical gold demanded in different countries, dynamic regression models are proposed in order to deliver better results.

In order to select the most appropriate model specification, a Wooldridge test (Wooldridge (2002)) is implemented to test for serial correlation in the idiosyncratic errors of the linear panel-data model.

Table 9.6: Wooldridge Test for Autocorrelation in Panel Data: Total Demand for Gold

F (1, 11)	=	19.112
Prob >F	=	0.0011

The results in Table 9.6 suggest to reject the null hypothesis of no first-order autocorrelation, advising to proceed with a dynamic regression model able to fit low-order moving average correlation in the idiosyncratic error.

Table 9.7: Linear Dynamic Panel-Data Estimation: Total Demand for Gold

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
lnmoney	-0.40269	0.06566	-6.13	0.000	-0.53138	-0.27399
lncpi	-1.32638	0.28198	-4.70	0.000	-1.87906	-0.77371
lngdp	0.90758	0.25652	3.54	0.000	0.40482	1.41034
lnexchange	-0.20172	0.10070	-2.00	0.045	-0.39909	-0.00436
lyield	-0.05365	0.01685	-3.18	0.001	-0.08667	-0.02063
syield	0.03950	0.01082	3.65	0.000	0.01830	0.06070
lnequity	0.43865	0.05536	7.92	0.000	0.33014	0.54715
lnuncertainty	0.35836	0.04342	8.25	0.000	0.27325	0.44347
_cons	11.67001	2.48238	4.70	0.000	6.80463	16.53539

The results of the dynamic model in Table 9.7 are in line with the results of the linear fixed effect model in Table 9.6, namely that all the variables in the system are identified as significant in a system explaining changes in demand for physical gold across multiple countries. These results are also in line with Starr and Tran (2008) who only identify inflation rates and stock market indices as significant under more complex model specifications. It should also be noted that the exchange rate to the US Dollar is again the *weakest* variable in the model (Tables 9.6 and 9.7).

In the light of somewhat conflicting results in regard to certain variables, leading the way the CPI indices and the stock market indices, the bias-corrected Least-Squares Dummy Variables (LSDVC) dynamic panel data estimator is used to have optimal results in the light of a relatively small amount of data points.

Table 9.8: LSDVC Dynamic Panel-Data Estimation: Total Demand for Gold

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
L1.lngdemand	0.78665	0.04677	16.82	0.000	0.69498	0.87833
lnmoney	-0.09607	0.07801	-1.23	0.218	-0.24896	0.05682
lncpi	-0.34806	0.33039	-1.05	0.292	-0.99560	0.29949
lngdp	0.11212	0.29924	0.37	0.708	-0.47437	0.69862
lnexchange	-0.18624	0.11463	-1.62	0.104	-0.41091	0.03843
lyield	-0.04038	0.01935	-2.09	0.037	-0.07830	-0.00245
syield	0.02080	0.01249	1.66	0.096	-0.00368	0.04528
lnequity	0.06210	0.06538	0.95	0.342	-0.06604	0.19023
lnuncertainty	0.11225	0.05196	2.16	0.031	0.01042	0.21408

Results in Table 9.8 reveal that the CPI indices and the stock market indices are not found to be explanatory variables. Furthermore, money supply also fails to be statistically significant, uncovering very interesting results about the relationship between gold and inflation across a multitude of countries. Indeed, while a linear relationship was identified between gold and inflation in certain countries (Batten et al. (2014), Hoang et al. (2016), or even earlier chapters of this thesis), a linear relationship between the total quantity of gold demanded and the level of inflation can not be empirically derived when considering physical demand data for 17 countries. This finding is an indication that the relationship between inflation and gold is channeled through the price of the precious metal, not through it's demand. In other words: in light of inflation, the price of gold rises without necessarily having to change hands. The results for the GDP are quite surprising since a greater GDP should trigger a larger demand for gold as a production asset, but also trigger a larger demand for gold as a luxury asset and an investment asset given that a greater amount of wealth is now at the disposition of the citizens. Hopefully, results on the breakdown of gold demand provided later on will help to shed more light on the relationship. Economically, a strong relationship between gold demand and the exchange rate would have been expected. Indeed, a weaker US Dollar makes it cheaper for other countries to purchase gold (O'Connor et al. (2015)) given that the yellow precious metal is officially quoted in US Dollars. Further investigation in this chapter will help uncover whether this relationship is only true for certain aspects of gold demand, or whether the economic reasoning proposed by O'Connor et al. (2015) might not apply for physical demand. Only three variables are identified at the 10% level: long term yields, short term yields, and the Economic Uncertainty index. It is not very surprising to see that short term yields and the Economic Uncertainty index have a positive relationship with gold demand: the physical demand for gold is higher when economic uncertainty is high. The same relationship holds for short term yields: when short term yields are high and point towards greater insecurity in the markets, the demand for physical gold rises. The relationship between physical gold demand and long term yields however is negative, so that physical demand for gold drops when long term yields rise. A negative relationship between bond and gold prices was observed by Baur and Lucey (2010) and Baur and McDermott (2010), who find evidence for the ability of gold to function as a hedge against debt prices of certain countries. Results in Table 9.8 offer support to this finding and argue that this negative relationship is also channeled through physical demand as well as through gold prices.

9.1.2 Luxury Demand

Luxury demand is the demand for physical gold arising from jewellery demand. Some countries particularly stand out for their large jewellery consuption, particularly India, where gold jewellery is considered a cultural asset rather than a luxury asset per se. The following section will identify the drivers of physical gold demand for the jewellery consumption across 17 countries.

9.1.2.1 General-to-Specific Model Prediction

In a first step, the General-to-Specific procedure is applied in order to get a basic understanding of which set of variables is the best fit for a linear model explaining gold jewellery consumption.

Table 9.9: General-to-Specific Modelling Algorithm: Luxury Demand for Gold

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.20718	0.01573	13.17	0.000	0.17622	0.23814
lngdp	-0.16611	0.02347	-7.08	0.000	-0.21232	-0.11991
lnexchange	0.097754	0.01912	5.11	0.000	0.06011	0.13540
lyield	0.07619	0.01824	4.18	0.000	0.04028	0.11209
lnequity	-0.33804	0.03975	-8.51	0.000	-0.41629	-0.25979
_cons	11.07939	0.43632	25.39	0.000	10.22037	11.93841

The results in Table 9.9 suggest that a good model reflecting changes in the quantity of physical gold demanded for jewellery consumption should consists of the following variables: money supply, the GDP, the exchange rate, long term Government debt yields, and finally, changes in equity prices. In other words, three variables are deleted out of the system: the country's CPI index, short term yields and economic uncertainty. An ad-hoc explanation on why two macroeconomic variables that reflect possible uncertainty in the underlying economy are not identified as significant could be that India, amongst others, has a record of a steady jewellery demand that seems relatively unaffected by changes in the state of the economy; while a generic explanation could be that gold jewellery is purchased when the economic climate is positive, but also purchased in times of crises, as an anticipated protection rather than for decorative use. However, the coefficient of determination of the model in Table 9.9 is far from optimal: with an R^2 value of

0.5530 and an adjusted R^2 value of 0.5447, a better calibration of the model should be considered.

9.1.2.2 Optimising Linear Regression Models

In a next step, a classical pooled OLS regression specifying the standard errors as robust to model misspecification is run.

Table 9.10: Pooled OLS Regression: Luxury Demand for Gold

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.23030	0.02129	10.82	0.000	0.18830	0.27230
lncpi	-0.11898	0.20675	-0.58	0.566	-0.52681	0.28884
lngdp	-0.26204	0.02592	-10.11	0.000	-0.31318	-0.21091
lnexchange	0.09768	0.02427	4.02	0.000	0.04980	0.14556
lyield	-0.04379	0.07930	-0.55	0.581	-0.20020	0.11263
syield	0.16032	0.07693	2.08	0.038	0.00858	0.31206
lnequity	-0.32059	0.06689	-4.79	0.000	-0.45253	-0.18865
lnuncertainty	0.02013	0.10749	0.19	0.852	-0.19190	0.23216
_cons	12.4166	1.75071	7.09	0.000	8.96327	15.86993

Results in Table 9.10 are somewhat in line with the GenSpec model specification procedure (Table 9.9) where the results indicate that no statistically significant linear association can be observed between the physical demand for gold used in jewellery consumption and both the CPI index and the Economic Uncertainty index. However, while the GenSpec model indicated that long term Government bond yields should be included in the model, a pooled OLS regression tends to favour short term rather than long term yields (Table 9.10). While the coefficient of determination of the pooled OLS is significantly higher than that of the GenSpec procedure, an R^2 value of 0.6262 is still suggesting to continue the endeavour of optimising the linear regression model considered.

The Breusch and Pagan (1979) test is used to identify possible misspecification of the previous model.

Table 9.11: Breusch and Pagan Lagrangian Multiplier Test for Random Effects: Luxury Demand for Gold

	Var	sd = sqrt (Var)
lnldemand	1.75125	1.323348
e	0.0609137	0.2468069
u	2.442971	1.563001
	$\bar{\chi}^2$ (1)	119.41
	Prob >$\bar{\chi}^2$	0.0000

The results in Table 9.11 advice to reject the null hypothesis and identify a variance of unobserved fixed effects different to 0, suggesting that a pooled OLS regression might not be the appropriate model to use.

Uncovering the question whether the data should be fitted in a random effect or a fixed effect model, the Hausman Specification Test (Hausman (1978)) is run to determine the optimal determination of the coefficients in the model.

Table 9.12: Hausman Specification Test: Luxury Demand for Gold

	(b) **Fixed**	**(B)** **Random**	**(b-B)** **Difference**	**sqrt(diag($V_b - V_B$))** **S.E.**
lnmoney	-0.84267	-0.65786	-0.18480	0.03820
lncpi	-2.42540	-1.57461	-0.85079	0.22965
lngdp	2.01146	0.36112	1.65034	0.29274
lnexchange	0.36893	0.20546	0.16347	0.08972
lyield	0.01068	-0.01382	0.02450	0.00689
syield	-0.00966	0.00491	-0.01457	0.00182
lnequity	0.27685	0.33724	-0.06039	0.02432
lnuncertainty	-0.04107	-0.04277	0.00170	0.00684
			χ^2 (8)	68.36
			Prob >χ^2	0.0000

Results in Table 9.12 suggest working with a fixed effect specification when modelling changes in the physical demand for gold used in jewellery consumption.

A linear panel data model approximating the coefficients by a fixed effects estimator is therefore run in a final step.

Table 9.13: Fixed Effects Linear Regression Model: Luxury Demand for Gold

	Coef.	**Std.**	**Err.**	**t**	**P>|t|**	**95% Confidence Interval**
lnmoney	-0.84267	0.08756	-9.62	0.000	-1.01545	-0.66988
lncpi	-2.42540	0.37334	-6.50	0.000	-3.16211	-1.68868
lngdp	2.01146	0.33964	5.92	0.000	1.34125	2.68167
lnexchange	0.36893	0.13275	2.78	0.006	0.10698	0.63089
lyield	0.01068	0.02238	0.48	0.634	-0.03347	0.05484
syield	-0.00966	0.01433	-0.67	0.501	-0.03794	0.01862
lnequity	0.27685	0.07283	3.80	0.000	0.13313	0.42056
lnuncertainty	-0.04107	0.05784	-0.71	0.479	-0.15521	0.07308
_cons	10.65641	3.31175	3.22	0.002	4.12132	17.19150
σ_u	6.23528					
σ_e	0.24681					
ρ	0.99844					

The results in Table 9.13 identify the following variables as significant: money supply, CPI indices, the GDP, the national exchange rate to the US Dollar, and finally, national stock market indices. In line with previous model specifications (Tables 9.9 and 9.10), debt yields and economic uncertainty indices are not found to have a significant relationship with the physical demand for gold in jewellery production across the 17 countries considered. However, the CPI is identified as statistically significant in Table (9.13), while both the GenSpec procedure (Table 9.9) and a pooled OLS model (Table 9.10) observed an opposed result. The R^2 value of the fixed effects linear regression model amounts to 0.1337, suggesting that the model as such fails to deliver robust results. A dynamic approach should therefore be considered.

9.1.2.3 Dynamic Regression Models

In order to select the most appropriate model, the Wooldridge (2002) test for autocorrelation in panel data is applied.

Table 9.14: Wooldridge Test for Autocorrelation in Panel Data: Luxury Demand for Gold

F (1, 11)	=	51.747
Prob >F	=	0.0000

Results in Table 9.14 indicate autocorrelation in the data and advice to proceed with a dynamic regression model that is able to fit low-order moving average correlation in the idiosyncratic error.

Table 9.15: Linear Dynamic Panel-Data Estimation: Luxury Demand for Gold

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
lnmoney	-0.85950	0.03608	-23.82	0.000	-0.93021	-0.78879
lncpi	-2.29112	0.15343	-14.93	0.000	-2.59184	-1.99040
lngdp	1.94865	0.14057	13.86	0.000	1.67313	2.22417
lnexchange	0.44273	0.05480	8.08	0.000	0.33533	0.55014
lyield	0.00572	0.00927	0.62	0.537	-0.01245	0.02389
syield	-0.01044	0.00588	-1.77	0.076	-0.02198	0.00109
lnequity	0.26575	0.03079	8.63	0.000	0.20540	0.32610
lnuncertainty	-0.05618	0.02386	-2.36	0.019	-0.10294	-0.00942
_cons	10.48549	1.35022	7.77	0.000	7.83911	13.13187

The results in Table 9.15 are not very helpful in shedding additional light on the problem as it identifies every variable as statistically significant except for short term yields. Instead, a panel data approach optimised for a small amount of data points should be considered. The bias-corrected Least-Squares Dummy Variables (LSDVC) procedure is used to propose a more reliable model of the dataset on hand.

Table 9.16: LSDVC Dynamic Panel-Data Estimation: Luxury Demand for Gold

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
L1.lnldemand	0.82649	0.03852	21.46	0.000	0.75100	0.90198
lnmoney	-0.07822	0.05792	-1.35	0.177	-0.19175	0.03530
lncpi	-0.70786	0.21177	-3.34	0.001	-1.12291	-0.29280
lngdp	0.08229	0.19893	0.41	0.679	-0.30761	0.47219
lnexchange	-0.00178	0.07146	-0.02	0.980	-0.14184	0.13828
lyield	-0.00639	0.01173	-0.54	0.586	-0.02939	0.01660
syield	-0.00671	0.00753	-0.89	0.373	-0.02147	0.00804
lnequity	0.07642	0.03917	1.95	0.051	-0.00035	0.15319
lnuncertainty	-0.02431	0.03032	-0.80	0.423	-0.08374	0.03513

Results in Table 9.16 only identify the CPI and the national equity indices as having a statistically significant degree of linear association with physical gold demand through the bias of jewellery consumption. The results for the CPI are conflicting with the previous models which suggested that no association between inflation rates and jewellery consumption exists. However, equity indices were also identified as relevant in previous model specification. It can therefore be concluded with certain confidence, that a positive relationship between higher equity prices and greater jewellery consumption exists (Table 9.16). In the light that high equity prices both reflect and lead to a greater amount of wealth in the population, a positive relationship with the demand for luxury products is economically easily understandable. The negative relationship with the CPI that failed to appear in a linear model, suggests a lower consumption of gold jewellery during times of greater inflation. This again makes sense in the light that individuals spend more money on goods they deem as really necessary rather than on luxury products such as jewellery. No relationship is identified between jewellery consumption and debt yields. While different models offered conflicting result on the relationship between the variables, the final LSDVC procedure suggested no significant relationship between them (Table 9.16). In light of the above findings, some variables demand additional care, such as the GDP and the exchange rate to the US Dollar; indeed, linear regression models suggested some sort of relationship while dynamic approaches offered conflicting results.

9.1.3 Investment Demand

Investment demand consists of the identified physical demand for bars and coins in each of the 17 countries mentioned above. So in contrary to the two other demand facets, luxury and production demand, investment demand for physical gold is not a consumptive demand; instead the gold bought is hoarded in anticipation of rising prices or an economic downturn. The following section will identify the drivers of physical investment demand into gold across 17 countries.

9.1.3.1 General-to-Specific Model Prediction

The General-to-Specific procedure is applied to get an understanding of the variables that are likely to explain movements and changes in physical investment demand.

Table 9.17: General-to-Specific Modelling Algorithm: Investment Demand for Gold

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnequity	0.53101	0.12222	4.34	0.000	0.29029	0.77174
lnuncertainty	0.67404	0.19884	3.39	0.001	0.28239	1.06569
_cons	1.62370	1.49617	1.09	0.279	-1.32323	4.57063

Results in Table 9.17 identify two variables: the level of the national stock market index and the Economic Uncertainty index. The coefficients suggest a positive relationship between gold investment demand and the level of economic uncertainty in the country, an economically sound result in the light of gold's alleged role as protection asset during times of economic and political tensions. On the other hand, a negative relationship with stock market indices could have been expected, indicating that gold would serve as an equity hedge (Baur and Lucey (2010)). While the previous chapter of this thesis uncovered a positive relationship between the price of gold and certain equity indices, mainly in Asia, the positive relationship identified for physical investment demand could be an indication, that in certain countries, a new creation of wealth led to investment into physical gold for reasons of disposable income rather than for the sake of wealth protection per se. An example is China, were the demand quantity for physical gold was growing alongside the level of wealth of the country (Gold Field Mineral Services Ltd. (2016)). However, the R^2 and adjusted R^2 values of the GenSpec model are quite low: with 0.0886 and 0.0812 respectively, they suggest to recalibrate the model.

9.1.3.2 Optimising Linear Regression Models

Building upon the results displayed in Table 9.17, the investigation is continued by running a pooled OLS regression in which the standard errors are specified as robust to possible model misspecification.

Table 9.18: Pooled OLS Regression: Investment Demand for Gold

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	-0.08018	0.05774	-1.39	0.167	-0.19409	0.03372
lncpi	1.54311	0.55553	2.78	0.006	0.44731	2.63891
lngdp	0.06757	0.08180	0.83	0.410	-0.09378	0.22893
lnexchange	-0.26088	0.07139	-3.65	0.000	-0.40170	-0.12006
lyield	-0.15750	0.19332	-0.81	0.416	-0.53883	0.22382
syield	0.22624	0.13564	1.67	0.097	-0.04132	0.49380
lnequity	0.29240	0.20579	1.42	0.157	-0.11352	0.69833
lnuncertainty	0.62715	0.20004	3.14	0.002	0.23256	1.02174
_cons	-5.26810	5.06208	-1.04	0.299	-15.25320	4.71700

Regression results in Table 9.18 support the findings in Table 9.17; that there is a positive linear relationship between investment demand for gold and economic uncertainty. However, no significant linear association is observed between the level of national equity and the amount of investment demand in Table 9.18, results opposed to those in Table 9.17. Furthermore, three additional variables are identified in the later procedure, namely: the CPI, the national exchange rate to the US Dollar, and finally, short term interest rates. It should be noted that the relationship with both the CPI and the short term yields is positive. In other words, investment demand for gold rises alongside inflation, a finding that is somewhat expected and also the very subject of previous parts of this thesis. The positive relationship with short term interest yields is a further indication of a rising investment demand into gold when the economic climate is complicated: indeed, short term debt yields can be considered a reliable proxy for the state of the economic climate. Finally, the negative relationship between national exchange rates to the US Dollar and physical investment demand is in line with the argumentation of O'Connor et al. (2015), that a weak US Dollar makes it cheaper for other countries to buy gold. Indeed, the results are an indication that when a currency grows in strength against the Dollar, the market actors of that given economy tend to purchase more physical gold for investment reasons. It is worth noting that the R^2 value of the pooled OLS procedure, 0.2387, is significantly higher than that of the GenSpec procedure.

Having now considered two linear regression models, an important issue arises in terms of model fitness. In other words, whether or not OLS specifications are appropriate for the data on hand. A Breusch and Pagan (1979) procedure is used to test for model misspecification.

Table 9.19: Breusch and Pagan Lagrangian Multiplier Test for Random Effects: Investment Demand for Gold

	Var	**sd = sqrt (Var)**
lnidemand	7.905248	2.811627
e	5.155148	2.270495
u	2.066116	1.437399
	$\bar{\chi}^2$ (1)	0.65
	Prob $>\bar{\chi}^2$	0.2092

The results in Table 9.19 suggest failing to reject the null hypothesis and therefore that the variance of the unobserved fixed effects is null. More specifically, there is no evidence of significant differences across the countries - a simple OLS regression is therefore appropriate.

In the light of robust results, the investigation could be terminated here: indeed, findings suggest that the difference in the type and nature of variables identified by a simple linear regression procedure does not depend on the country considered per panel (9.19). However, for the pure sake of argumentation, the investigation is continued and dynamic approaches considered that will differentiate amongst the individual panels. In a first step, the Hausman (1978) Specification Test is run to determine whether or not the coefficients should be determined by a random or fixed effect model.

Table 9.20: Hausman Specification Test: Investment Demand for Gold

	(b) Fixed	**(B) Random**	**(b-B) Difference**	**sqrt(diag($V_b - V_B$)) S.E.**
lnmoney	-2.08860	-0.13447	-1.95413	0.78229
lncpi	12.56170	1.62354	10.93816	3.28355
lngdp	-7.66229	0.04157	-7.70386	3.11390
lnexchange	-0.48677	-0.18258	-0.30419	1.20982
lyield	-0.35557	-0.12713	-0.22844	0.11702
syield	0.06115	0.10991	-0.04876	0.03243
lnequity	0.98335	0.58288	0.40047	0.56643
lnuncertainty	0.43485	0.67579	-0.24094	0.33420
			χ^2 (8)	1.96
			Prob >χ^2	0.9821

Not surprisingly, the results in Table 9.20 suggest failure to reject the null hypothesis and to suggest a random effect specification. Running a random effect model should however deliver inferior results to the pooled OLS shown in Table 9.18 as the Breusch and Pagan (1979) procedure advised favouring a linear regression to more complex model specifications.

Table 9.21: Random Effects Linear Regression Model: Investment Demand for Gold

	Coef.	**Std.**	**Err.**	**t**	**P>|t|**	**95% Confidence Interval**
lnmoney	-0.13447	0.19205	-0.70	0.484	-0.51088	0.24195
lncpi	1.62354	1.00715	1.61	0.107	-0.35044	3.59752
lngdp	0.04157	0.25724	0.16	0.872	-0.46261	0.54575
lnexchange	-0.18258	0.16659	-1.10	0.273	-0.50909	0.14394
lyield	-0.12713	0.16935	-0.75	0.453	-0.45905	0.20479
syield	0.10991	0.12778	0.86	0.390	-0.14054	0.36036
lnequity	0.58288	0.35786	1.63	0.103	-0.11851	1.28427
lnuncertainty	0.67579	0.41410	1.63	0.103	-0.13583	1.48742
_cons	-7.20782	8.58740	-0.84	0.401	-24.03882	9.62318
σ_u	1.43740					
σ_e	2.27049					
ρ	0.28612					

As suggested, no variable is identified as significant in Table 9.21. Again, the Breusch and Pagan (1979) results suggested to stick with the results in Table 9.18, and the continuation of the panel data investigation into the drivers of investment demand for gold should be considered in the light of a robustness procedure to *doublecheck* that the results would indeed have been inferior. An R^2 value of 0.2074 was identified for the random effects linear regression model in Table 9.21.

9.1.3.3 Dynamic Regression Models

While linear models are found to be sufficient to model the changes in gold investment demand due to insignificant differences between the different countries, dynamic regression models can be used to detract information that would be dependent on the panels considered. So while the above regression delivered empirical results, dynamic panel modelling is used to identify possible variables that might have gone down in a classical OLS approach.

A Wooldridge (2002) procedure is run in order to test for autocorrelation in the panel data.

Table 9.22: Wooldridge Test for Autocorrelation in Panel Data: Investment Demand for Gold

F (1, 11)	=	3.079
Prob >F	=	0.1071

The results in Table 9.22 suggest that there is no first-order autocorrelation in the data, advising to proceed with an Arellano and Bond (1991) dynamic panel-data procedure optimised for datasets with many panels and only a few periods.

Table 9.23: Arellano and Bond (1991) Dynamic Panel-Data Estimation: Investment Demand for Gold

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
L1.lnidemand	0.54833	0.06893	7.96	0.000	0.41324	0.68343
lnmoney	-0.88004	0.72567	-1.21	0.225	-2.30233	0.54225
lncpi	4.31713	3.25947	1.32	0.185	-2.07131	10.70556
lngdp	-2.40289	2.87806	-0.83	0.404	-8.04378	3.23799
lnexchange	0.14239	1.09170	0.13	0.896	-1.99731	2.28209
lyield	-0.33581	0.18256	-1.84	0.066	-0.69363	0.02201
syield	0.13345	0.11782	1.13	0.257	-0.09748	0.36439
lnequity	0.37587	0.60840	0.62	0.537	-0.81659	1.56832
lnuncertainty	0.43273	0.47050	0.92	0.358	-0.48944	1.35490
_cons	13.37387	27.22846	0.49	0.623	-39.99293	66.74066

Results in Table 9.23 identify a negative relationship between physical investment demand for gold and long term interests. So the demand for gold as an investment asset in a given country is higher if the long term interest rates of that given country are low. In light of the previously identified positive relationship between physical gold investment demand and national equity prices, the findings of Table 9.23 support the argumentation that more wealth in a country seems to favour investment demand, rather than a negative long-term outlook on the economy that could lead market actors to purchase gold in anticipation of troublesome times ahead. It should be noted that some countries in the dataset, such as China or India have seen their demand for gold rise very strongly over the sample period as well as the relative wealth of their citizens. This identified positive relationship between long term yields and investment demand is a reflection of the mentioned phenomenon.

In a next step, the Blundell and Bond (1998) procedure is considered. This procedure is very similar to Arellano and Bond (1991) but uses additional moments conditions and includes lagged differences of the observations. Methodologically very close to one another, the Blundell and Bond (1998) procedure is run to check that the results obtained are not too far away from those delivered by the Arellano and Bond (1991) procedure in Table 9.23.

Table 9.24: Blundell and Bond (1998) Dynamic Panel-Data Estimation: Investment Demand for Gold

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
L1.lnidemand	0.52514	0.05479	9.59	0.000	0.41775	0.63252
lnmoney	0.00231	0.24894	0.01	0.993	-0.48559	0.49022
lncpi	1.60453	1.78221	0.90	0.368	-1.88853	5.09759
lngdp	-0.10498	0.26517	-0.40	0.692	-0.62470	0.41474
lnexchange	0.02416	0.14891	0.16	0.871	-0.26769	0.31602
lyield	-0.22657	0.14436	-1.57	0.117	-0.50951	0.05636
syield	0.18341	0.10404	1.76	0.078	-0.02050	0.38732
lnequity	0.14091	0.32734	0.43	0.667	-0.50066	0.78248
lnuncertainty	0.29217	0.37570	0.78	0.437	-0.44419	1.02854
_cons	-8.01489	11.89474	-0.67	0.500	-31.32815	15.29838

Findings in Table 9.24 point towards the importance of short term yields rather than long term yields (Table 9.23). However, the positive relationship between short term yields and investment demand for gold is in line with linear regression results

(Table 9.21) where it was argued that investment demand rises alongside short term interest rates, a proxy for the state of the economy. In the light of somewhat conflicting results in Tables 9.23 and 9.24, which are on the one hand pointing towards the importance of debt yields, but on the other hand unclear about whether long-term or short-term interest rates are more important, a Least Squares Dummy Variables (LSDVC) dynamic panel data estimator is run to help reconciling the results obtained from different dynamic regression models specifications.

Table 9.25: LSDVC Dynamic Panel-Data Estimation: Investment Demand for Gold

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
L1.lnidemand	0.55552	0.06569	8.46	0.000	0.42678	0.68427
lnmoney	-0.89626	0.69784	-1.28	0.199	-2.26401	0.47148
lncpi	3.90851	3.09304	1.26	0.206	-2.15374	9.97076
lngdp	-2.04618	2.73196	-0.75	0.454	-7.40073	3.30837
lnexchange	0.01399	1.03769	0.01	0.989	-2.01985	2.04783
lyield	-0.34894	0.17485	-2.00	0.046	-0.69165	-0.00624
syield	0.14205	0.11283	1.26	0.208	-0.07910	0.36320
lnequity	0.29228	0.57572	0.51	0.612	-0.83611	1.42068
lnuncertainty	0.42831	0.45262	0.95	0.344	-0.45881	1.31543

The LSDVC results in Table 9.25 provide results in favour of the Arellano and Bond (1991) procedure and suggest that a negative relationship between long term debt yields and investment demand for physical gold exists.

Overall, the results are very insightful. In contrary to total and luxury demand for gold, the empirical aspects for investment demand can be captured by a linear regression model. The results of a pooled OLS approach show evidence for a significant positive relationship between inflation and economic uncertainty with the investment demand for gold. Furthermore, a positive relationship is also identified between short term interest rates and gold investment demand, pointing towards the alleged protection abilities of gold. Another variable identified as significant is the national exchange rate to the US Dollar, where a negative relationship is in line with the argumentation that a weaker US Dollar makes non-American gold purchases cheaper (O'Connor et al. (2015)). Though the linear approaches can be considered robust enough to derive empirical observations, the second part of the investigation into the drivers of gold investment demand looked into dynamic regression models which pointed out a negative relationship between investment demand and long term interest rates. In the latter model specifications, more weighting is allocated to the differences amongst panels, suggesting that the negative relationship is country specific rather than empirical. However, the rise of the demand for gold in certain new economies, such as China and India, alongside dropping interest rates linked to economic growth is indeed an observation in line with the above finding.

9.1.4 Production Demand

The production demand for gold is composed of three main elements: electronics, dental and medical, and other, non-attributable industry demand. Being alongside jewellery consumption a demand facet where gold is consumed rather than hoarded, this section will identify the drivers of industrial gold demand using linear and non-linear modelling approaches on a panel dataset consisting of 17 different countries.

9.1.4.1 General-to-Specific Model Prediction

The GenSpec procedure is applied in order to get a basic understanding of which variables are likely to explain movements in industrial demand for gold.

Table 9.26: General-to-Specific Modelling Algorithm: Production Demand for Gold

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lngdp	-0.52071	0.04200	-12.40	0.000	-0.60338	-0.43803
lnexchange	0.19189	0.03529	5.44	0.000	0.12242	0.26136
lyield	-0.27786	0.03251	-8.55	0.000	-0.34186	-0.21386
lnequity	-0.20445	0.07323	-2.79	0.006	-0.34861	-0.06029
_cons	17.50999	0.73994	23.66	0.000	16.05333	18.9667

Results in Table 9.26 highlight four variables: the GDP, the national exchange rate to the US Dollar, long term debt yields, and finally, national stock price indices. The significant negative relationship with the GDP is very suprising; indeed, a positive relationship between a country's Gross Domestic Product and the amount of gold consumed by the industry could have been expected. Instead, the GenSpec procedure seems to suggest that a higher GDP is associated with a lower demand for gold as an input of production. The significant negative relationship between national exchange rates to the US Dollar and gold demand for production is not less surprising; Table 9.26 suggests a linear association between a greater demand for gold when the US Dollar is stronger. Previous results of this thesis suggested a negative relationship between the US Dollar and the price of gold, where a strong US Dollar is associated with a lower price of gold. However, the findings pointing towards a negative relationship between the price of gold and exchange rates to the US Dollar shouldn't be attributed directly to a weakening of the gold price as the *Dollar effect* might vanish in light of a weakening power of the currency. So while a stronger US Dollar might push down the price of gold, it doesn't necessarily do so from the point of view of a foreign investor. The suggested relationship between gold and long-term equity yields is negative, pointing towards an association between higher yields and a smaller gold demand for production purposes. In light of higher interest rates paid by Governments when the national industry weakens, the findings in Table 9.26 are in line with basic economic intuition. Finally, the negative relationship between equity prices and production demand for gold is indicating an association between higher stock index levels and smaller production demand for gold. So it seems that the national production demand for gold is smaller when the biggest public companies of that country are doing well; a result that might be linked to the under-representation of gold demanding companies in the stock indices. The R^2 and adjusted R^2 values are 0.5301 and 0.5232 respectively, suggesting a recalibration of the model.

9.1.4.2 Optimising Linear Regression Models

The investigation into the drivers of production demand for physical gold is continued by running a pooled OLS regression in which standard errors are specified as robust to model misspecification.

Table 9.27: Pooled OLS Regression: Production Demand for Gold

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.38283	0.02816	13.60	0.000	0.32729	0.43837
lncpi	0.01085	0.20692	0.05	0.958	-0.39731	0.41901
lngdp	-0.79078	0.03786	-20.89	0.000	-0.86546	-0.71609
lnexchange	0.29708	0.02469	12.03	0.000	0.24838	0.34577
lyield	-0.21483	0.07339	-2.93	0.004	-0.35960	-0.07006
syield	0.16977	0.05977	2.84	0.005	0.05186	0.28767
lnequity	0.09674	0.06883	1.41	0.162	-0.03904	0.23252
lnuncertainty	0.14676	0.09605	1.53	0.128	-0.04271	0.33623
_cons	10.01221	1.84503	5.43	0.000	6.37283	13.65158

Concerning the GDP, the exchange rate to the US Dollar and long term debt yields, results in Table 9.27 are in line with those suggested by the General-to-Specific procedure in Table 9.26. However, a pooled OLS regression identifies a linear association between gold production demand and two further variables: money supply and short term debt yields. For both indicators, the relationship is positive, indicating that a higher inflation rate, as well as higher short term yields, are associated with a greater demand for gold as an industrial production asset. Indeed, an increase in money supply could be an indication of greater industrial productivity channeled through inflation effects, explaining the identified positive relationship. Regarding short term interest rates, it is somewhat surprising to find that an increased insecurity in the debt markets is associated with a greater demand for gold as a production asset. However, with an R^2 value of 0.7715, the pooled OLS procedure doesn't seem to be completely inappropriate; still, in the light of somewhat surprising results in Tables 9.26 and 9.27, a Breusch and Pagan (1979) Lagrange Multiplier test is used to test for model misspecification.

Table 9.28: Breusch and Pagan Lagrangian Multiplier Test for Random Effects: Production Demand for Gold

	Var	**sd = sqrt (Var)**
lnpdemand	4.117452	2.029151
e	0.1509182	0.3884819
u	0.9936948	0.9968424
	$\bar{\chi}^2$ (1)	798.93
	Prob $>\bar{\chi}^2$	0.0000

Table 9.28 suggest that the variance of the unobserved fixed effects is different than 0, indicating that a pooled OLS regression might not be the appropriate model to use.

In preparation of specifying panel data models, the Hausman (1978) procedure is used to determine whether the coefficients in a model should be determined by a random or a fixed effect model.

Results in Table 9.29 advice to use a fixed effect specification.

A linear panel data model approximating the coefficients by a fixed effect estimator is therefore run in a final step.

Table 9.29: Hausman Specification Test: Production Demand for Gold

	(b) Fixed	(B) Random	(b-B) Difference	sqrt(diag($V_b - V_B$)) S.E.
lnmoney	-0.28321	0.05790	-0.34111	0.10139
lncpi	-0.55639	-0.77090	0.21451	0.45659
lngdp	-0.24091	-0.69860	0.45769	0.51476
lnexchange	0.33240	0.29565	0.03676	0.18687
lyield	-0.07306	-0.06713	-0.00593	0.01063
syield	0.01325	0.02990	-0.01665	0.00000
lnequity	0.15890	0.11904	0.05062	0.02690
lnuncertainty	-0.13302	-0.12901	-0.00401	0.00000
			χ^2 (8)	15.71
			Prob >χ^2	0.0467

Table 9.30: Fixed Effects Linear Regression Model: Production Demand for Gold

	Coef.	Std.	Err.	t	P>|t|	95% Confidence Interval
lnmoney	-0.28321	0.13782	-2.05	0.041	-0.55518	-0.01124
lncpi	-0.55639	0.58765	-0.95	0.345	-1.71601	0.60322
lngdp	-0.24091	0.53460	-0.45	0.653	-1.29584	0.81403
lnexchange	0.33240	0.20895	1.59	0.113	-0.07993	0.74473
lyield	-0.07306	0.03522	-2.07	0.039	-0.14256	-0.00356
syield	0.01325	0.02256	0.59	0.558	-0.03126	0.05776
lnequity	0.15890	0.11464	1.39	0.167	-0.06731	0.38512
lnuncertainty	-0.13302	0.09105	-1.46	0.146	-0.31269	0.04664
_cons	17.95628	5.21280	3.44	0.001	7.66984	28.24272
σ_u	2.16163					
σ_e	0.38848					
ρ	0.96871					

Results from a panel linear regression approach in Table 9.30 support the identified association between production demand for physical gold and both money supply and long-term interest rates. However, the R^2 value of 0.0098 strongly suggests to consider more sophisticated dynamic approaches in light of the dataset on hand.

9.1.4.3 Dynamic Regression Models

An important issue to clarify before calibrating dynamic linear panel models, is to identify possible serial correlation in the idiosyncratic errors of the model. A Wooldridge (2002) test is implemented and the results are displayed in Table 9.31.

Table 9.31: Wooldridge Test for Autocorrelation in Panel Data: Production Demand for Gold

F (1, 11)	=	123.699
Prob >F	=	0.0000

With evidence for first-order autocorrelation on hand, a dynamic regression model able to fit low-order moving average correlation in the idiosyncratic error is considered.

Table 9.32: Linear Dynamic Panel-Data Estimation: Production Demand for Gold

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
lnmoney	-0.28081	0.09269	-3.03	0.002	-0.46248	-0.09914
lncpi	-0.56467	0.39805	-1.42	0.156	-1.34484	0.21550
lngdp	-0.25168	0.36210	-0.70	0.487	-0.96139	0.45804
lnexchange	0.33372	0.14215	2.35	0.019	0.05511	0.61233
lyield	-0.07392	0.02378	-3.11	0.002	-0.12054	-0.02731
syield	0.01451	0.01527	0.95	0.342	-0.01541	0.04444
lnequity	0.15612	0.07815	2.00	0.046	0.00295	0.30929
lnuncertainty	-0.12830	0.06130	-2.09	0.036	-0.24845	-0.00816
_cons	18.10444	3.50421	5.17	0.000	11.23633	24.97256

Interesting results are delivered by a dynamic linear panel approach model (Table 9.32). A significant relationship is identified between the level of demand for gold as an industrial production factor and money supply, the US Dollar exchange rate, long term debt yields, stock market indices, and finally, economic uncertainty. In contrary to previous model specifications, the relationship with money supply is negative, where more money in the economy is associated with a lower demand for gold coming from producers. However money supply is the only variable to change sign and calls for a more robust and detailed investigation into the relationship between the two variables that would be out of the scope of this thesis. An explanation for the identified relationship with the other variables, except for economic uncertainty, has been provided in earlier parts of this section. Interestingly though, the Economic Uncertainty index appears to be more relevant than initially suggested when considering dynamic panel-data modelling procedures. Here, a negative relationship suggests an association between a lower demand for gold and greater economic uncertainty. Being an economically sound finding, it is of special interest in the light that empirical conclusions for the total demand for gold tend to favour a positive relationship between the two, economic uncertainty was also identified as significant when comparing total physical gold demand earlier on. So while economic uncertainty might push up the total demand for gold, it seems however to push down the production demand for the yellow precious metal.

In order to close the investigation into the drivers of physical gold demand for industrial production purposes, the Least-Squares Dummy Variables dynamic panel data estimator is used to identify possible effects uncovered by a procedure specifically designed for panels consisting of a relatively small amount of data.

Table 9.33: LSDVC Dynamic Panel-Data Estimation: Production Demand for Gold

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
L1.lngdemand	0.58650	0.05900	9.94	0.000	0.47086	0.70214
lnmoney	-0.11848	0.11211	-1.06	0.291	-0.33822	0.10125
lncpi	-0.11114	0.47556	-0.23	0.815	-1.04322	0.82095
lngdp	-0.44790	0.43063	-1.04	0.298	-1.29193	0.39612
lnexchange	0.06308	0.17028	0.37	0.711	-0.27066	0.39682
lyield	-0.04376	0.02854	-1.53	0.125	-0.09971	0.01219
syield	0.00827	0.01825	0.45	0.651	-0.02750	0.04403
lnequity	0.08902	0.09267	0.96	0.337	-0.09261	0.27064
lnuncertainty	0.00497	0.07468	0.07	0.947	-0.14139	0.15134

Results in Table 9.33 fail to identify a signification association between production demand for gold and any of the variables suggested. So reconciling the results identified throughout the section, it seems very difficult to identify an empirical set of variables that would have a significant relationship with the production demand for gold. However, some individual variables appeared throughout the different models and deserve to be mentioned in the concluding part of this section. National stock indices are deemed to have a positive linear association with production demand; indeed one can easily imagine that higher equity prices reflect greater industrial activity and therefore a higher demand for gold coming from industry for means of production. A similar argumentation can be made for the negative relationship between production demand and long-term interest rates; where higher long term yields reflect a slowdown of industrial activity and therefore a slowing down of production demand for gold. The positive relationship between gold demand and exchange rates to the US Dollar is, on the other hand, somewhat puzzling. While discussed above, the relationship is in direct opposition to what was observed when considering the total demand level for gold, suggesting that the argumentation of O'Connor et al. (2015) that a weaker US Dollar makes it cheaper for non-American investors to buy gold, might only hold at the aggregated demand level and not when individual demand aspects are considered. Finally, the relationship between industrial demand for gold and money supply was found to be both negative and positive depending on the test considered - conflicting results that call for a more formal investigation into the matter.

9.2 Silver

In the same fashion as the previous section investigating the drivers of physical gold demand across multiple countries, this section will employ different panel-data methods to obtain a better understanding of the drivers of physical silver demand. The demand for silver is broken down into four different categories: total demand, luxury demand, investment demand, and finally, industrial production demand. The demand for the following 13 different countries were extracted based on their relative importance on the silver market: Australia, Canada, China, Germany, India, Italy, Japan, Mexico, Russia, South Korea, Thailand, the United Kingdom of Great Britain and Northern Ireland, and finally, the United States of America.

9.2.1 Total Demand

The total demand for silver is simply the aggregated total sum of silver that was demanded in each individual country per year. Total demand therefore consists of luxury demand, investment demand, and industrial production demand.

9.2.1.1 General-to-Specific Model Prediction

A GenSpec procedure is run to detect the best model specification taking into account 13 different demand panels, results of linear regression analyses are displayed in Table 9.34.

Table 9.34: General-to-Specific Modelling Algorithm: Total Demand for Silver

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.15334	0.01774	8.64	0.000	0.11838	0.18829
lngdp	-0.22704	0.02186	-10.38	0.000	-0.27012	-0.18397
lyield	-0.08477	0.02582	-3.28	0.001	-0.13563	-0.03390
syield	0.00438	0.01038	0.42	0.674	-0.01607	0.02482
_cons	11.41844	0.41341	27.62	0.000	10.60394	12.23294

Results of the GenSpec procedure suggest that three variables have a linear association with total physical demand for silver across the 13 countries: money supply, the GDP, and long-term Government debt yields. The relationship with money supply is positive, indicating that a higher amount of money in the economy is associated with greater demand for silver; the opposite relationship is observed for the GDP and long-term debt yields: here it seems that greater values are associated with a smaller demand for silver. The observed relationship between silver and money supply is quite interesting in the light that previous findings, such as Batten et al. (2010) find that changes in monetary variables do not affect the volatility of the silver price, though their investigation is not focused on physical demand. A positive relationship between silver prices and money supply is however observed by Apergis et al. (2014) where positive money supply shocks lead to higher silver prices. In the light of silver as an important input of industrial production, a positive relationship with a country's GDP could have been expected - previous research however, such as Christie-David et al. (2000) find no evidence for a relationship between silver prices and GDP announcements, results supported by Adrangi et al. (2003) who find only a weak correlation between silver prices and industrial activity, and by Batten et al. (2010) arguing that industrial production doesn't have a significant effect on the volatility of the silver price. Little research was done about the relationship between long-term debt yields and silver, with one prominent example (Batten et al. (2010)) arguing that long-term debt yields do not affect the volatility of silver prices. While the results of the GenSpec procedure in Table 9.34 offer interesting initial insights into the relationship between a set of macroeconomic variables and physical silver demand across different countries, the R^2 and adjusted R^2 values of 0.4573 and 0.4480 respectively, suggest to continue the investigation and rethink the calibration of the model.

9.2.1.2 Optimising Linear Regression Models

With the previous results on hand, the investigation into the drivers of physical silver demand is continued by running a pooled Ordinary Least Squares (OLS) regression in which the standard errors are specified as robust to model misspecification.

Results in Table 9.35 support the results suggested by the GenSpec procedure in Table 9.34 and identify three additional variables: the CPI, the national exchange rate to the US Dollar, and short term debt yields. A positive relationship between inflation rates and silver was suggested by Taylor (1998), Adrangi et al. (2003) and partially by Bampinas and Panagiotidis (2015), who all argue for the hedging potential of silver. The positive relationship between silver prices and national exchange rates to the US Dollar indicates that the demand for silver grows when the purchasing power of a country's currency falls, indicating possible currency

Table 9.35: Pooled OLS Regression: Total Demand for Silver

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.21700	0.01860	11.67	0.000	0.18031	0.25368
lncpi	0.32980	0.18437	1.79	0.075	-0.03387	0.69347
lngdp	-0.32254	0.02823	-11.42	0.000	-0.37823	-0.26684
lnexchange	0.03567	0.01976	1.80	0.073	-0.00332	0.07465
lyield	-0.25003	0.06201	-4.03	0.000	-0.37235	-0.12772
syield	0.14792	0.04828	3.06	0.003	0.05268	0.24315
lnequity	-0.01909	0.05360	-0.36	0.722	-0.12481	0.08663
lnuncertainty	0.08753	0.06851	1.28	0.203	-0.04761	0.22268
_cons	8.96961	1.60012	5.61	0.000	5.81333	12.12589

hedging abilities of silver. Also indicating possible hedging abilities is the positive relationship between demand for physical silver and short term debt yields, pointing towards higher demand for silver in more uncertain economic environments. With a value of 0.6029, the R^2 value of the pooled OLS model presented in Table 9.35 is substantially higher than that of previous models but still challenges the quality of linear regression models as such.

In the light that the previous model specifications might not optimally fit the data, the Lagrangian Multiplier test by Breusch and Pagan (1979) is used to test for model misspecification.

Table 9.36: Breusch and Pagan Lagrangian Multiplier Test for Random Effects: Total Demand for Silver

	Var	**sd = sqrt (Var)**
lnsdemand	1.345909	1.160133
e	0.1130418	0.3362169
u	1.33936	1.157307
	$\bar{\chi}^2$ (1)	432.23
	Prob $>\bar{\chi}^2$	0.0000

The results in Table 9.36 suggest that a pooled OLS might not be the appropriate model to use, advising to reconsider earlier model specifications. In order to understand if the data should be fitted in a random effect or a fixed effect model, the Hausman Specification Test (Hausman (1978)) is used to decide how the coefficients should be determined in future models.

Table 9.37: Hausman Specification Test: Total Demand for Silver

	(b) Fixed	(B) Random	(b-B) Difference	sqrt(diag($V_b - V_B$)) S.E.
lnmoney	-0.51484	-0.19253	-0.32231	0.06481
lncpi	-0.11934	0.71575	-0.83510	0.33620
lngdp	2.54168	0.25090	2.29078	0.43079
lnexchange	-0.40216	-0.16037	-0.24179	0.14566
lyield	-0.02162	-0.07269	0.05107	0.00000
syield	0.03078	0.05004	-0.01926	0.00000
lnequity	0.12550	0.19869	-0.07319	0.00000
lnuncertainty	0.10907	0.11292	-0.00384	0.00000
			χ^2 (8)	66.09
			Prob $>\chi^2$	0.0000

Results in Table 9.37 suggest to run a linear panel data model in which the coefficients are approximated by a fixed effects estimator.

Table 9.38: Fixed Effects Linear Regression Model: Total Demand for Silver

	Coef.	Std.	Err.	t	P>|t|	95% Confidence Interval
lnmoney	-0.51484	0.11928	-4.32	0.000	-0.75022	-0.27946
lncpi	-0.11934	0.50859	-0.23	0.815	-1.12295	0.88426
lngdp	2.54168	0.46268	5.49	0.000	1.62867	3.45469
lnexchange	-0.40216	0.18084	-2.22	0.027	-0.75901	-0.04530
lyield	-0.02162	0.03048	-0.71	0.479	-0.08177	0.03853
syield	0.03078	0.01952	1.58	0.117	-0.00774	0.06930
lnequity	0.12550	0.09922	1.26	0.208	-0.07028	0.32128
lnuncertainty	0.10907	0.07880	1.38	0.168	-0.04642	0.26457
_cons	-11.62759	4.51149	-2.58	0.011	-20.53013	-2.72505
σ_u	6.14933					
σ_e	0.33622					
ρ	0.99702					

The results in Table 9.38 are in contrast to those identified by previous linear model specifications. Interestingly, a linear approach that weighs more importance towards different individual panels identifies only three variables as having an association with physical silver demand: money supply, the GDP, and the national exchange rate to the US Dollar. It should be noted that the signs changed for all the three variables in comparison to previous model specifications. So a panel approach would suggest that a higher GDP or a stronger national currency against the US Dollar is associated with a higher silver demand. On the other hand, it seems that increases in money supply are associated with lower demand for silver. While previous testing procedures advice to consider panel approaches, the R^2 value of 0.3565 from the model displayed in Table 9.38 is further evidence suggesting to consider more sophisticated linear regression models.

9.2.1.3 Dynamic Regression Models

In a first step, a Wooldridge (2002) test is used to detect possible serial correlation in the idiosyncratic error of the linear panel-data model.

Table 9.39: Wooldridge Test for Autocorrelation in Panel Data: Total Demand for Silver

F (1, 11)	=	27.551
Prob >F	=	0.0003

The results in Table 9.39 identify autocorrelation in the data and advice to proceed with a dynamic regression model able to fit low-order moving average in the idiosyncratic error.

Table 9.40: Linear Dynamic Panel-Data Estimation: Total Demand for Silver

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
lnmoney	-0.52528	0.04547	-11.55	0.000	-0.61439	-0.43616
lncpi	-0.20459	0.19526	-1.05	0.295	-0.58730	0.17812
lngdp	2.63095	0.17763	14.81	0.000	2.28280	2.97910
lnexchange	-0.44300	0.06973	-6.35	0.000	-0.57967	-0.30633
lyield	-0.02521	0.01167	-2.16	0.031	-0.04808	-0.00235
syield	0.03252	0.00749	4.34	0.000	0.01784	0.04720
lnequity	0.10434	0.03834	2.72	0.006	0.02920	0.17947
lnuncertainty	0.10585	0.03007	3.52	0.000	0.04691	0.16478
_cons	-11.53976	1.71897	-6.71	0.000	-14.90888	-8.17063

The results in Table 9.40 are in line with the fixed effects linear regression model in Table 9.39 in regard to the identified linear association between physical silver demand and money supply, the GDP, and the national exchange rate to the US Dollar. The results of Table 9.40 are however very lax given that only the CPI is ruled out as a significant variable. It is therefore advisable to close the investigation with a bias-corrected Least-Squares Dummy Variables (LSDVC) dynamic panel data estimator in order to optimise the results in light of a relatively small amount of data points.

Table 9.41: LSDVC Dynamic Panel-Data Estimation: Total Demand for Silver

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
L1.lnsdemand	0.92159	0.03967	23.23	0.000	0.84384	0.99934
lnmoney	-0.12616	0.06191	-2.04	0.042	-0.24751	-0.00481
lncpi	0.20534	0.25473	0.81	0.420	-0.29391	0.70460
lngdp	0.19704	0.25226	0.78	0.435	-0.29737	0.69146
lnexchange	-0.02544	0.09181	-0.28	0.782	-0.20538	0.15450
lyield	-0.01343	0.01526	-0.88	0.379	-0.04333	0.01647
syield	-0.00074	0.00989	-0.07	0.940	-0.02013	0.01865
lnequity	0.02819	0.04986	0.57	0.572	-0.06954	0.12592
lnuncertainty	-0.03258	0.03994	-0.82	0.415	-0.11085	0.04570

Results in Table 9.41 report that only changes in money supply are significantly associated with changes in the physical demand for silver across the 13 different countries. The negative relationship suggests that a smaller supply of money is associated with a higher demand for silver, strongly questioning possible hedging potential of silver - more detailed investigations into the different constituents of demand later on will hopefully shed more light on the relationship. Reconciling the results in Table 9.41 with those displayed in Table 9.38, an importance of the GDP and the national exchange rate to the US Dollar should also be mentioned. Indeed, the relationship between a country's GDP and that country's demand for silver seems to be positive, results pointing towards both the industrial importance of the white precious metal but also to the beneficial effects of an increase of national wealth pushing up luxury demand for silver. The observed negative relationship between the national exchange rate to the US Dollar and the physical demand for silver could be regarded as the effect that a weaker US Dollar makes it cheaper for other countries to buy silver (O'Connor et al. (2015)), though again, a more formal investigation would be required before drawing any conclusions. Most interestingly, formal econometric procedures uncovered that the relationship between total physical demand for silver and different macroeconomic variables can not fully be captured in a linear model, much more, should panel approaches be considered because the effects of different variables vary across countries. Throughout the rest of this section, a similar investigation will be undertook in order to detect the drivers of physical silver demand as a luxury asset, an investment asset, and finally, an industrial production asset, always keeping in mind the three variables detected for total demand: money supply, the GDP and the national exchange rate to the US Dollar.

9.2.2 Luxury Demand

Luxury demand for silver is composed of the demand required in the production of jewellery and silverware. In a fashion similar to gold, luxury demand could have some investment aspects as a general belief is that jewellery and silverware somewhat hold their value over time. In this section, multiple models are proposed in order to understand more about the drivers of physical demand for silver through the bias of luxury good consumption.

9.2.2.1 General-to-Specific Model Prediction

The GenSpec procedure is applied to get a basic understanding of the variables that would best fit a linear model explaining silver jewellery and silverware consumption.

Table 9.42: General-to-Specific Modelling Algorithm: Luxury Demand for Silver

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.10815	0.02458	4.40	0.000	0.05967	0.15664
lngdp	-0.25615	0.02824	-9.07	0.000	-0.31186	-0.20045
lyield	-0.22404	0.05267	-4.25	0.000	-0.32794	-0.12015
syield	0.17902	0.04306	4.16	0.000	0.09409	0.26394
lnequity	-0.56680	0.05334	-10.63	0.000	-0.67201	-0.46160
lnuncertainty	-0.60971	0.08530	-7.15	0.000	-0.77796	-0.44145
_cons	17.64245	0.97746	18.05	0.000	15.71451	19.57038

Results in Table 9.42 suggest a positive linear association between silver luxury demand and both money supply and short term interest rates. These initial results might be suggesting a certain alleged hedging potential of luxury goods made out of silver, where the demand increases during potentially less stable economic environments. This however would be in contrast with the observed negative relationship between the economic uncertainty index and luxury demand for silver, where the demand is smaller during more uncertain times. On the other hand, somewhat similar findings are observed for the GDP and equity prices, where the negative relationship with luxury silver demand is negative, indicating that an increase of industrial production and wealth in a country is associated with a decreasing demand for luxury goods made out of silver. In the light of somewhat conflicting results and an R^2 and adjusted R^2 value of 0.5886 and 0.6011 respectively, the investigation should be continued and the model proposed in Table 9.42 recalibrated.

9.2.2.2 Optimising Linear Regression Models

Building upon the somewhat conflicting previous results, a classical pooled Ordinary Least Squares regression specifying the standard errors as robust to model misspecification is considered.

Table 9.43: Pooled OLS Regression: Luxury Demand for Silver

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.09903	0.02088	4.74	0.000	0.05784	0.14022
lncpi	0.51022	0.19007	2.68	0.008	0.13530	0.88515
lngdp	-0.30538	0.02506	-12.19	0.000	-0.35481	-0.25596
lnexchange	0.12324	0.02414	5.11	0.000	0.07562	0.17086
lyield	-0.16505	0.07260	-2.27	0.024	-0.30827	-0.02184
syield	0.14641	0.06530	2.24	0.026	0.01759	0.27522
lnequity	-0.45856	0.06620	-6.93	0.000	-0.58913	-0.32799
lnuncertainty	-0.65899	0.10046	-6.56	0.000	-0.85715	-0.46082
_cons	13.26284	1.67104	7.94	0.000	9.96666	16.55902

OLS results presented in Table 9.43 are in line with the results from the GenSpec procedure (Table 9.42) but also identify the two last variables as statistically significant: the CPI and the national exchange rate to the US Dollar. The positive coefficients of money supply and Consumer Prince Indices suggest that a rising inflation rate is associated with a rising demand for silver luxury goods, indicating possible hedging abilities. The positive relationship with exchange rates suggests a rising demand when the US Dollar strengthens, though previous investigations presented in this thesis suggested an association between a strong US Dollar and a weaker price of silver. The R^2 value of 0.6653 for the model outlined in Table 9.43 is somewhat stronger than that of the GenSpec procedure but a formal investigation of whether or not a classical OLS model is appropriate should still be considered.

The Breusch and Pagan (1979) test is used to identify possible model misspecification.

Table 9.44: Breusch and Pagan Lagrangian Multiplier Test for Random Effects: Luxury Demand for Silver

	Var	**sd = sqrt (Var)**
lnldemand	1.807237	1.344335
e	0.0653435	0.2556237
u	2.33022	1.526506
	$\bar{\chi}^2$ (1)	165.11
	Prob $>\bar{\chi}^2$	0.0000

The test results in Table 9.44 indeed suggest that a pooled OLS regression might not be the appropriate model to use, therefore suggesting to consider more complex models. In order to determine whether the coefficients should be determined by a fixed effect or a random effect model, the Hausman (1978) procedure is considered.

Table 9.45: Hausman Specification Test: Luxury Demand for Silver

	(b) Fixed	**(B) Random**	**(b-B) Difference**	**sqrt(diag($V_b - V_B$)) S.E.**
lnmoney	-0.24199	-0.16734	-0.07465	0.02794
lncpi	-1.43499	-0.44230	-0.99269	0.21432
lngdp	1.77057	0.17347	1.59710	0.30019
lnexchange	0.43353	0.22462	0.20891	0.08790
lyield	-0.01437	-0.04333	0.02896	0.00000
syield	0.02490	0.03559	-0.01069	0.00000
lnequity	0.04320	0.12075	-0.07755	0.00000
lnuncertainty	-0.23696	-0.23935	0.00238	0.00000
			χ^2 (8)	32.47
			Prob $>\chi^2$	0.0001

The results in Table 9.45 recommend a fixed effect specification when considering linear panel data modelling approaches. Results of a linear panel data model approximating the coefficients with a fixed effect estimator are displayed in Table 9.46.

Table 9.46: Fixed Effects Linear Regression Model: Luxury Demand for Silver

	Coef.	Std.	Err.	t	P>|t|	95% Confidence Interval
lnmoney	-0.24199	0.09069	-2.67	0.008	-0.42095	-0.06304
lncpi	-1.43499	0.38668	-3.71	0.000	-2.19802	-0.67196
lngdp	1.77057	0.35177	5.03	0.000	1.07642	2.46472
lnexchange	0.43353	0.13749	3.15	0.002	0.16221	0.70485
lyield	-0.01437	0.02317	-0.62	0.536	-0.06010	0.03137
syield	0.02490	0.01484	1.68	0.095	-0.00438	0.05419
lnequity	0.04320	0.07543	0.57	0.568	-0.10565	0.19205
lnuncertainty	-0.23696	0.05991	-3.96	0.000	-0.35519	-0.11874
_cons	-2.30261	3.43006	-0.67	0.503	-9.07116	4.46594
σ_u	5.49811					
σ_e	0.25562					
ρ	0.99784					

The results outlined in Table 9.46 rule out two variables in comparison to the pooled OLS regression in Table 9.43: long term debt yields and equity indices. Furthermore, sign changes are observed for the following three variables: money supply, the CPI, and the GDP. Indeed, results in Table 9.46 suggest an association between rising inflation and dropping demand for silver needed in the production of luxury goods. On the other hand, the positive coefficient observed for the GDP indicates that a rising level of industrial production and wealth in an economy is associated with a greater demand for silver luxury goods, which seems to be somewhat more reasonable economically. However, conflicting results between Tables 9.43 and 9.46, as well as an R^2 value of 0.0363 suggest considering dynamic model specification in order to derive drivers of luxury demand for silver.

9.2.2.3 Dynamic Regression Models

A Wooldridge (2002) test for autocorrelation in panel-data is applied in order to correctly specify the linear dynamic panel-data model to apply.

Table 9.47: Wooldridge Test for Autocorrelation in Panel Data: Luxury Demand for Silver

F (1, 11)	=	67.386
Prob >F	=	0.0000

Results in Table 9.47 detect autocorrelation in the data, so the advice would be to proceed with a dynamic model that is able to fit low-order moving average correlation in the idiosyncratic error.

Table 9.48: Linear Dynamic Panel-Data Estimation: Luxury Demand for Silver

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
lnmoney	-0.25581	0.03750	-6.82	0.000	-0.32930	-0.18232
lncpi	-1.61087	0.16102	-10.00	0.000	-1.92647	-1.29527
lngdp	1.91071	0.14648	13.04	0.000	1.62361	2.19781
lnexchange	0.36124	0.05750	6.28	0.000	0.24853	0.47394
lyield	-0.02295	0.00962	-2.39	0.017	-0.04180	-0.00409
syield	0.03097	0.00618	5.01	0.000	0.01887	0.04308
lnequity	-0.00212	0.03161	-0.07	0.947	-0.06408	0.05985
lnuncertainty	-0.23222	0.02480	-9.36	0.000	-0.28082	-0.18362
_cons	-1.80509	1.41755	-1.27	0.203	-4.58344	0.97325

The results in Table 9.48 are not very helpful as they only allow to rule out a linear association between equity prices and physical demand for silver luxury goods, while the results for the other variables are statistically significant. It is therefore advisable to finish the investigation with a bias-corrected Least-Squares Dummy Variables (LSDVC) procedure that delivers more reliable results in the light of a relatively small amount of data points on hand.

Table 9.49: LSDVC Dynamic Panel-Data Estimation: Luxury Demand for Silver

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
L1.lnldemand	0.89288	0.03785	23.59	0.000	0.81869	0.96707
lnmoney	-0.01342	0.04552	-0.29	0.768	-0.10264	0.07581
lncpi	-0.18253	0.19750	-0.92	0.355	-0.56962	0.20455
lngdp	-0.15590	0.19089	-0.82	0.414	-0.53003	0.21824
lnexchange	0.13777	0.06859	2.01	0.045	0.00333	0.27221
lyield	-0.04078	0.01143	-3.57	0.000	-0.06319	-0.01837
syield	0.00906	0.00736	1.23	0.218	-0.00536	0.02348
lnequity	0.01247	0.03710	0.34	0.737	-0.06025	0.08519
lnuncertainty	-0.02466	0.03073	-0.80	0.422	-0.08490	0.03558

In the final model specification of this section, only two variables are identified as having a linear association with physical silver demand for luxury goods (Table

9.49): national exchange rates to the US Dollar and long-term Government debt yields. The relationship with exchange rates is positive, indicating that a stronger US Dollar favours international purchases of silver luxury goods. Indeed, a more formal investigation into the role of the US Dollar on the price for silver in the previous chapter of this thesis indicated that a stronger US Dollar is associated with a weaker silver price. So in the context of Table 9.49, a weaker national currency is linked with a stronger US Dollar which in turn could be linked with a lower silver price; a more formal investigation would however be required to understand the effects across the 13 countries. Furthermore, results indicate a strong and significant association between silver luxury demand and long-term Government debt yields. The relationship is negative, indicating that higher debt yields are associated with a smaller demand. In the light that higher yields could be an indication for a more negative long-term outlook on the state of the national economy, individuals would be consuming more luxury goods in a more fruitful economic climate. This reasoning is easily compatible with basic economic reasoning, where one would indeed account for a higher demand for luxury goods during positive economic climates. However, the variability across the models point towards a relative complexity in computing the drivers for silver luxury goods demand across the different panels. So while panel-data models are favoured against classical linear approaches, the results still indicate possible strong individual country effects that offer room for country specific investigations as a topic of future research.

9.2.3 Investment Demand

Investment demand in physical silver is composed of two basic components: solid bars and coins. So while both luxury demand and industrial production consumes the physical silver demanded, investment demand is merely hoarding silver in the hope to gain some sort of financial profit out of it. This section will identify possible association between physical investment demand for silver and a list of macroeconomic variables across 13 different countries.

9.2.3.1 General-to-Specific Model Prediction

A GenSpec procedure is used to detect the variables that are most likely to move alongside investment demand in silver.

Table 9.50: General-to-Specific Modelling Algorithm: Investment Demand for Silver

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnexchange	-0.16117	0.01234	-13.06	0.000	-0.18549	-0.13685
lyield	-0.02853	0.01750	-1.63	0.104	-0.06302	0.00596
lnuncertainty	-0.07677	0.04507	-1.70	0.090	-0.16558	0.01205
_cons	3.22066	0.23942	13.45	0.000	2.74887	3.69246

Results in Table 9.50 suggest a linear association between investment demand for silver and the following three variables: national exchange rates to the US Dollar, long term Government yields, and finally, the economic uncertainty index. For all three, the relationship is negative, indicating a potentially higher demand for silver when a national currency grows in strength against the US Dollar. The negative relationship with long-term debt yields could be understood in the light that higher yields indicate a lower confidence in the outlook of the future of the national economy, being in a way very similar to the economic uncertainty index. However, the negative relationship is indicating a smaller investment demand for silver during troublesome economic times, a finding in stark contrast to what can be expected economically, where one might believe the investment demand to rise during stormy economic and political climate. The coefficients of determination of the model proposed in Table 9.50 also suggest continuing the investigation by recomputing the model specifications; indeed, the R^2 and adjusted R^2 values are of 0.4341 and 0.4266 respectively.

9.2.3.2 Optimising Linear Regression Models

The investigation is continued by running a pooled OLS model in which the standard errors are specified as robust to possible model misspecification.

Table 9.51: Pooled OLS Regression: Investment Demand for Silver

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	-0.06732	0.01325	-5.08	0.000	-0.09346	-0.04118
lncpi	-0.05231	0.13955	-0.37	0.708	-0.32758	0.22297
lngdp	0.02724	0.01570	1.74	0.084	-0.00373	0.05821
lnexchange	-0.17622	0.01718	-10.25	0.000	-0.21012	-0.14232
lyield	-0.06542	0.03664	-1.79	0.076	-0.13769	0.00685
syield	-0.00510	0.02729	-0.19	0.852	-0.05894	0.04874
lnequity	-0.11360	0.05640	-2.01	0.045	-0.22485	-0.00235
lnuncertainty	-0.15823	0.04334	-3.65	0.000	-0.24373	-0.07273
_cons	5.84998	1.26673	4.62	0.000	3.35132	8.34863

Only the CPI and short term interest rates are ruled out in Table 9.51, all the other variables indeed fall into the statistically significant threshold. Furthermore, it should be noted that the results for national exchange rates to the US Dollar, long-term debt yields and economic uncertainty in Table 9.51 are supporting those found in Table 9.50. The positive relationship between silver investments and the GDP is suggesting an association between an increase of national wealth and an increase in investment demand for silver. However, the R^2 value of the model suggested in Table 9.51 of 0.5436 might be suggesting that the model is not optimally computed as it doesn't optimally fit the data.

A Breusch and Pagan (1979) procedure is therefore advisable in order to understand whether or not a pooled OLS regression is appropriate to examine the dataset on hand.

Table 9.52: Breusch and Pagan Lagrangian Multiplier Test for Random Effects: Investment Demand for Silver

	Var	**sd = sqrt (Var)**
lnidemand	0.6287528	0.7929393
e	0.1197313	0.3460221
u	0.7498758	0.8659537
	$\bar{\chi}^2$ (1)	189.89
	Prob $>\bar{\chi}^2$	0.0000

Table 9.53: Hausman Specification Test: Investment Demand for Silver

	(b) Fixed	**(B) Random**	**(b-B) Difference**	**sqrt(diag($V_b - V_B$)) S.E.**
lnmoney	0.47862	0.14321	0.33541	0.08690
lncpi	-3.54094	-0.84171	-2.69923	0.39359
lngdp	2.38313	0.06345	2.31968	0.45716
lnexchange	-0.53080	-0.28671	-0.24409	0.16485
lyield	0.03271	-0.04280	0.07551	0.00000
syield	-0.00289	0.00562	-0.00851	0.00000
lnequity	-0.09402	-0.03885	-0.05517	0.03344
lnuncertainty	0.03934	0.01262	0.02672	0.00000
			χ^2 (8)	52.72
			Prob $>\chi^2$	0.0000

The results in Table 9.52 suggest that a linear OLS regression is inappropriate, results directly opposed to those found for the investment demand for gold (Table 9.19). So while linear regressions were able to model changes in the investment demand for gold, panel approaches have to be considered when modelling changes in the investment demand for silver.

A first step to take when venturing towards panel data models is to identify how the coefficients in the model should be determined; through a random or a fixed effect model (Hausman (1978)).

Building upon the results in Table 9.53, a fixed effect linear regression model is fitted and the results are displayed in Table 9.54.

The following four variables are identified as significant by the fixed effects linear regression model in Table 9.54: money supply, the CPI, the GDP, and finally, national exchange rates to the US Dollar. The importance of exchange rates was already identified in previous linear model specifications (Tables 9.50 and 9.51) and the negative coefficient in Table 9.54 indicate an association between a higher investment demand for silver and a weaker US Dollar. The coefficient for money supply in Table 9.54 is positive, while it is negative in previous linear specifications - indicating that an increase in money supply is associated with an increase in the investment demand for physical silver. The R^2 value of the model presented in Table 9.54, amounting to 0.0195, as well as the somewhat conflicting results across the different model specifications suggest to consider more complex panel-data model specifications.

Table 9.54: Fixed Effects Linear Regression Model: Investment Demand for Silver

	Coef.	Std.	Err.	t	P>|t|	95% Confidence Interval
lnmoney	0.47862	0.12276	3.90	0.000	0.23638	0.72086
lncpi	-3.54094	0.52342	-6.76	0.000	-4.57381	-2.50807
lngdp	2.38313	0.47617	5.00	0.000	1.44350	3.32276
lnexchange	-0.53080	0.18612	-2.85	0.005	-0.89807	-0.16354
lyield	0.03271	0.03137	1.04	0.298	-0.02919	0.09462
syield	-0.00289	0.02009	-0.14	0.886	-0.04253	0.03676
lnequity	-0.09402	0.10211	-0.92	0.358	-0.29551	0.10747
lnuncertainty	0.03934	0.08110	0.49	0.628	-0.12069	0.19936
_cons	-7.53416	4.64306	-1.62	0.106	-16.69633	1.62800
σ_u	6.77302					
σ_e	0.34602					
ρ	0.99740					

Table 9.55: Wooldridge Test for Autocorrelation in Panel Data: Total Demand for Silver

F (1, 11)	=	8.114
Prob >F	=	0.0158

9.2.3.3 Dynamic Regression Models

In order to optimally specify the dynamic panel-data model to choose, a Wooldridge (2002) procedure is used to test for autocorrelation in the data.

The results in Table 9.55 detect autocorrelation in the panel data and advice specifying a model able to fit low-order moving average correlation in the idiosyncratic error.

Five variables are identified in the dynamic panel-data model displayed in Table 9.56: money supply, the CPI, the GDP, the exchange rate to the US Dollar, and finally, national equity prices. All the variables were already identified in previous model specifications and a change can only really be noted for money supply where the coefficient is positive, indicating an association between an increase in money in the economy and an increase in the investment demand for silver. The investigation into the drivers of physical silver demand is concluded by running a Least-Squares Dummy Variables dynamic procedure delivering more robust result in the lights of relatively few data points across the different panels.

Table 9.56: Linear Dynamic Panel-Data Estimation: Investment Demand for Silver

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
lnmoney	0.40047	0.09615	4.16	0.000	0.21201	0.58893
lncpi	-3.90319	0.39233	-9.95	0.000	-4.67215	-3.13424
lngdp	2.91632	0.39250	7.43	0.000	2.14703	3.68560
lnexchange	-0.53329	0.15116	-3.53	0.000	-0.82955	-0.23703
lyield	-0.00292	0.02586	-0.11	0.910	-0.05360	0.04775
syield	-0.00327	0.01736	-0.19	0.851	-0.03730	0.03077
lnequity	-0.15630	0.08045	-1.94	0.052	-0.31398	0.00139
lnuncertainty	0.03751	0.06131	0.61	0.541	-0.08266	0.15768
_cons	-9.84535	3.85933	-2.55	0.011	-17.40949	-2.28121

Table 9.57: LSDVC Dynamic Panel-Data Estimation: Investment Demand for Silver

	Coef.	**Std. Err.**	**z**	**P>|z|**	**95% Confidence Interval**	
L1.lnidemand	0.41381	0.07304	5.67	0.000	0.27066	0.55697
lnmoney	0.29062	0.11833	2.46	0.014	0.05869	0.52255
lncpi	-2.29146	0.53304	-4.30	0.000	-3.33620	-1.24671
lngdp	1.51900	0.46601	3.26	0.001	0.60563	2.43237
lnexchange	-0.28594	0.17757	-1.61	0.107	-0.63398	0.06210
lyield	-0.01211	0.03008	-0.40	0.687	-0.07107	0.04686
syield	0.00514	0.01872	0.27	0.784	-0.03155	0.04182
lnequity	-0.13090	0.09484	-1.38	0.168	-0.31678	0.05498
lnuncertainty	-0.01022	0.07577	-0.13	0.893	-0.15872	0.13828

The investigation into the drivers of physical investment demand can be closed by identifying the following three variables (Table 9.57): money supply, the CPI and the GDP. The relationship with money supply is positive, indicating that an increase in money is associated with an increase in the demand for silver. This could be uncovering potential inflation hedging abilities but the negative relationship with the CPI is suggesting the opposite. So the results uncover the necessity of future and more formal investigations into the relationship between inflation and investment demand for silver. Indeed, the drivers of physical silver demand as an investment purpose are revealed to be much more complex than those identified for gold, where a pooled OLS regression was sufficient to uncover existing relationships amongst the time series. A final variable identified in Table 9.57 is the GDP, where the positive relationship suggests an increase in physical silver demand when the GDP rises. This could be an indication that an increase in the wealth of a country's population is associated with a higher demand for silver, indeed, it should be remembered that China allowed private bullion purchases in 2009, after a constantly rising GDP throughout the past years. However, the results obtained in this section point towards important panel specific effects, uncovering once more the greater complexity linked to modelling the demand for silver in comparison to gold. A possible explanation could be the potentially different perception of the white precious metal across the different countries: where only certain individuals consider silver to be a potentially attractive investment, while this view is quite widespread for gold. Surprisingly, economic uncertainty is not found to be significant, which goes very much against what could have been expected in an attempt to model investment demand for silver - all in all, the results on hand, while very revealing, might be suggesting country specific investigations rather than equally weighted panel data modelling.

9.2.4 Production Demand

Production demand for physical silver is made up of the following: electrical and electronic applications, brazing alloys and solders, photographic and photovoltaic use, and finally, demand from the ethylene oxide industry. With the data for silver demand across all the industrial applications of the 13 different countries considered, this section seeks to optimise models in order to understand changes in physical silver demand for industrial applications.

9.2.4.1 General-to-Specific Model Prediction

The GenSpec procedure is used to get a basic understanding of the variables that are likely to explain movements in industrial demand for physical silver.

Table 9.58: General-to-Specific Modelling Algorithm: Production Demand for Silver

	Coef.	**Std. Err.**	**t**	**P>|t|**	**95% Confidence Interval**	
lnmoney	0.28325	0.02793	10.14	0.000	0.22817	0.33833
lngdp	-0.44747	0.03439	-13.01	0.000	-0.51530	-0.37963
lyield	-0.32205	0.06283	-5.13	0.000	-0.44597	-0.19813
syield	0.21595	0.05267	4.10	0.000	0.11207	0.31983
lnuncertainty	0.30566	0.09788	3.12	0.002	0.11262	0.49871
_cons	10.27577	0.79574	12.91	0.000	8.70630	11.84524

The results in Table 9.58 are very surprising as they suggest relationships in direct opposition to what might have been expected from an economical point of view. Indeed, an association between a rising GDP and a falling industrial demand for silver is suggested. Also, greater economic uncertainty seems to be associated with a higher demand for silver; a result somewhat surprising in the light that economic uncertainty might reflect a cooldown of industrial activities. The R^2 and adjusted R^2 values of 0.5668 and 0.5556 respectively also entail that the model in Table 9.58 is not able to capture a large proportion of the changes in industrial demand for physical silver. Other models should therefore be considered.

9.2.4.2 Optimising Linear Regression Models

In a next step, a classical pooled OLS regression is considered. Here, the standard errors are specified as robust to model misspecification in order to obtain more reliable results.

Table 9.59: Pooled OLS Regression: Production Demand for Silver

	Coef.	Std. Err.	t	P>|t|	95% Confidence Interval	
lnmoney	0.29380	0.03012	9.75	0.000	0.23439	0.35322
lncpi	0.02565	0.21195	0.12	0.904	-0.39243	0.44373
lngdp	-0.48165	0.04171	-11.55	0.000	-0.56392	-0.39937
lnexchange	0.05017	0.02409	2.08	0.039	0.00265	0.09769
lyield	-0.28539	0.08281	-3.45	0.001	-0.44874	-0.12204
syield	0.20295	0.06055	3.35	0.001	0.08351	0.32239
lnequity	0.08285	0.06615	1.25	0.212	-0.04763	0.23252
lnuncertainty	0.31225	0.09310	3.35	0.001	0.12860	0.49590
_cons	9.22170	1.87331	4.92	0.000	5.52655	12.91686

The results in Table 9.59 are very much in line with those in Table 9.58 for the exception that national exchange rates to the US Dollar are also identified as statistically significant. The positive relationship indicates that a stronger US Dollar is associated with an increase in industrial demand for silver. However, the R^2 value of 0.5750 is very similar to that identified for the model in Table 9.58 indicating that the results in Table 9.59 are not of significantly higher quality than those in Table 9.58.

An important issues arises in terms of model fitness, in other words: is a pooled OLS regression the appropriate model to use? A Breusch and Pagan (1979) procedure is used to test for possible model misspecification.

Table 9.60: Breusch and Pagan Lagrangian Multiplier Test for Random Effects: Production Demand for Silver

	Var	sd = sqrt (Var)
lnpdemand	2.506039	1.583047
e	0.066620	0.258109
u	1.797581	1.340739
	$\bar{\chi}^2$ (1)	1345.39
	Prob $>\bar{\chi}^2$	0.0000

The results in Table 9.60 are suggesting that a simple OLS regression might not be an appropriate procedure to use and that panel approaches should be considered. A Hausman (1978) procedure is used in order to understand how the coefficients in the model should be determined.

Table 9.61: Hausman Specification Test: Production Demand for Silver

	(b) Fixed	(B) Random	(b-B) Difference	sqrt(diag($V_b - V_B$)) S.E.
lnmoney	-0.41392	-0.24977	-0.16415	0.03507
lncpi	0.30705	0.69215	-0.38509	0.23034
lngdp	1.26199	0.15608	1.10591	0.31269
lnexchange	-0.27669	-0.17087	-0.10582	0.09599
lyield	-0.02418	-0.04800	0.02383	0.00000
syield	0.00394	0.01384	-0.00990	0.00000
lnequity	0.10774	0.14461	-0.03687	0.00508
lnuncertainty	-0.09661	-0.08969	-0.00691	0.00000
			χ^2 (8)	44.12
			Prob $>\chi^2$	0.0000

According to the results in Table 9.61, the coefficient in a linear panel-data model should be determined by a fixed effect model.

Table 9.62: Fixed Effects Linear Regression Model: Production Demand for Silver

	Coef.	Std.	Err.	t	P>|t|	95% Confidence Interval
lnmoney	-0.41392	0.09157	-4.52	0.000	-0.59462	-0.23322
lncpi	0.30705	0.39044	0.79	0.433	-0.46340	1.07750
lngdp	1.26199	0.35519	3.55	0.000	0.56109	1.96289
lnexchange	-0.27669	0.13883	-1.99	0.048	-0.55065	-0.00274
lyield	-0.02418	0.02340	-1.03	0.303	-0.07035	0.02200
syield	0.00394	0.01499	0.26	0.793	-0.02564	0.03351
lnequity	0.10774	0.07617	1.41	0.159	-0.04256	0.25804
lnuncertainty	-0.09661	0.06049	-1.60	0.112	-0.21598	0.02276
_cons	-0.32957	3.46340	-0.10	0.924	-7.16392	6.50478
σ_u	3.85744					
σ_e	0.25811					
ρ	0.99554					

Only three variables are identified when a panel-approach is taken: money supply, the GDP, and the national exchange rate to the US Dollar. The relationship with money supply is negative, indicating that a rise in money supply is associated with a drop in industrial demand for silver. Interesting results in the light that an increase in money supply could be considered to be linked to an increase in investment into industrial companies and would therefore be beneficial

Table 9.63: Wooldridge Test for Autocorrelation in Panel Data: Production Demand for Silver

F (1, 11)	=	1.930
Prob >F	=	0.1923

for industrial silver demand; however, the exact opposite seems to be the case. On the other hand, a more reasonable explanation could be that money supply increases during weak economic times, when industrial activity is slow and the demand for inputs low. The positive relationship with the GDP is very much in line with economic expectations, where an increase in the GDP of a country would reflect an increase in the industrial activities of that country and hence an increase in the demand for industrial inputs, amongst which silver. Finally, the negative relationship between exchange rates and industrial demand for physical silver indicates that if the US Dollar weakens against a currency, the industrial demand for silver of that foreign country will increase. A possible explanation could be that a weaker US Dollar against a given currency reflects increased industrial activity and wealth of that specific country, which in turn reflects the exchange rate behaviour, a more formal investigation would however be advisable. The overall R^2 value of the model in Table 9.62 of 0.4467 suggests to consider more complex dynamic model specifications.

9.2.4.3 Dynamic Regression Models

In the quest of designing optimal dynamic panel-data regression models, a Wooldridge (2002) procedure is used to detect possible first-order autocorrelation in the data.

Results in Table 9.63 suggest no first-order autocorrelation and advice to proceed with an Arellano and Bond (1991) dynamic panel-data procedure optimised for datasets with many panels and only few periods.

Interestingly, dynamic regression model results in Table 9.64 only identify money supply, the GDP and economic uncertainty as variables to be statistically significantly associated with industrial demand for silver. However, the results in Table 9.64 are indeed supporting the linear panel-data estimation of Table 9.62.

In a next step, the Blundell and Bond (1998) procedure is considered. While methodologically very close to the procedure from Arellano and Bond (1991), Blundell and Bond (1998) use additional moments conditions and include lagged difference of observations, allowing the researcher to *doublecheck* previous results.

Table 9.64: Arellano and Bond (1991) Dynamic Panel-Data Estimation: Production Demand for Silver

	Coef.	Std. Err.	z	P>|z|	95% Confidence Interval	
L1.lnpdemand	0.54810	0.05681	9.65	0.000	0.43676	0.65943
lnmoney	-0.25135	0.07277	-3.45	0.001	-0.39398	-0.10872
lncpi	0.08753	0.30113	0.29	0.771	-0.50267	0.67773
lngdp	0.71197	0.28532	2.50	0.013	0.15275	1.27119
lnexchange	-0.15188	0.11008	-1.38	0.168	-0.36764	0.06387
lyield	-0.01777	0.01807	-0.98	0.325	-0.05318	0.01765
syield	-0.00168	0.01160	-0.14	0.885	-0.02442	0.02106
lnequity	0.04946	0.05912	0.84	0.403	-0.06642	0.16533
lnuncertainty	-0.09210	0.04638	-1.99	0.047	-0.18301	-0.00118
_cons	-0.16228	2.65608	-0.06	0.951	-5.36811	5.04354

Table 9.65: Blundell and Bond (1998) Dynamic Panel-Data Estimation: Production Demand for Silver

	Coef.	Std. Err.	z	P>|z|	95% Confidence Interval	
L1.lnpdemand	0.92388	0.03443	26.84	0.000	0.85641	0.99136
lnmoney	-0.00965	0.02629	-0.37	0.714	-0.06118	0.04188
lncpi	0.07093	0.19652	0.36	0.718	-0.31425	0.45610
lngdp	-0.04226	0.03491	-1.21	0.226	-0.11069	0.02616
lnexchange	0.02997	0.02668	1.12	0.261	-0.02233	0.08227
lyield	-0.03500	0.01945	-1.80	0.072	-0.07313	0.00313
syield	0.00257	0.01358	0.19	0.850	-0.02405	0.02919
lnequity	-0.05074	0.04766	-1.06	0.287	-0.14415	0.04266
lnuncertainty	-0.08174	0.04589	-1.78	0.075	-0.17170	0.00821
_cons	1.66077	1.42462	1.17	0.244	-1.13143	4.45296

Results in Table 9.65 identify only long-term interest rates as a variable that has a statistically significant association with industrial demand for physical silver. Results in stark contrast to those in Table 9.64 hat pointed towards money supply, the GDP and economic uncertainty. In order to finalise this section and shed more light on these conflicting results, a Least Squares Dummy Variables procedure is considered in order to reconcile results obtained in Tables 9.64 and 9.65.

Table 9.66: LSDVC Dynamic Panel-Data Estimation: Production Demand for Silver

	Coef.	Std. Err.	z	P>|z|	95% Confidence Interval	
L1.lngdemand	0.59483	0.05450	10.91	0.000	0.48801	0.70164
lnmoney	-0.22577	0.07322	-3.08	0.002	-0.36928	-0.08226
lncpi	0.17664	0.30388	0.58	0.561	-0.41895	0.77223
lngdp	0.56063	0.28334	1.98	0.048	0.00530	1.11596
lnexchange	-0.09189	0.10917	-0.84	0.400	-0.30586	0.12208
lyield	-0.01245	0.01823	-0.68	0.495	-0.04818	0.02329
syield	-0.00483	0.01172	-0.41	0.680	-0.02780	0.01814
lnequity	0.07157	0.05941	1.20	0.228	-0.04486	0.18801
lnuncertainty	-0.08983	0.04713	-1.91	0.057	-0.18220	0.00255

Indeed, the results in Table 9.66 support the Arellano and Bond (1991) results in Table 9.64. A negative relationship between money supply and industrial demand for silver is observed, pointing towards a weaker demand when money supply increases. This observation calls for a more formal investigation as an initial economic explanation can only difficulty be provided with the results on hand. More sense can be read into the positive relationship with the GDP. Here, it seems that a higher GDP is linked with a greater industrial demand for physical silver - logical results in light of silver as a production input. Finally, the negative relationship between the economic uncertainty indices and silver demand is *de facto* supporting the positive relationship observed for the GDP: in an economically uncertain environment, the industrial demand for silver is usually lower. The results identified in this section are very insightful and reveal the complexity of the silver demand aspects by accounting them to their different fields: luxury, investment and industrial production.

9.3 Conclusion

Starr and Tran (2008) attempt to understand the effects of certain macroeconomic factors on the quantity of physical gold demanded by the central banks of different countries. This chapter took the investigation a step further and considers the effects of different variables on the aggregated quantity of gold and silver demanded by the private sector in different countries.

Results for gold are very insightful for market actors and uncover the following: total gold demand indicate a positive relationship with short-term yields and economic uncertainty, suggesting an increase in the demand when the economic climate is bad. However, the exact opposite is observed for industrial gold demand, where a positive relationship with economic activity is observed. Furthermore, results indicate a rising luxury demand linked to increases in national wealth, and towards a positive relationship between investment demand for gold and both inflation and economic uncertainty. Gold traders can use these results to better anticipate physical gold demand and act upon changing macroeconomic indicators.

Regarding silver, results are found to be more country-specific, pointing towards the greater complexity of the nature of the metal. Considering total physical demand for silver, only money supply seems to be significantly associated with changes in demand, while increases in luxury demand seem to occur in fruitful economic climates. Results for investment demand are somewhat puzzling, where a positive relationship with money supply might be suggesting possible inflation hedging abilities, though the negative relationship with the CPI is rejecting such a conclusion. Finally, clearer results are obtained for production demand, where a positive relationship with the GDP, alongside a negative relationship with economic uncertainty points towards the importance of a fruitful economic climate in determining the level of physical silver demand as a production input. The results on hand uncover the complexity of the physical silver market and suggest to silver traders to consider individual country analysis when determining future changes in the quantity demanded for silver.

Chapter 10

Conclusion

This chapter provides both a conclusion and suggestions for future research. The thesis started with a gentle introduction into the historical role of gold and silver and their importance in international currency systems. While a lot of research exists on the financial economics of the two precious metals, a thorough literature review uncovered that many questions yet have to be addressed. A detailed methodology section outlined the econometric procedures considered throughout the thesis and argued for the appropriateness of the individual methods and systems considered. The two following sections will synthesise the findings of the three result chapters, offering an outlook on potential future research.

10.1 Summary of Results

Chapter 7 presented a formal investigation into the relationship between precious metals and inflation in the United States of America, the United Kingdom of Great Britain and Northern Ireland, and Japan. Inflation was considered using three different measures: the CPI, the PPI, and Money Supply. Furthermore, expected inflation and inflation surprise was derived through an econometric procedure in order to get a clearer view on the relationship between gold and inflation.

Results for gold indicate that it was a hedge against nominal inflation in the United States of America only until the 1990s, and that the true inflation hedging potential of gold in the USA is against money supply. While financial crises act in a detrimental fashion against the long-run relationship between gold and US inflation, deflationary episodes helped gold to reincarnate the ability to act as an inflation hedge. In the United Kingdom, gold was an effective hedge against the CPI but less so against the PPI and money supply. Furthermore, evidence points towards a detrimental effect of interest rate increases for the inflation-hedging potential of gold. Considering the final country, Japan, gold was only a hedge against inflation during the late 1970s. Interestingly, the effect of interest rates on gold's inflation-hedging potential in Japan is the exact contrary to what is observed for the United Kingdom, reflecting the very different economic environments the two countries were in during the sample considered.

Silver is found to be a surprisingly bad long-run inflation hedge in the Unites States of America but reveals some effective short-run inflation hedging qualities. In the United Kingdom, silver proves to be a better long-run inflation hedge than gold against rises of the CPI, but is, rather, a short-run inflation hedge against the PPI and Money Supply. The superiority of silver's hedging potential is also revealed for Japanese money supply, where silver was a hedge during periods where gold failed to be.

In terms of policy implications, the results reveal the undeniable detachment of precious metals from money over the past decades; questioning the appropriateness of central bankers to rely on them as a guarantor of monetary strength. On the other hand, the results will be of interest to investors who can use precious metals to protect their portfolios from inflation.

Chapter 8 offered a sober investigation into the relationship between gold and silver, and a large amount of different macroeconomic variables. A comprehensive choice of variables was made in regard to previous research findings and a modern methodology was used to uncover robust relationships from several million different model specifications. Furthermore, different system calibrations were considered in order to test the robustness of the results obtained from a naive approach regressing all possible explanatory variables against both gold and silver.

Results outlined the important association between classical variables and the gold price; variables included the US Dollar and national inflation indices. However, results also pointed towards new, less classical variables, such as the S&P Case-Shiller National Home Price Index and the UK economic uncertainty index. Indeed, the negative relationship between gold and American real estate prices is in line with the sharp increase in the price of gold and the burst of the real estate bubble during the time-window considered. More interestingly, the significant positive relationship between gold prices and UK uncertainty uncovers the as yet unstudied importance of the British economy to the price of gold. Whilst this does require further study, it is a strong indication of the importance of the United Kingdom on the global gold market price, which points towards the effect that London has on fixing the official price of gold.

Regarding silver, the association with inflation rates is found to be far less important than for gold. In line with what was observed for gold, British macroeconomic indicators are found to be more important than suggested - more specifically, the relationship between silver and the UK CPI is stronger than between silver and the US CPI. Furthermore, sophisticated system specifications indicate that the US Dollar is not a stand-alone currency associated with movements in the price of silver, but that a wider set of international currencies play a role in the price of silver. Finally, weaker relationships between the price of silver and international debt and equity measures indicate that silver is the more speculative asset in comparison to gold.

Interesting results are uncovered for policy makers. First and foremost, the results call for a deeper investigation into the relationship between gold and British macroeconomic variables. Furthermore, market actors and researchers makers will benefit from the finding that the importance of the US Dollar is far more important on gold than on silver. Finally, policy makers benefit from the knowledge that silver is by far the more speculative asset in comparison to gold.

Chapter 9 provided a unique investigation into the physical demand for gold and silver in several countries. A mixture of panel and non-panel models are proposed, and goodness of fit statistics used in order to develop the best model possible with the data on hand. The total demand amount considered for gold and silver was broken down into luxury demand, investment demand, and finally, industrial production demand.

Results for total gold demand indicate a positive relationship with short-term yields and economic uncertainty: demand rises when the economic climate is bad, akin to the importance of investment demand. Indeed, results for the investment demand of gold indicated that no country-effects can be identified, so that a positive relationship between investment demand and both inflation and economic uncertainty can be observed for all 17 countries. Results for industrial demand of gold are more complex and suggest considering a more formal country specific investigation. However, a positive relationship with equity prices, alongside a negative relationship with long-term national debt yields, indicate a positive relationship between economic activity and gold demand as a production asset. Luxury demand for gold is found to have a negative relationship with inflation and a positive relationship with equity prices; indicating rising demand alongside an increase in national wealth.

Results for total physical silver demand are more complicated to obtain due to stronger country-specific effects. However, a generally negative relationship with money supply is identified. More specific results for investment demand suggest a positive relationship with money supply, indicating a possible inflation hedging ability. However, the negative relationship with the CPI strongly questions this suggestion; a possible explanation can be found in the different perception of silver across the different countries, where only certain individuals consider silver to be an attractive investment, while this view is more widespread for gold. Regarding silver luxury demand, results point towards strong country-specific effects. However, a stronger US Dollar is found to be beneficial for luxury demand by pushing down the price of silver. Furthermore, a negative relationship with long-term debt yields indicates that the consumption for luxury goods made out of silver is greater during fruitful economic climates. Considering physical demand for silver in industrial production, a positive relationship with the GDP and a negative relationship with economic uncertainty is observed, indicating that production demand is higher under a growing economy. However, the negative relationship observed with money supply, driving the identical relationship observed for total demand, calls for a more formal investigation.

These results will be of interest to market actors and decision makers on the gold market. Indeed, the global response to changes in economic uncertainty and inflation reflects safe haven abilities of gold, though changes in the industrial demand are more country-specific and require additional attention. In this sense, the results for silver indicate the country-specific effects on the demand and the failure of physical silver to serve as a reliable hedging instrument.

10.2 Future Research and Outlook

Throughout this thesis different possible future research questions have been outlined. While possible research on gold and silver could fill more than one lifetime, some question should be addressed more urgently than others. One such question is that of country-specific effects on the silver market - investigating in which countries silver is an investment asset, and in which countries it is an industrial asset. Further future work should look deeper into the relationship between precious metals and individual macroeconomic indicators, using the time-varying framework proposed in this thesis to understand more about the effects of certain variables in different economic climates. Furthermore, more knowledge should be provided on the financial importace of precious metals in *new economies*, such as China, Indian, and Iran. Quantifying the effect of different currencies on the prices of gold and silver should also be considered. Finally, two very wide and new research fields are the markets of platinum and palladium, though I leave this to another doctoral student.

APPENDIX A

ARIMA(1,1,3) Model Selection - Consumer Price Index, United States of America

The appropriate ARIMA model used to derive predicted values of the US Consumer Price Index was selected based on different possible model specifications in Stata. The model selected has an Autoregressive Order (p) of 1, an Integrated (difference) Order (d) of 1, and a Moving-average Order (q) of 3 - resulting into an ARIMA(1,1,3) model. No independent variable was specified in the model. The table and figures in this Appendix can be used to understand the accuracy of the ARIMA(1,1,3) model specified. All figures and results were obtained using Stata 13.

Table A.1: ARIMA (1,1,3) Regression US CPI

	Coefficient	Standard Error	z	P >|z|	Lower 95%	Upper 95%
ln_cpi						
_cons	0.0037	0.0012	3.16	0.002	0.0014	0.0060
ARMA						
ar						
L1	0.9873	0.0083	119.28	0.000	0.9711	1.0035
ma						
L1	-0.4187	0.0315	-13.31	0.000	-0.4804	-0.3571
L2	-0.3464	0.0354	-9.77	0.000	-0.4158	-0.2769
L3	-0.0705	0.0464	-1.52	0.128	-0.1614	0.0204
/sigma	0.0024	0.0000	48.98	0.000	0.0023	0.0025

Obs.	ll (null)	ll (model)	df	AIC	BIC	Wald Chi2 (4)	Prob > Chi2
480	.	2218.147	6	-4424.294	-4399.251	20280.91	0

Figure A.1: Line Plot of the US Consumer Price Index between January 1974 and January 2014

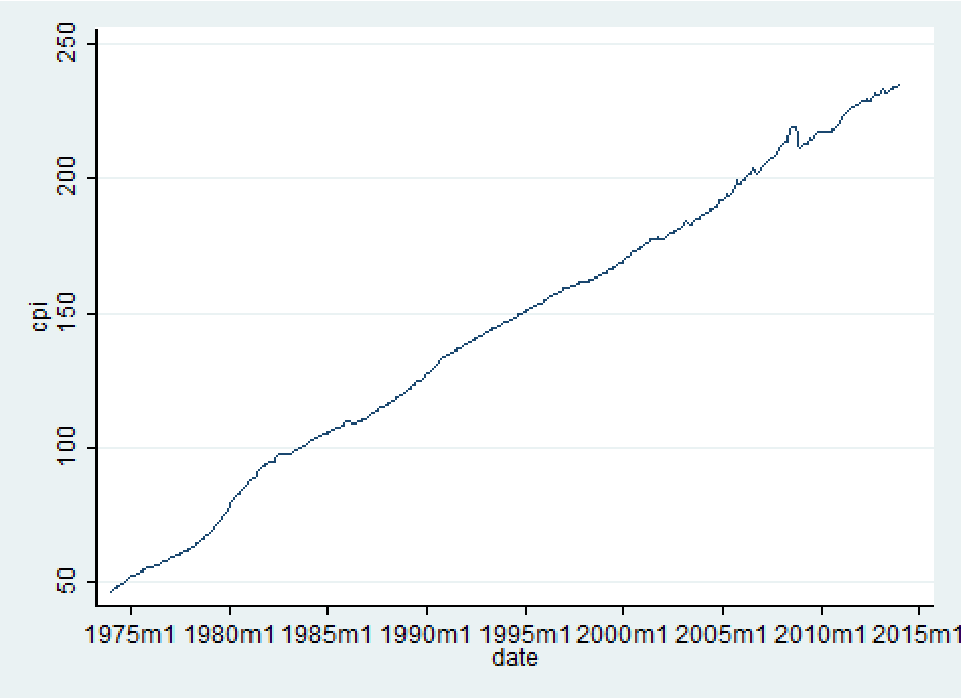


Figure A.2: Line Plot of the Natural Logarithm of the US Consumer Price Index between January 1974 and January 2014

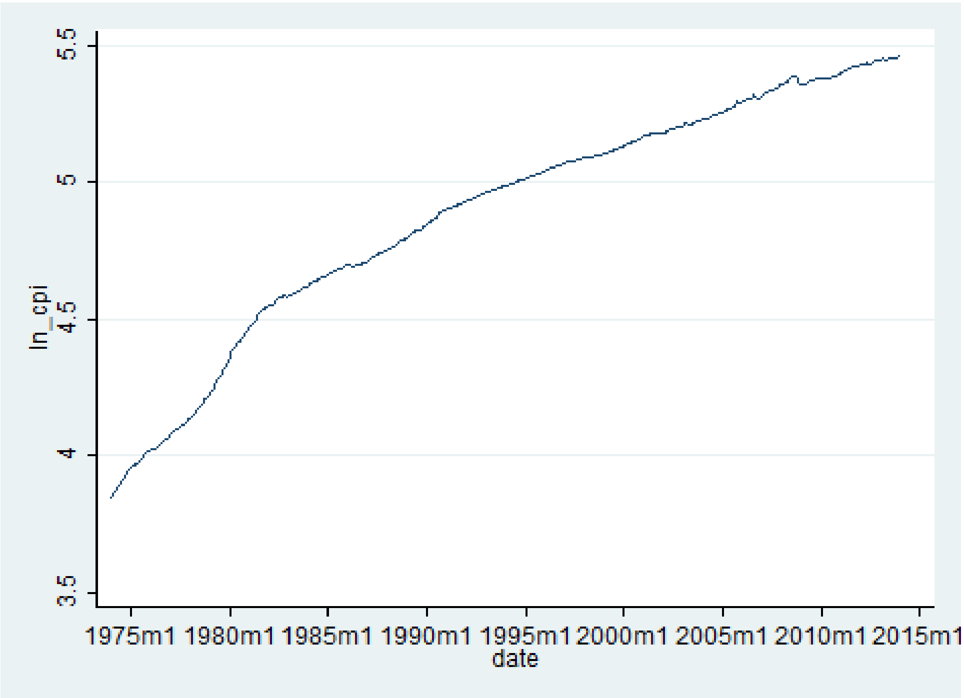


Figure A.3: Line Plot of the First Difference of the Natural Logarithm of the US Consumer Price Index between January 1974 and January 2014

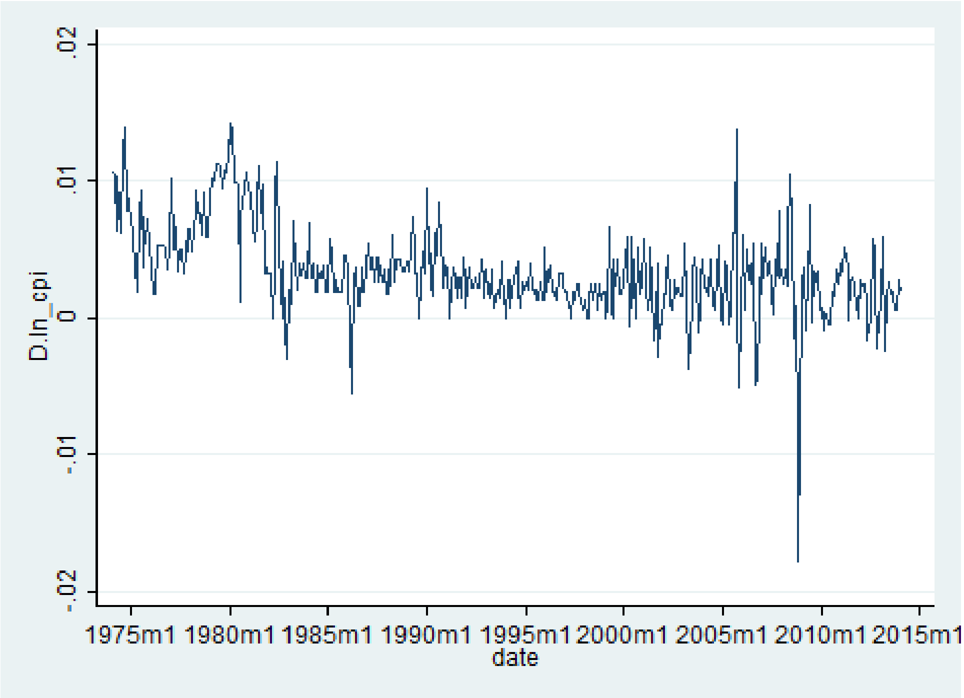


Figure A.4: Graph of Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the US Consumer Price Index between January 1974 and January 2014

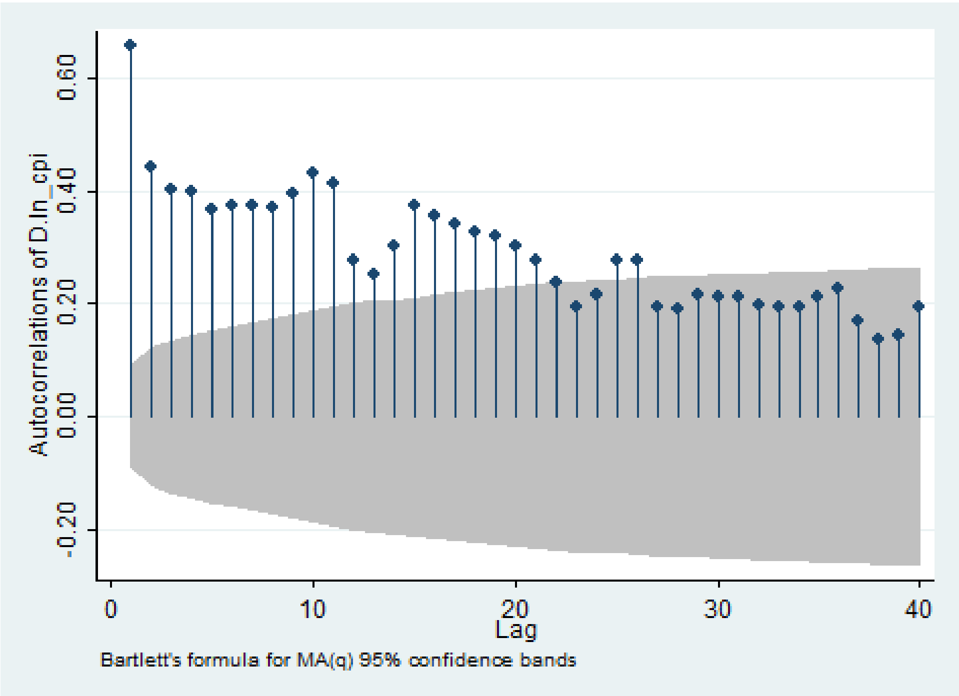
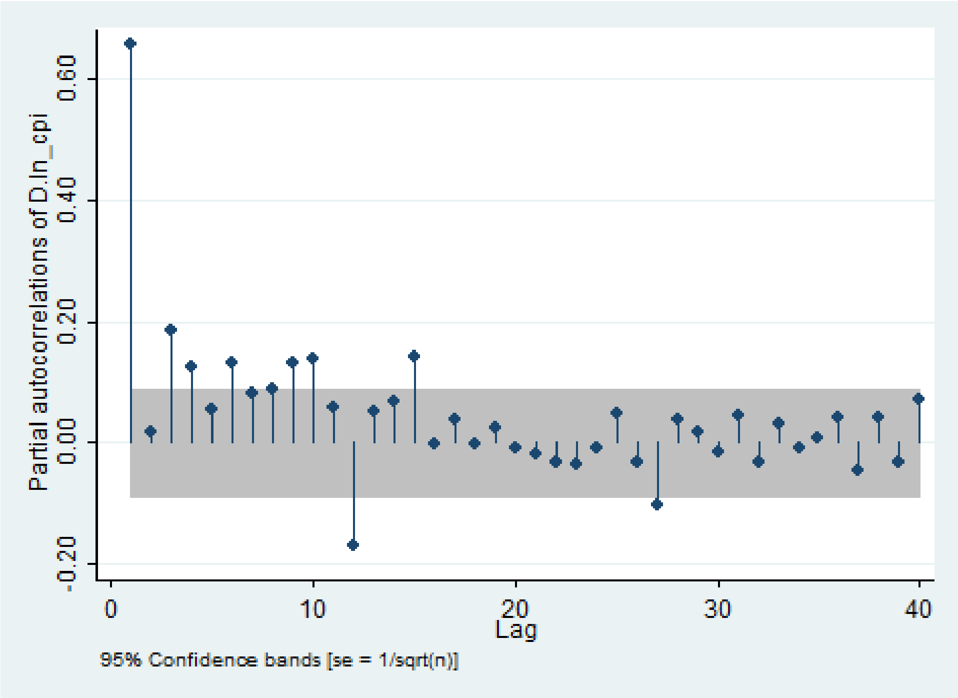


Figure A.5: Graph of Partial Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the US Consumer Price Index between January 1974 and January 2014



APPENDIX B

ARIMA(2,1,1) Model Selection - Producer Price Index, United States of America

The appropriate ARIMA model used to derive predicted values of the US Consumer Price Index was selected based on different possible model specifications in Stata. The model selected has an Autoregressive Order (p) of 2, an Integrated (difference) Order (d) of 1, and a Moving-average Order (q) of 1 - resulting into an ARIMA(2,1,1) model. No independent variable was specified in the model. The table and figures in this Appendix can be used to understand the accuracy of the ARIMA(2,1,1) model specified. All figures and results were obtained using Stata 13.

Table B.1: ARIMA (2,1,1) Regression US PPI

	Coefficient	Standard Error	z	P > |z|	Lower 95%	Upper 95%
ln_ppi						
_cons	0.0033	0.0010	3.22	0.001	0.0013	0.0052
ARMA						
ar						
L1	1.1749	0.0550	21.37	0	1.0672	1.2827
L2	-0.1980	.0402	-4.92	0	-.2769	-0.1191
ma						
L1	-0.8970	0.0450	-19.94	0	-0.9852	-0.8089
/sigma	0.0054	0.0001	52.36	0	0.0052	0.0056

Obs.	ll (null)	ll (model)	df	AIC	BIC	Wald Chi2 (3)	Prob > Chi2
480	.	1826.955	5	-3643.910	-3623.041	8042.44	0

Figure B.1: Line Plot of the US Producer Price Index between January 1974 and January 2014

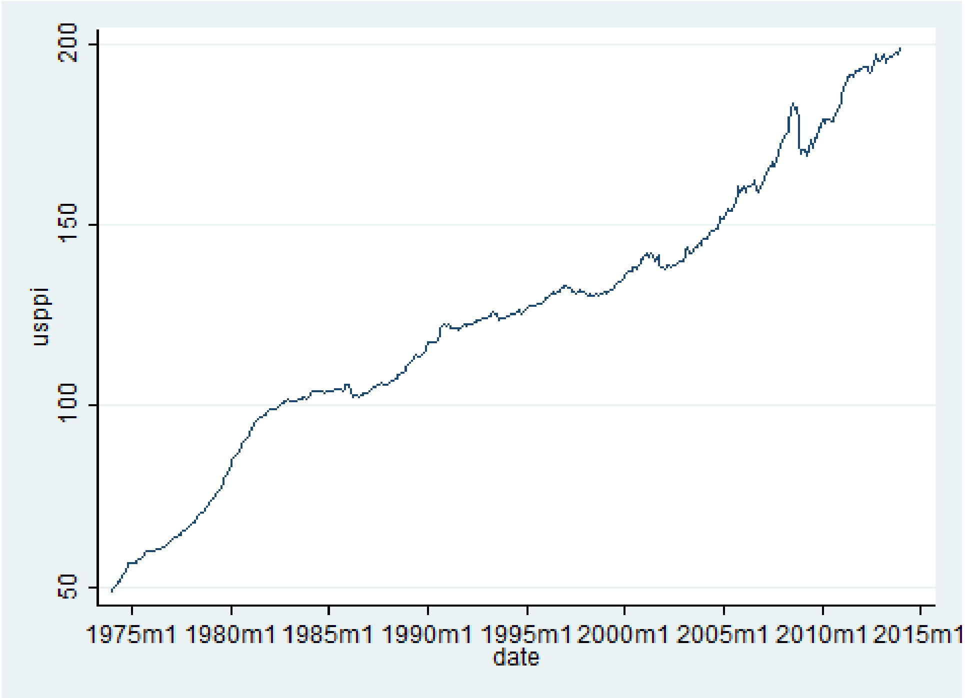


Figure B.2: Line Plot of the Natural Logarithm of the US Consumer Price Index between January 1974 and January 2014

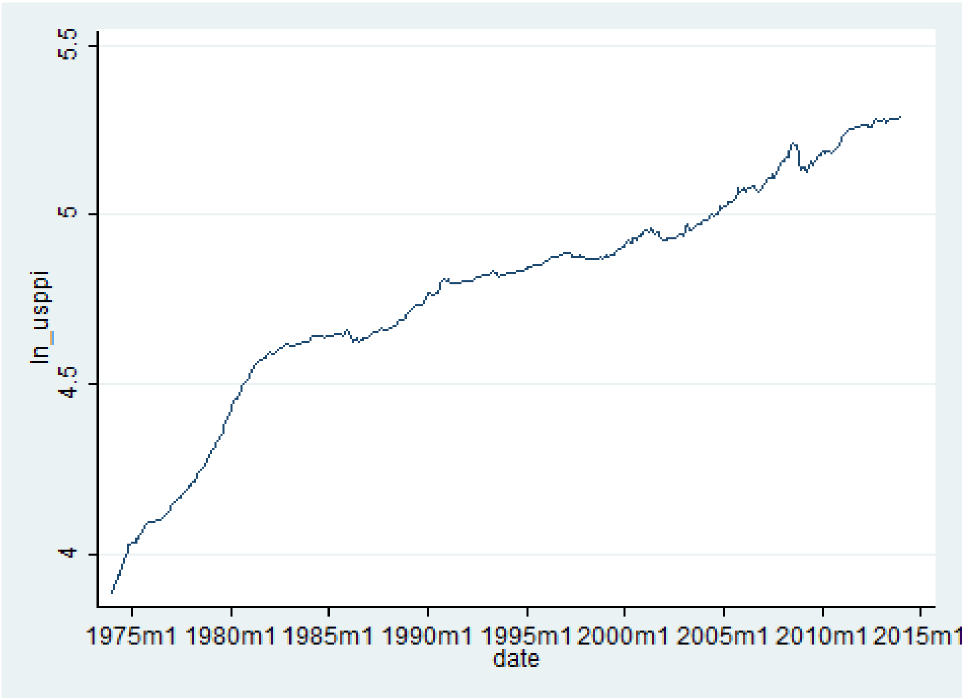


Figure B.3: Line Plot of the First Difference of the Natural Logarithm of the US Producer Price Index between January 1974 and January 2014

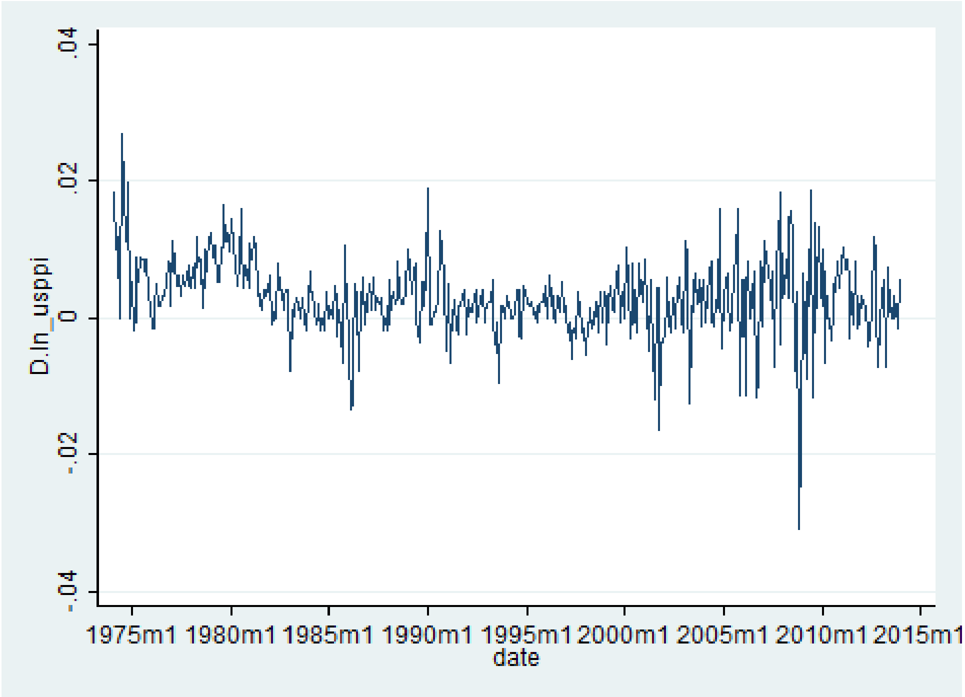


Figure B.4: Graph of Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the US Producer Price Index between January 1974 and January 2014

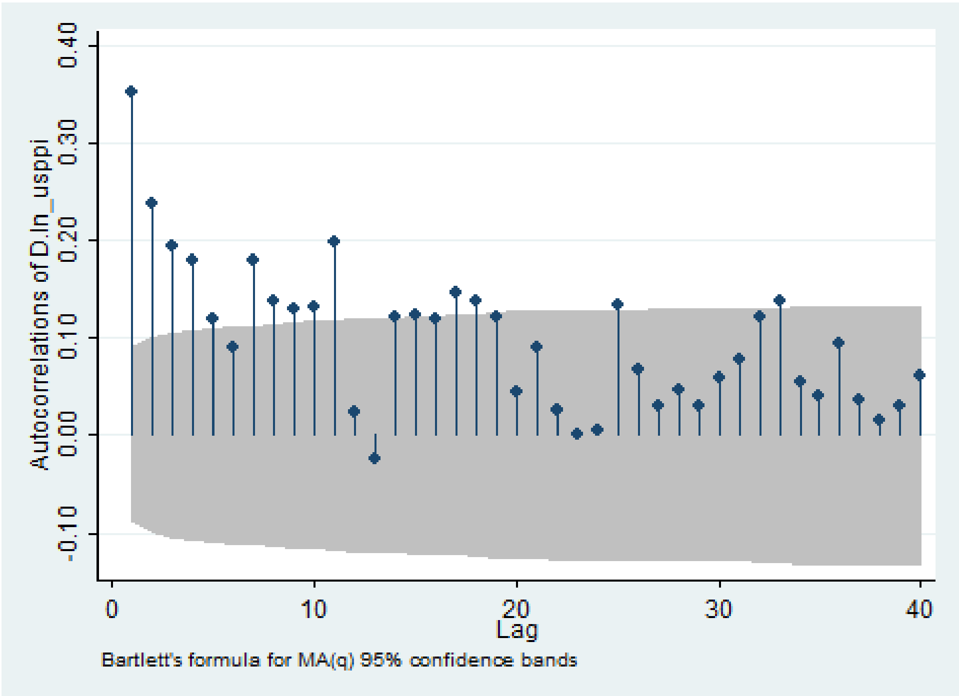
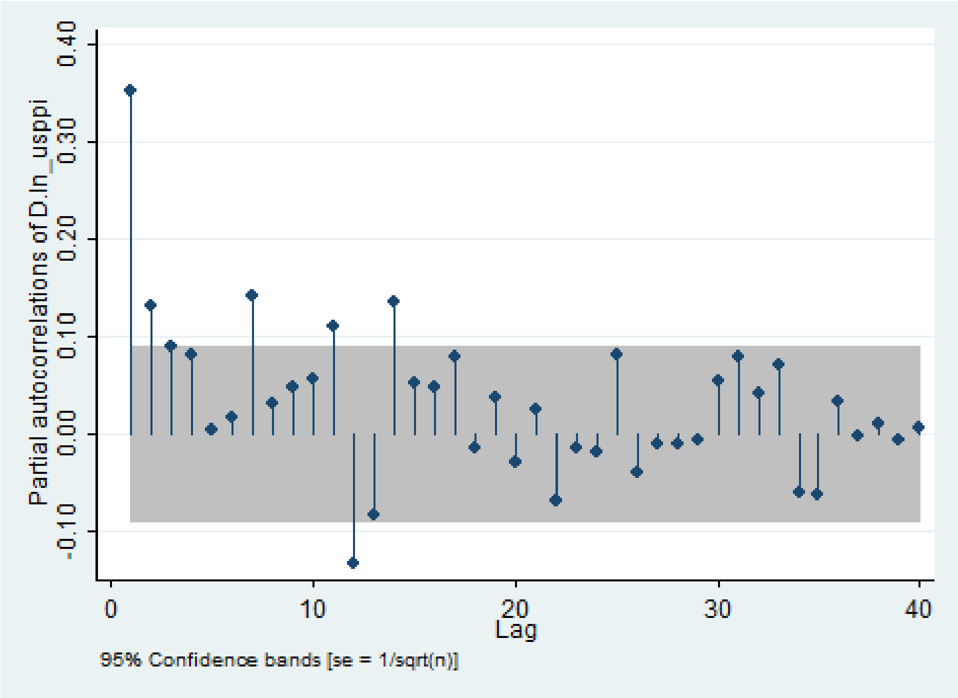


Figure B.5: Graph of Partial Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the US Producer Price Index between January 1974 and January 2014



APPENDIX C

Figures: Gold and Inflation - United States of America

Plotting the Trace Statistic of the Johansen (1991, 1995) test allows a visualisation of the cointegration relationship between gold and the inflation series considered. If the blue line is below the horizontal black line, the two series are cointegrated. In case the blue line is above the horizontal black line, there is no evidence for cointegration.

Figure C.1: The nominal US CPI and Gold in $ between 1974 to 2014

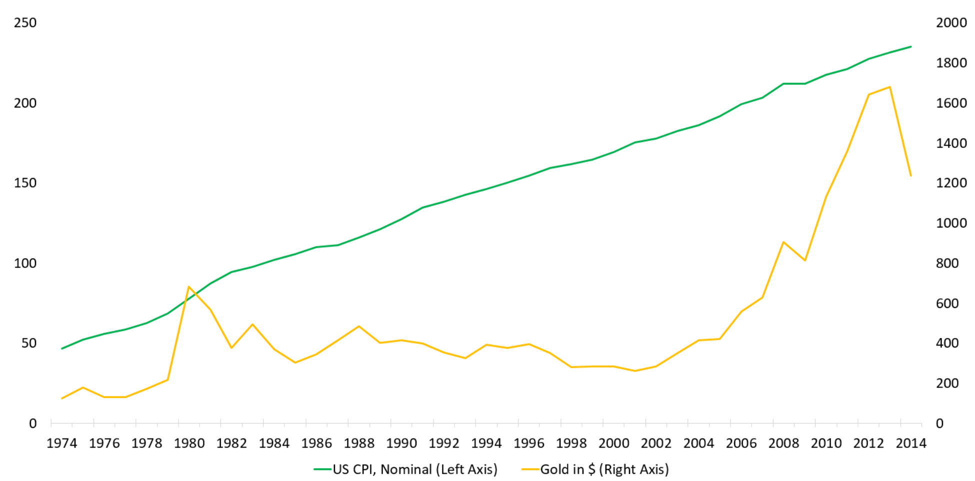


Figure C.2: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal US CPI (Scaled by the 5% Critical Value) - All Parameters

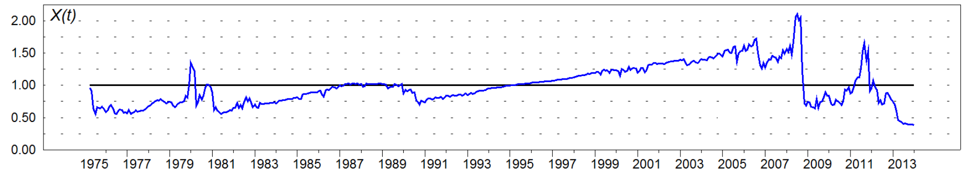


Figure C.3: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted US CPI (Scaled by the 5% Critical Value) - All Parameters

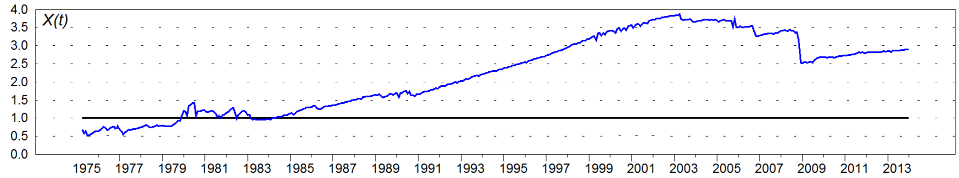


Figure C.4: US CPI Surprise Index and Gold between 1974 and 2014

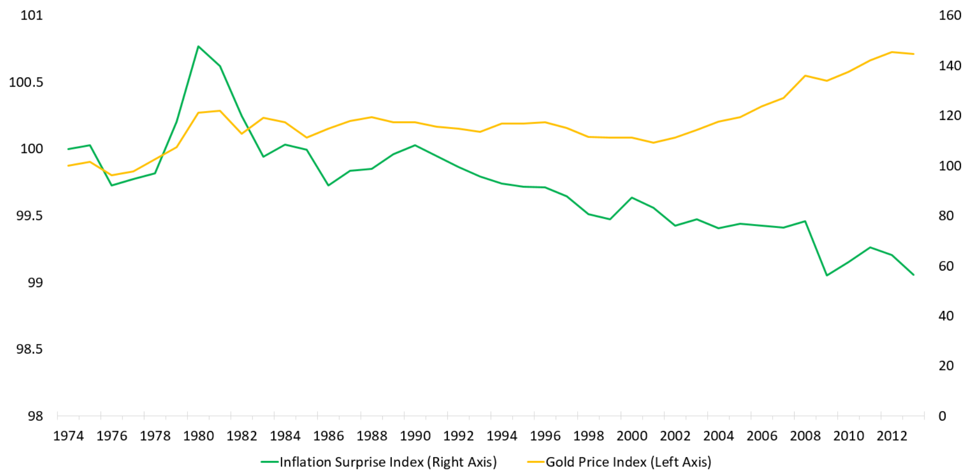


Figure C.5: The nominal US PPI and Gold in $ between 1974 to 2014

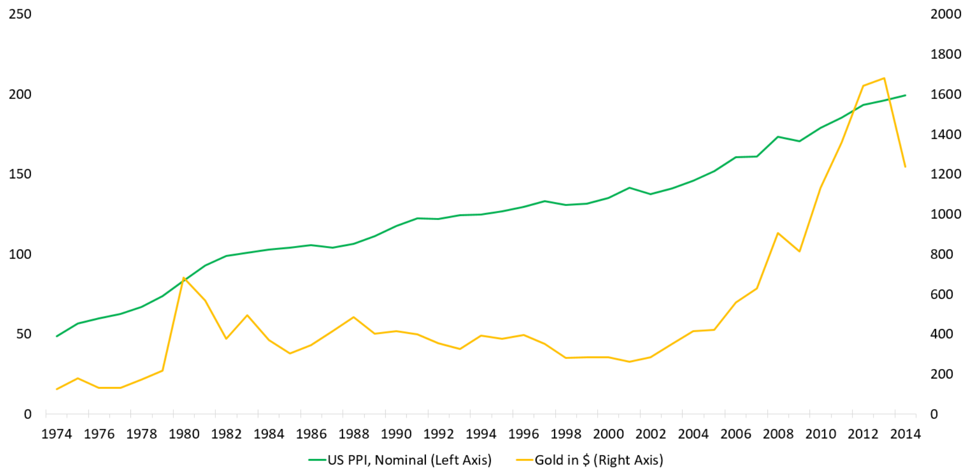


Figure C.6: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal US PPI (Scaled by the 5% Critical Value) - All Parameters

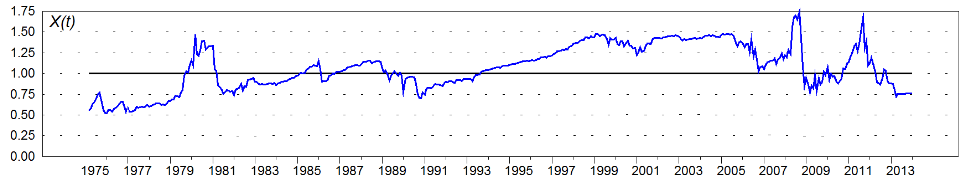


Figure C.7: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted US PPI (Scaled by the 5% Critical Value) - All Parameters

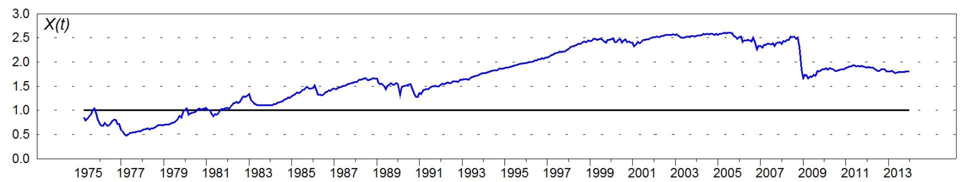


Figure C.8: US PPI Surprise Index and Gold between 1974 and 2014

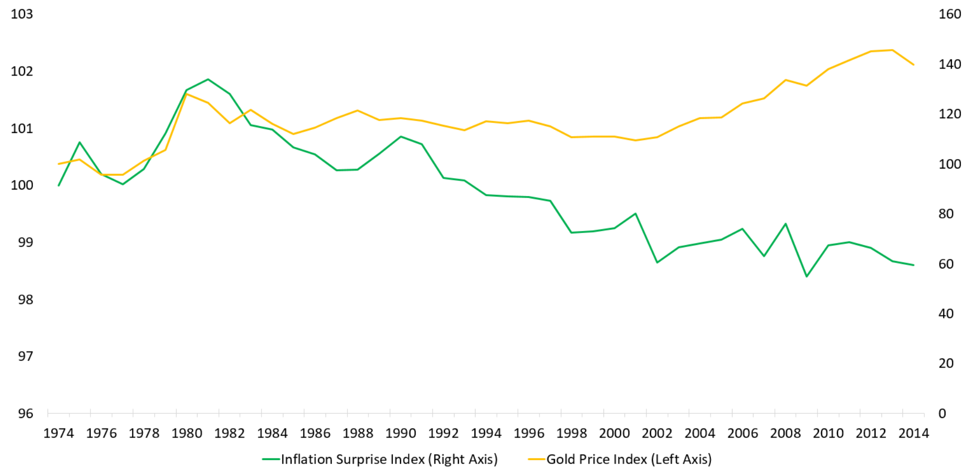


Figure C.9: Money Zero Maturity and Gold in $ between 1974 to 2014

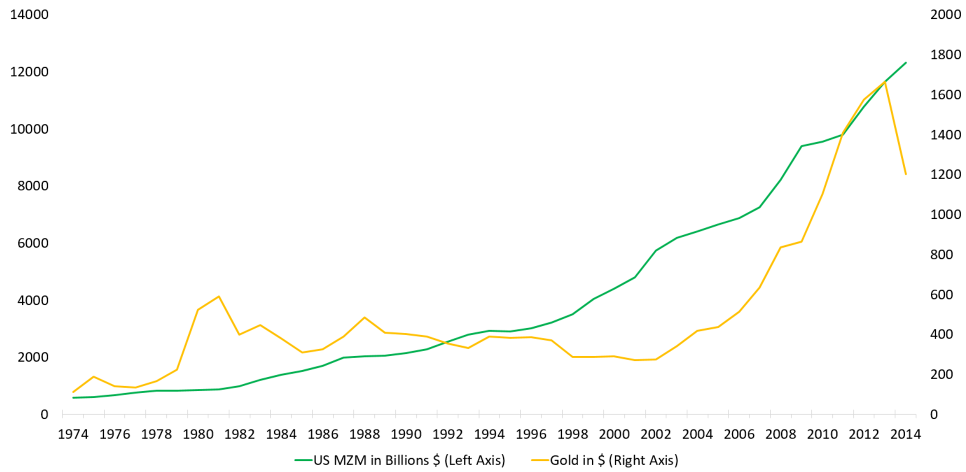


Figure C.10: Recursive Plot of Johansen's Trace Statistic for Gold and US Money Zero Maturity (Scaled by the 5% Critical Value) - Long-Run Parameters

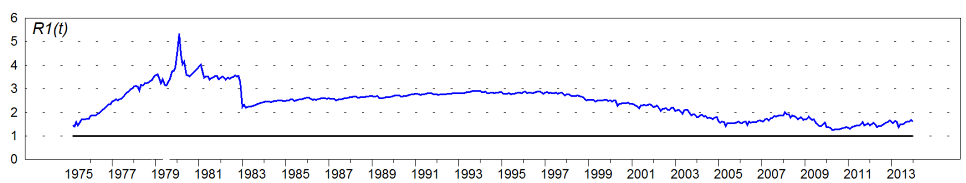
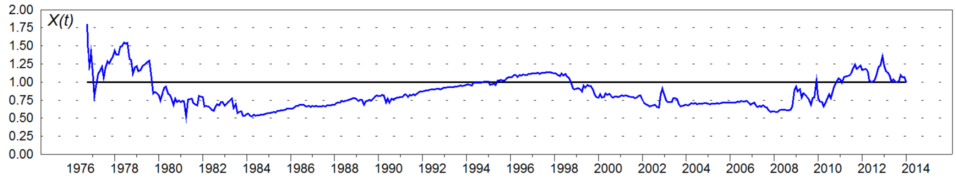


Figure C.11: Recursive Plot of Johansen's Trace Statistic for Gold and US Money Zero Maturity (Scaled by the 5% Critical Value) - All Parameters



APPENDIX D

Figures: Silver and Inflation - United States of America

Plotting the Trace Statistic of the Johansen (1991, 1995) test allows a visualisation of the cointegration relationship between gold and the inflation series considered. If the blue line is below the horizontal black line, the two series are cointegrated. In case the blue line is above the horizontal black line, there is no evidence for cointegration.

Figure D.1: The nominal US CPI and Silver in $ between 1974 to 2014

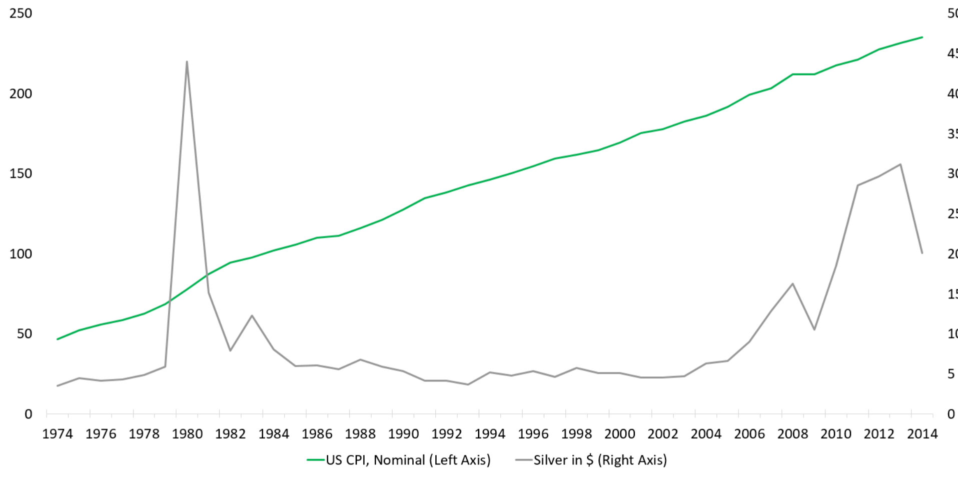


Figure D.2: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US CPI (Scaled by the 5% Critical Value) - Long-Run Parameters

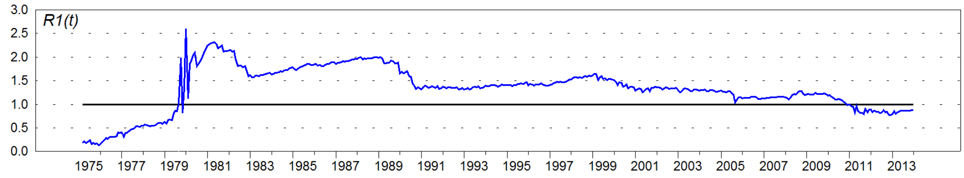


Figure D.3: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US CPI (Scaled by the 5% Critical Value) - All Parameters

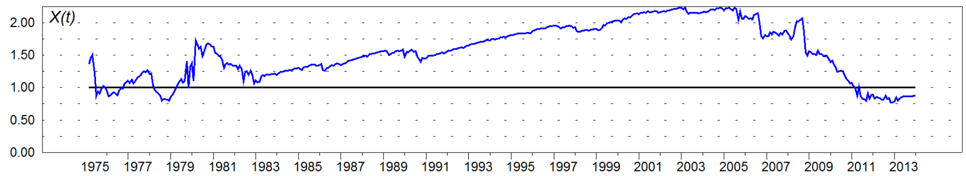


Figure D.4: The nominal US PPI and Silver in $ between 1974 to 2014

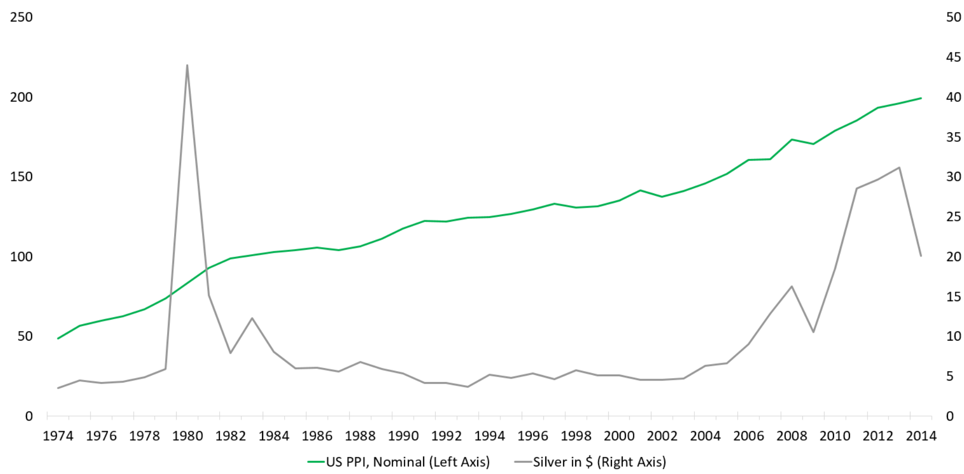


Figure D.5: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US PPI (Scaled by the 5% Critical Value) - Long-Run Parameters

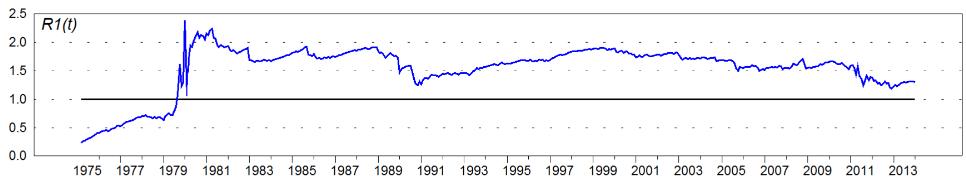


Figure D.6: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US PPI (Scaled by the 5% Critical Value) - All Parameters

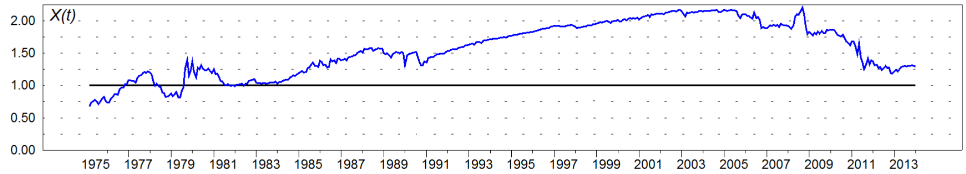


Figure D.7: Money Zero Maturity and Silver in $ between 1974 to 2014

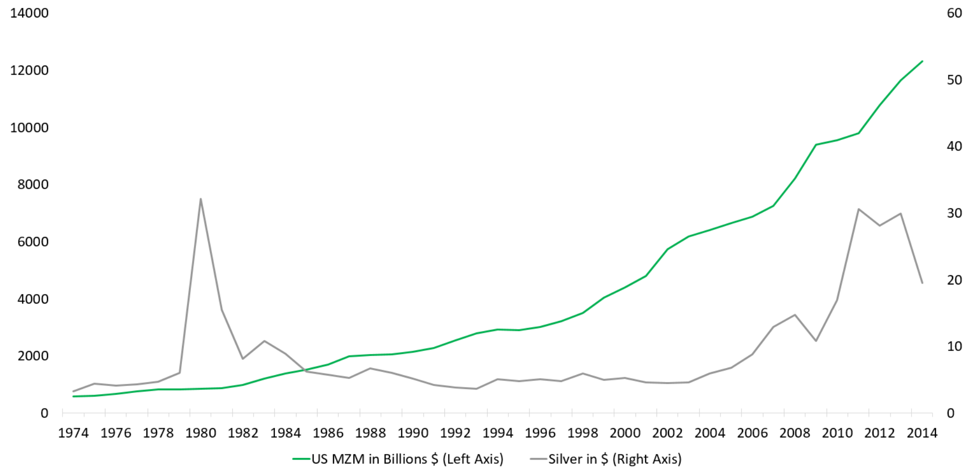


Figure D.8: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US MZM (Scaled by the 5% Critical Value) - Long-Run Parameters

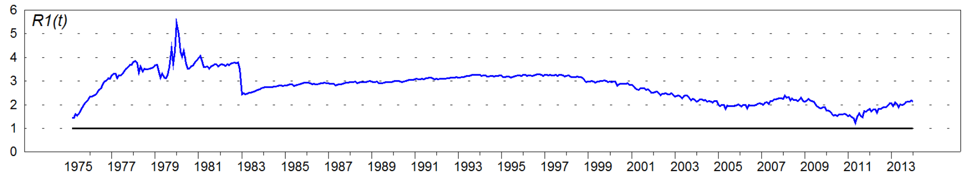
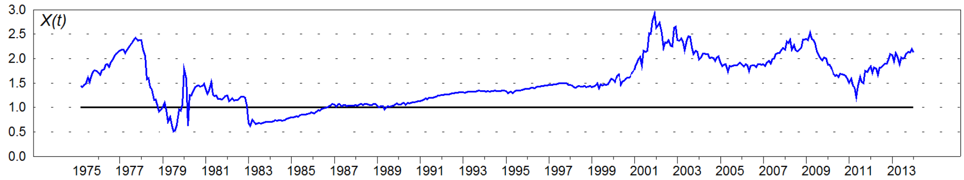


Figure D.9: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal US MZM (Scaled by the 5% Critical Value) - All Parameters



APPENDIX E

ARIMA(12,1,6) Model Selection - Consumer Price Index, United Kingdom of Great Britain and Northern Ireland

The appropriate ARIMA model used to derive predicted values of the UK Consumer Price Index was selected based on different possible model specifications in Stata. The model selected has an Autoregressive Order (p) of 12, an Integrated (difference) Order (d) of 1, and a Moving-average Order (q) of 6 - resulting into an ARIMA(12,1,6) model. No independent variable was specified in the model. The table and figures in this Appendix can be used to understand the accuracy of the ARIMA(12,1,6) model specified. All figures and results were obtained using Stata 13.

Figure E.1: Line Plot of the UK Consumer Price Index between January 1988 and January 2014

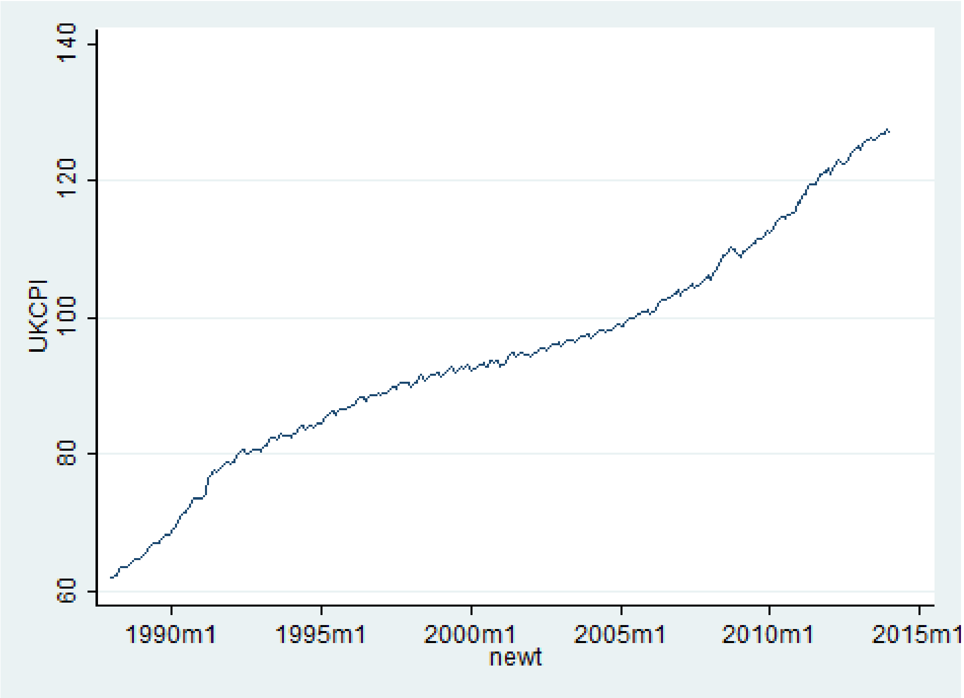


Figure E.2: Line Plot of the Natural Logarithm of the UK Consumer Price Index between January 1988 and January 2014

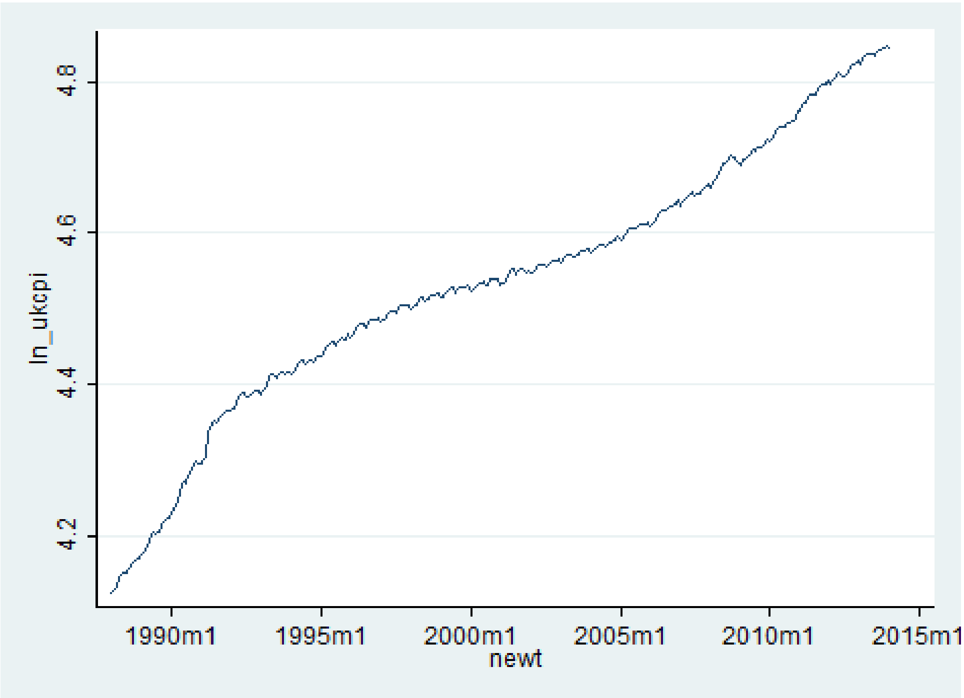


Figure E.3: Line Plot of the First Difference of the Natural Logarithm of the UK Consumer Price Index between January 1988 and January 2014

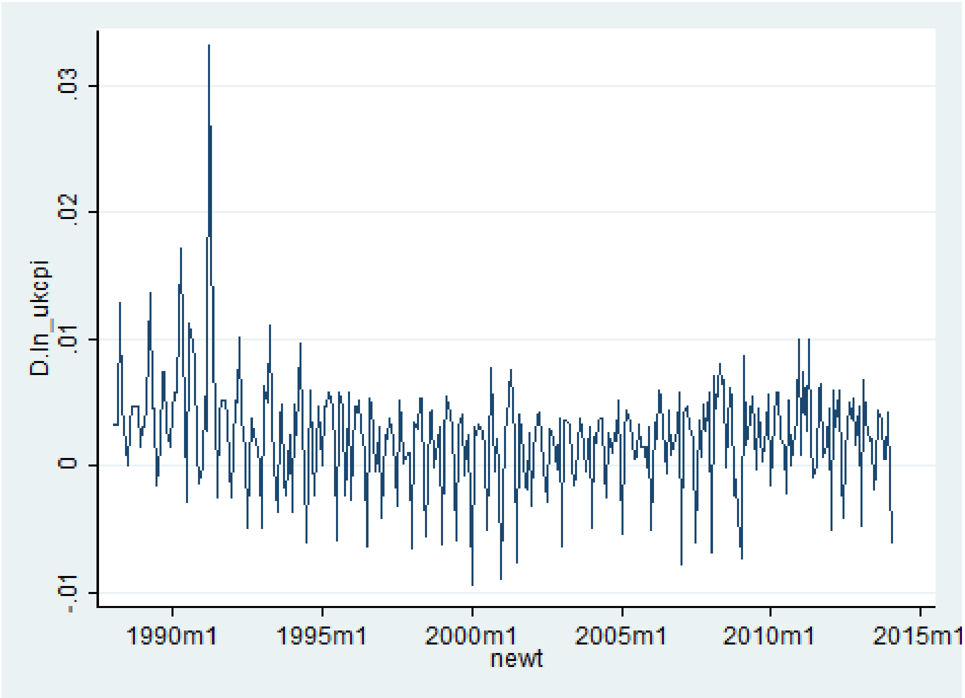


Figure E.4: Graph of Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the UK Consumer Price Index between January 1988 and January 2014

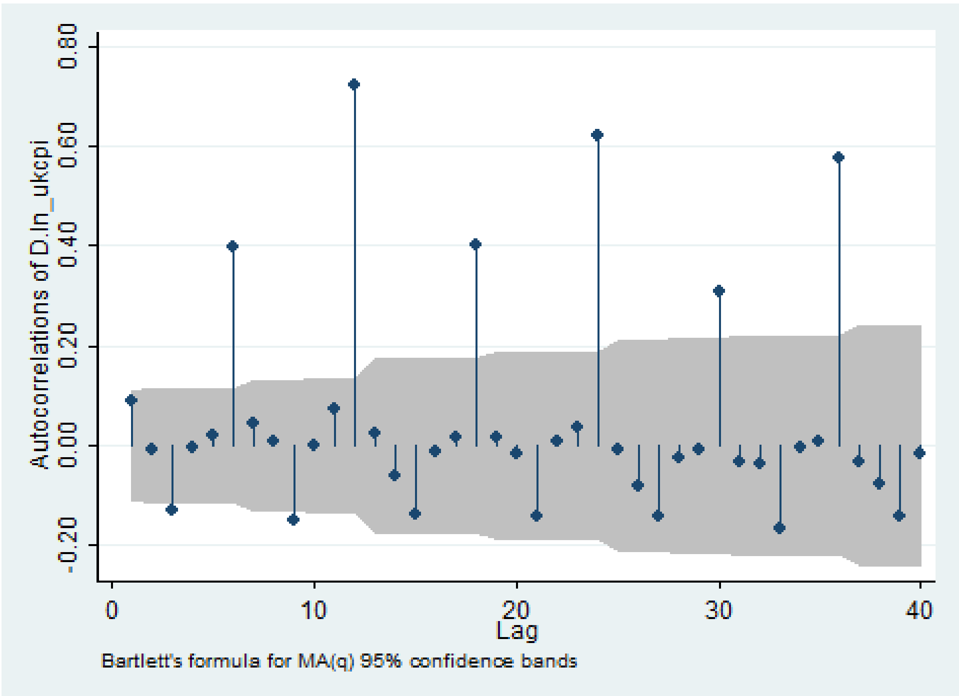
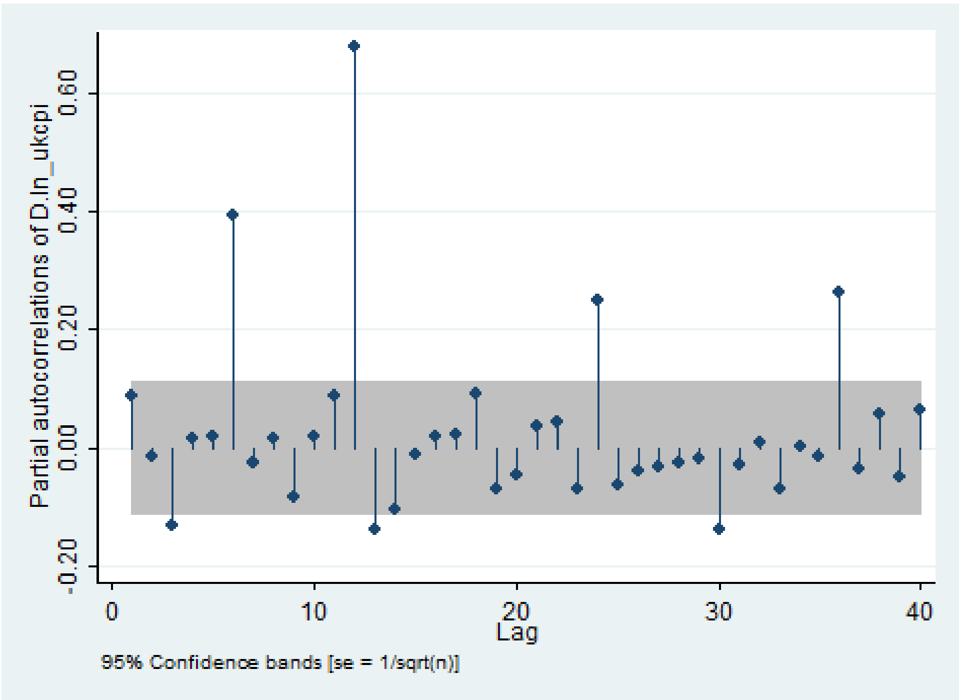


Table E.1: ARIMA (12,1,6) Regression UK CPI

	Coefficient	**Standard Error**	**z**	**P > |z|**	**Lower 95%**	**Upper 95%**
ln_cpi						
_cons	0.0024	0.0008	2.89	0.004	0.0008	0.0040
ARMA						
ar						
L1	-0.0784	0.0868	-0.90	0.366	-0.2486	0.0917
L2	-0.0950	0.0835	-1.14	0.255	-0.2587	0.0687
L3	-0.0242	0.0747	-0.32	0.746	-0.1705	0.1222
L4	-0.0003	0.0809	-0.00	0.997	-0.1588	0.1582
L5	-0.0727	0.0892	-0.82	0.415	-0.2475	0.1021
L6	0.3001	0.0574	5.23	0.000	0.1876	0.4127
L7	0.0378	0.0672	0.56	0.573	-0.0938	0.1695
L8	0.0478	0.0584	0.82	0.413	-0.0667	0.1624
L9	-0.0175	0.0604	-0.29	0.772	-0.1358	0.1008
L10	-0.0023	0.0693	-0.03	0.974	-0.1381	0.1335
L11	0.0445	0.0705	0.63	0.528	-0.0938	0.1827
L12	0.5965	0.0362	16.49	0.000	0.5256	0.6674
ma						
L1	0.2122	0.0993	2.14	0.033	0.0176	0.4068
L2	0.1679	0.1055	1.59	0.111	-0.0387	0.3746
L3	0.0912	0.0918	0.99	0.321	-0.0887	0.2711
L4	-0.0018	0.1042	-0.02	0.986	-0.2061	0.2025
L5	0.0997	0.1054	0.95	0.344	-0.1069	0.3063
L6	-0.3384	0.0663	-5.11	0.000	-0.4682	-0.2085
/sigma	0.0027	0.0001	32.92	0.000	0.0025	0.0029

Obs.	**ll (null)**	**ll (model)**	**df**	**AIC**	**BIC**	**Wald Chi2 (18)**	**Prob > Chi2**
312	.	1396.051	20	-2752.103	-2677.243	2799.75	0

Figure E.5: Graph of Partial Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the UK Consumer Price Index between January 1988 and January 2014



APPENDIX F

ARIMA(2,1,2) Model Selection - Producer Price Index, United Kingdom of Great Britain and Northern Ireland

The appropriate ARIMA model used to derive predicted values of the UK Producer Price Index was selected based on different possible model specifications in Stata. The model selected has an Autoregressive Order (p) of 2, an Integrated (difference) Order (d) of 1, and a Moving-average Order (q) of 2 - resulting into an ARIMA(2,1,2) model. No independent variable was specified in the model. The table and figures in this Appendix can be used to understand the accuracy of the ARIMA(2,1,2) model specified. All figures and results were obtained using Stata 13.

Table F.1: ARIMA (2,1,2) Regression UK PPI

	Coefficient	Standard Error	z	P >|z|	Lower 95%	Upper 95%
ln_ppi						
_cons	0.0082	0.0084	0.98	0.328	-0.0082	0.0246
ARMA						
ar						
L1	1.6510	0.1631	10.13	0.000	1.3314	1.9706
L2	-0.6517	0.1626	-4.01	0.000	-0.9703	-0.3330
ma						
L1	-1.4120	0.1753	-8.05	0.000	-1.7557	-1.0683
L2	0.4500	0.1535	2.93	0.003	0.1492	0.7509
/sigma	0.0044	0.0001	51.47	0.000	0.0043	0.0046

Obs.	ll (null)	ll (model)	df	AIC	BIC	Wald Chi2 (4)	Prob > Chi2
480	.	1917.523	6	-3823.046	-3798.003	1968.73	0

Figure F.1: Line Plot of the UK Producer Price Index between January 1974 and January 2014

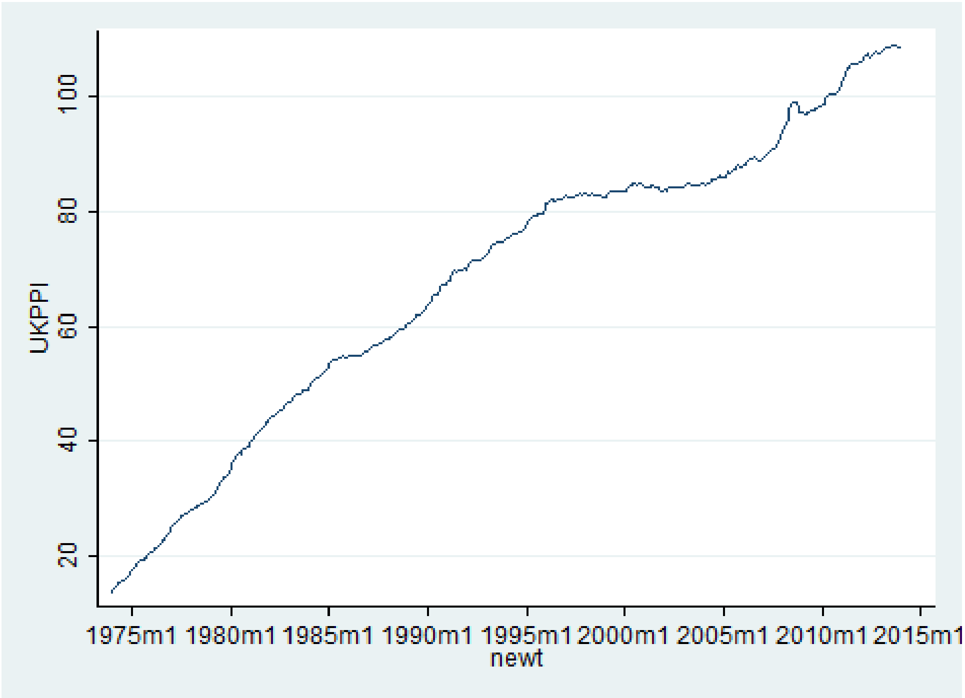


Figure F.2: Line Plot of the Natural Logarithm of the UK Producer Price Index between January 1974 and January 2014

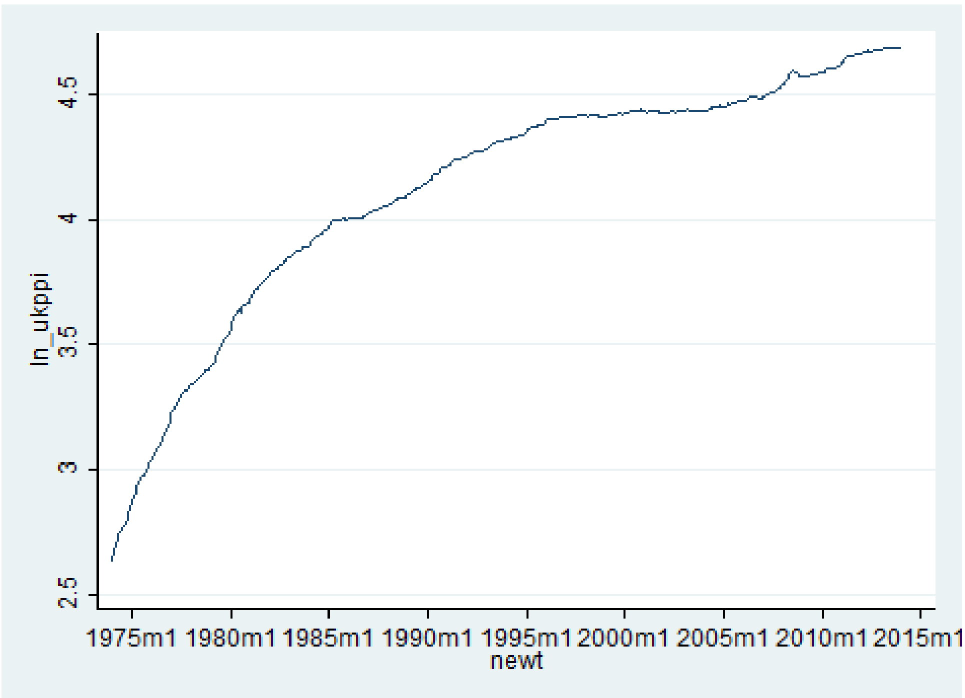


Figure F.3: Line Plot of the First Difference of the Natural Logarithm of the UK Producer Price Index between January 1974 and January 2014

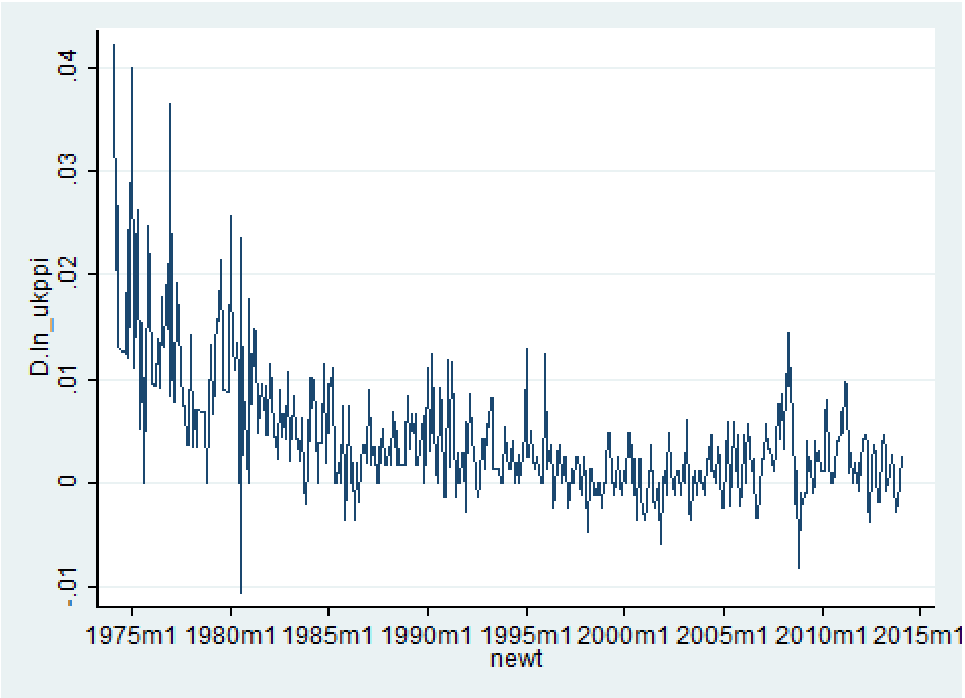


Figure F.4: Graph of Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the UK Producer Price Index between January 1974 and January 2014

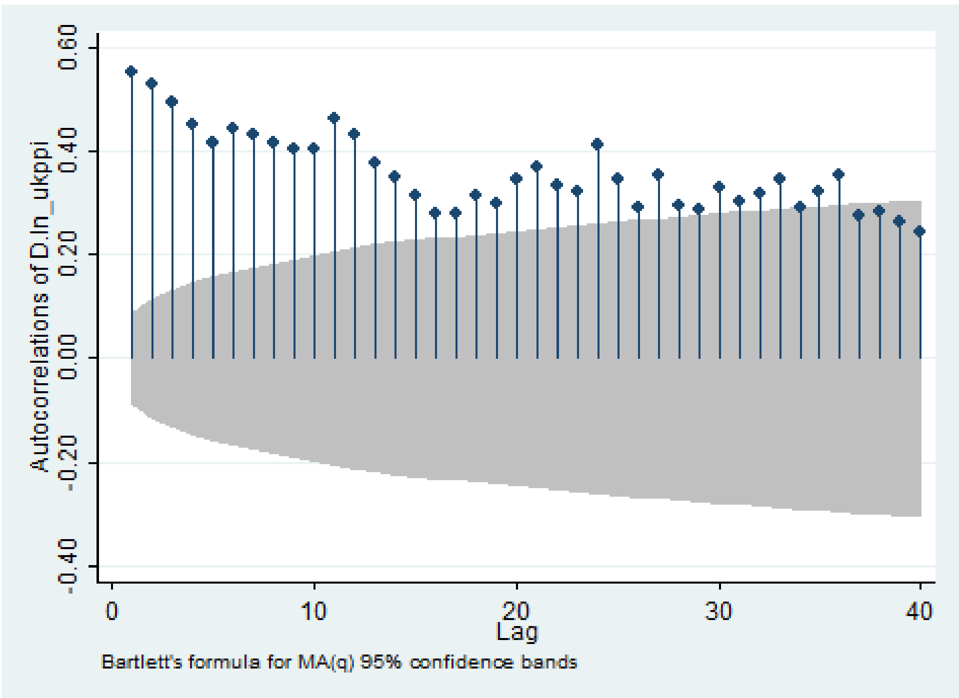
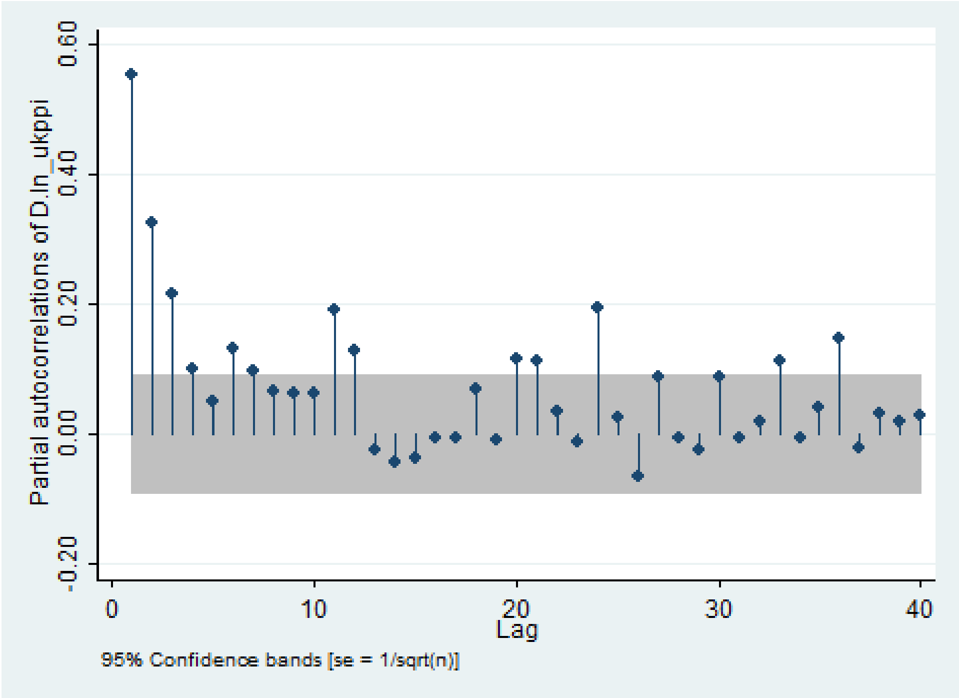


Figure F.5: Graph of Partial Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the UK Producer Price Index between January 1974 and January 2014



APPENDIX G

Figures: Gold and Inflation - United Kingdom of Great Britain and Northern Ireland

Plotting the Trace Statistic of the Johansen (1991, 1995) test allows a visualisation of the cointegration relationship between gold and the inflation series considered. If the blue line is below the horizontal black line, the two series are cointegrated. In case the blue line is above the horizontal black line, there is no evidence for cointegration.

Figure G.1: The nominal UK CPI and Gold in £ between 1988 and 2014

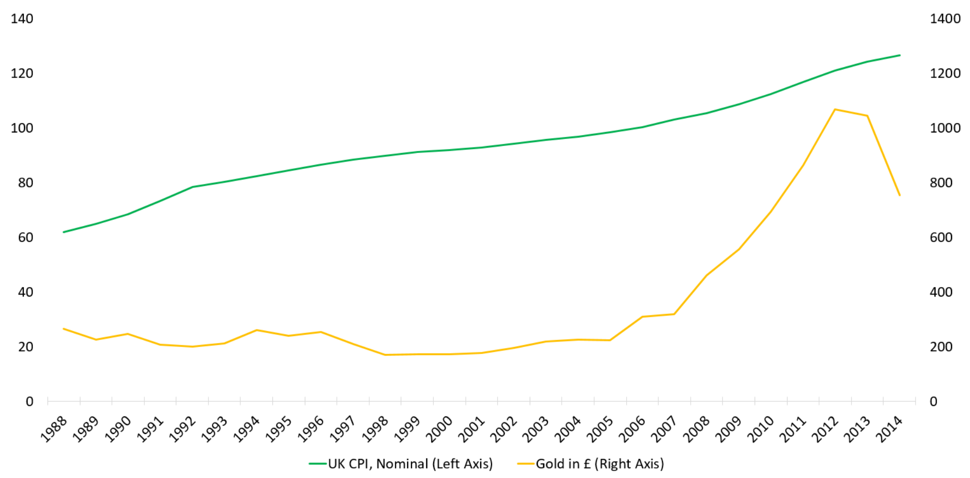


Figure G.2: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal UK CPI (Scaled by the 5% Critical Value) - All Parameters

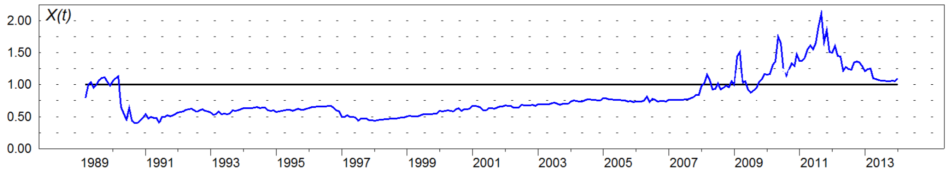


Figure G.3: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted UK CPI (Scaled by the 5% Critical Value) - All Parameters

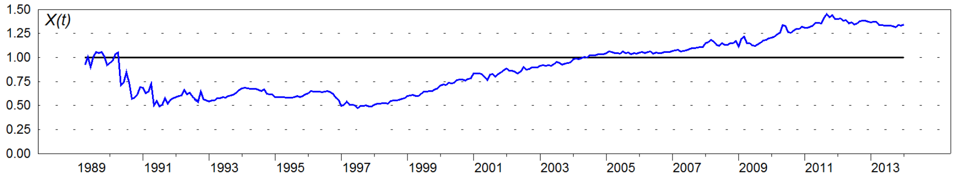


Figure G.4: UK CPI Surprise Index and Gold between 1988 and 2014

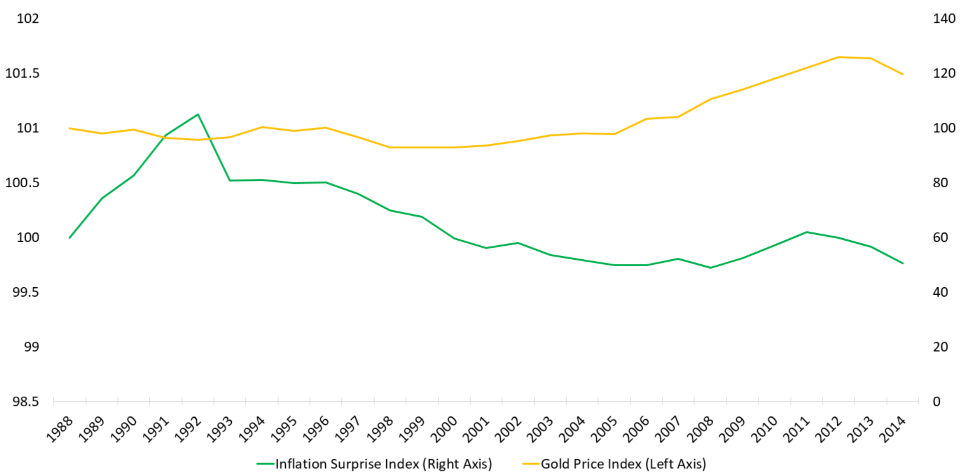


Figure G.5: The nominal UK PPI and Gold in £ between 1974 and 2014

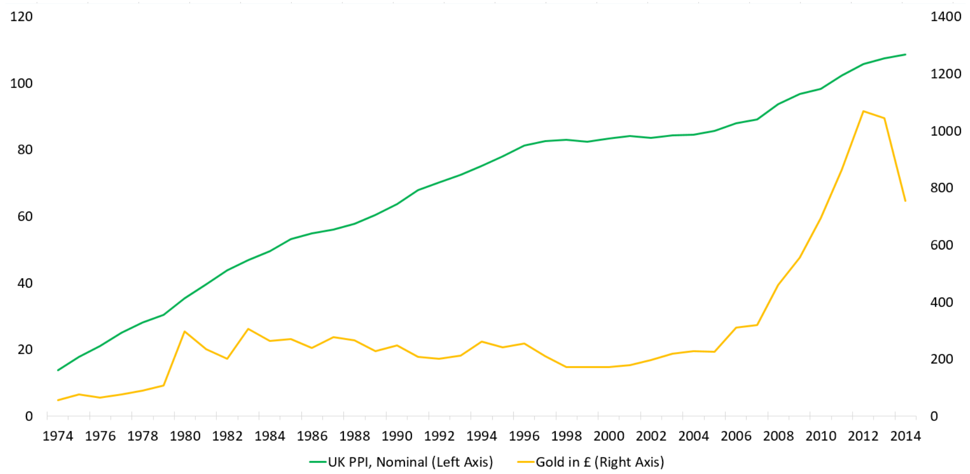


Figure G.6: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal UK PPI (Scaled by the 5% Critical Value) - All Parameters

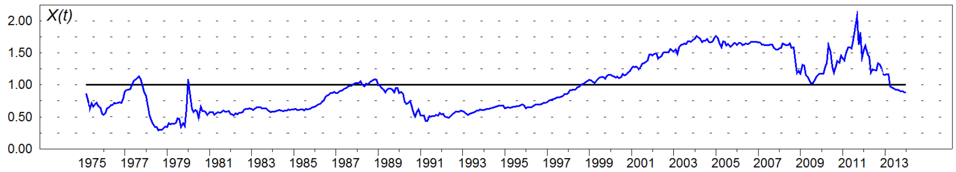


Figure G.7: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted UK PPI (Scaled by the 5% Critical Value) - All Parameters

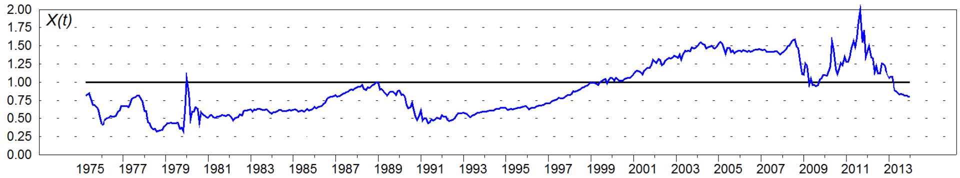


Figure G.8: Recursive Plot of Johansen's Trace Statistic for Gold and the Indexed Surprise UK PPI (Scaled by the 5% Critical Value) - All Parameters

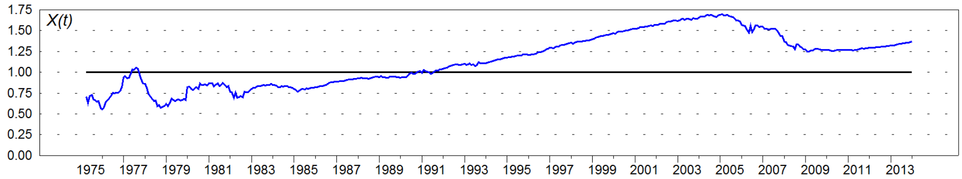


Figure G.9: UK Narrow Money and Gold in £ between 1974 and 2014

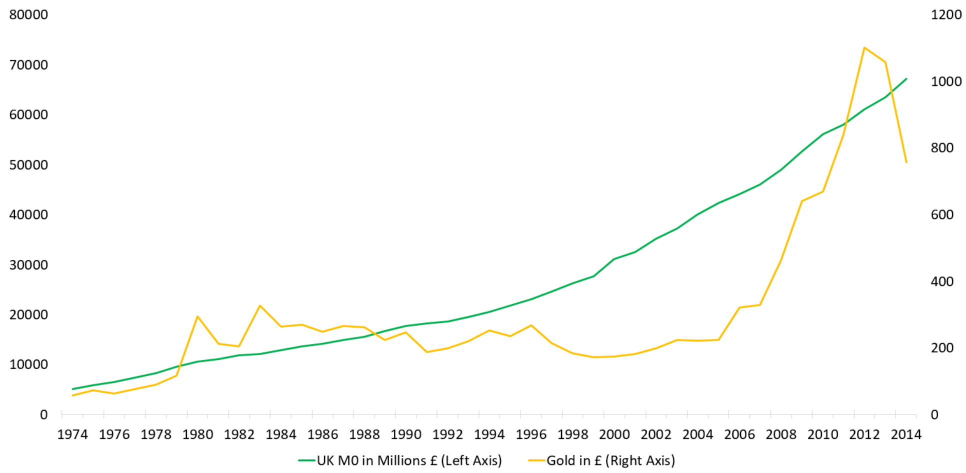
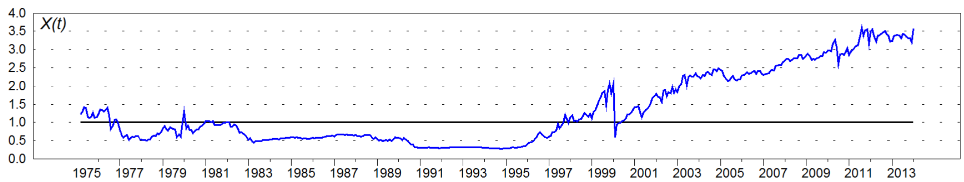


Figure G.10: Recursive Plot of Johansen's Trace Statistic for Gold and UK Narrow Money (Scaled by the 5% Critical Value) - All Parameters



APPENDIX H

Figures: Silver and Inflation - United Kingdom of Great Britain and Northern Ireland

Plotting the Trace Statistic of the Johansen (1991, 1995) test allows a visualisation of the cointegration relationship between gold and the inflation series considered. If the blue line is below the horizontal black line, the two series are cointegrated. In case the blue line is above the horizontal black line, there is no evidence for cointegration.

Figure H.1: The nominal UK CPI and Silver in £ between 1988 and 2014

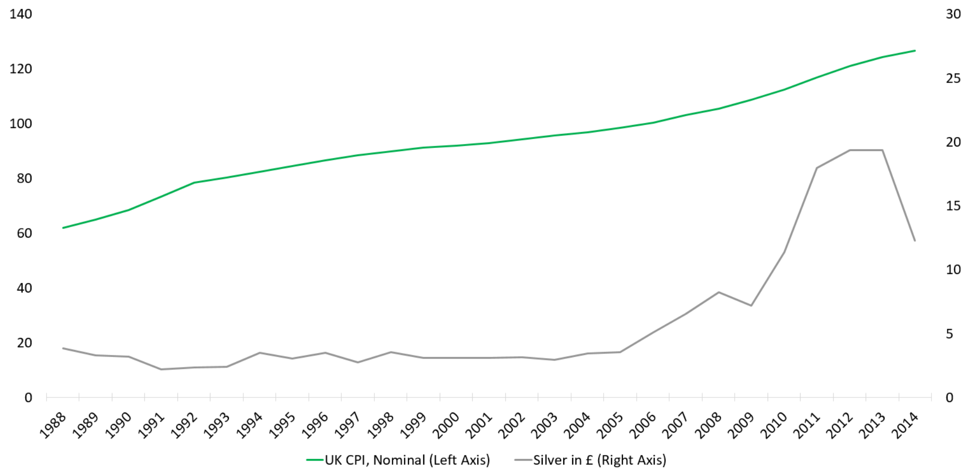


Figure H.2: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal UK CPI (Scaled by the 5% Critical Value) - All Parameters

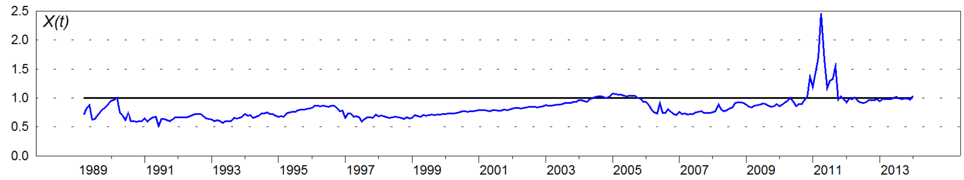


Figure H.3: The nominal UK PPI and Silver in £ between 1974 and 2014

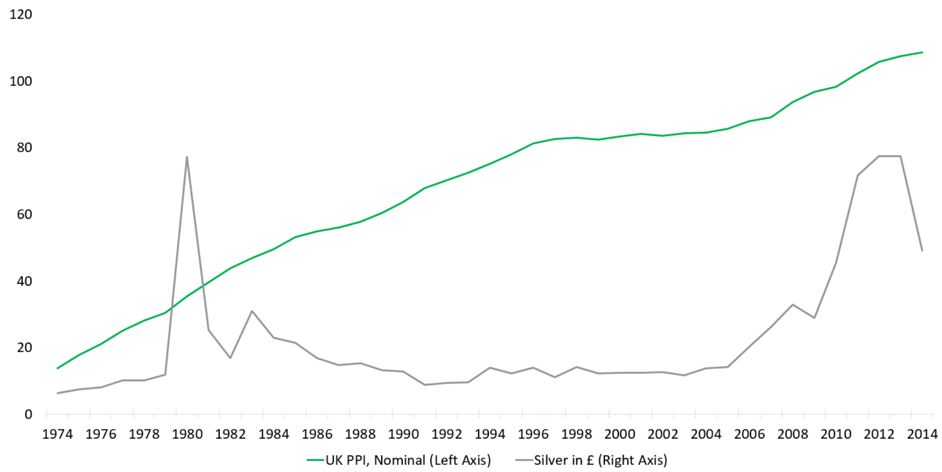


Figure H.4: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal UK PPI (Scaled by the 5% Critical Value) - Long-Run Parameters

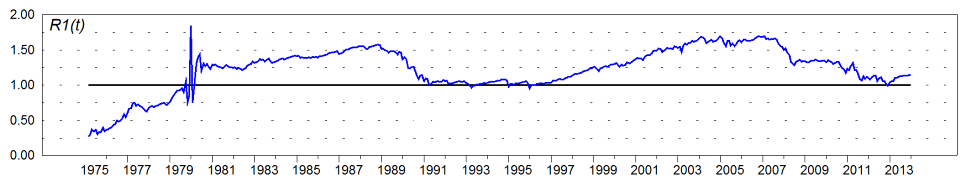


Figure H.5: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal UK PPI (Scaled by the 5% Critical Value) - All Parameters

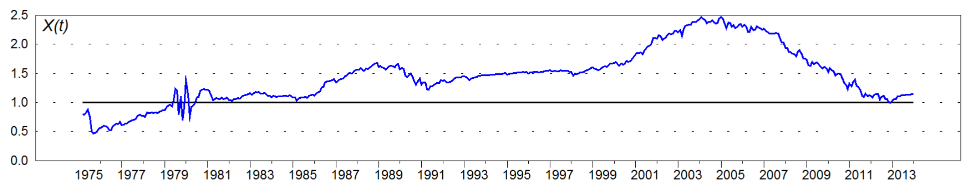


Figure H.6: UK Narrow Money and Silver in £ between 1974 and 2014

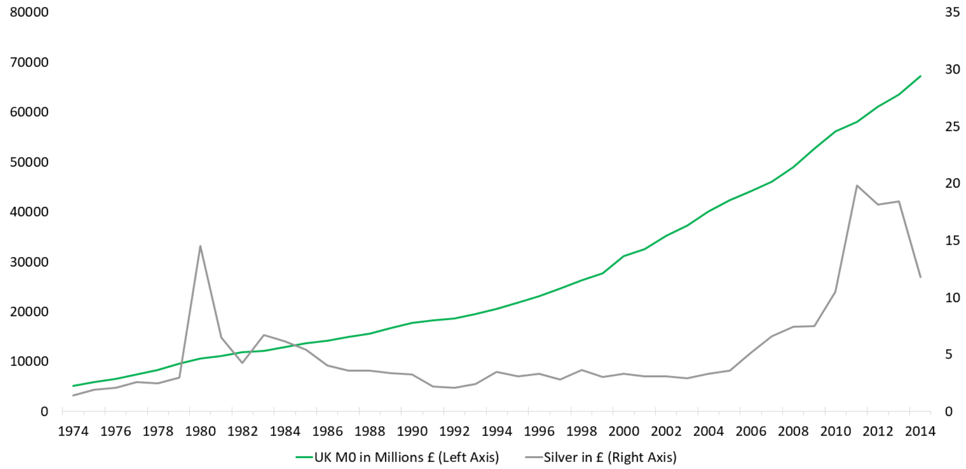


Figure H.7: Recursive Plot of Johansen's Trace Statistic for Silver and UK Narrow Money (Scaled by the 5% Critical Value) - Long-Run Parameters

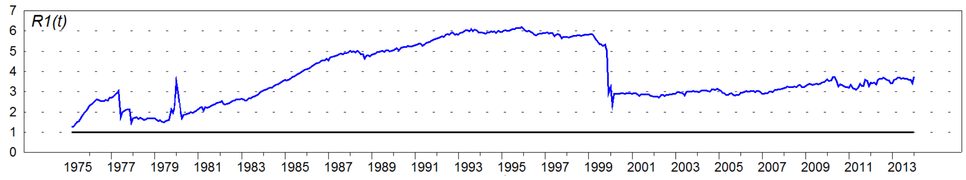
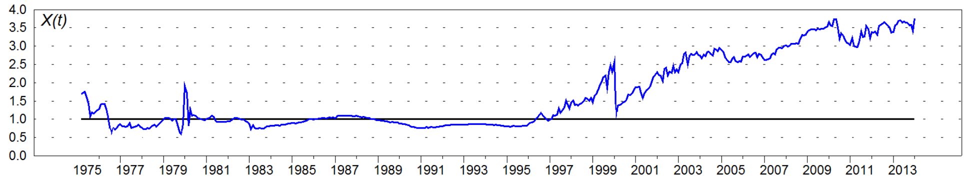


Figure H.8: Recursive Plot of Johansen's Trace Statistic for Silver and UK Narrow Money (Scaled by the 5% Critical Value) - All Parameters



APPENDIX I

ARIMA(6,1,5) Model Selection - Consumer Price Index, Japan

The appropriate ARIMA model used to derive predicted values of the Japanese Consumer Price Index was selected based on different possible model specifications in Stata. The model selected has an Autoregressive Order (p) of 6, an Integrated (difference) Order (d) of 1, and a Moving-average Order (q) of 5 - resulting into an ARIMA(6,1,5) model. No independent variable was specified in the model. The table and figures in this Appendix can be used to understand the accuracy of the ARIMA(6,1,5) model specified. All figures and results were obtained using Stata 13.

Table I.1: ARIMA (6,1,5) Regression Japan CPI

	Coefficient	Standard Error	z	P > |z|	Lower 95%	Upper 95%
ln_cpi						
_cons	0.0044	0.0051	0.86	0.391	-0.0056	0.0144
ARMA						
ar						
L1	0.9351	0.0466	20.07	0.000	0.8438	1.0265
L2	-0.9279	0.0468	-19.81	0.000	-1.0197	-0.8361
L3	0.9242	0.0467	19.80	0.000	0.8327	1.0157
L4	-0.9307	0.0445	-20.91	0.000	-1.0179	-0.8434
L5	0.9316	0.0450	20.68	0.000	0.8433	1.0198
L6	0.0599	0.0452	1.33	0.185	-0.0286	0.1484
ma						
L1	-0.9578	0.0296	-32.32	0.000	-1.0159	-0.8997
L2	0.9957	0.0302	32.94	0.000	0.9364	1.0549
L3	-0.9205	0.0385	-23.91	0.000	-0.9959	-0.8450
L4	0.9863	0.0347	28.44	0.000	0.9183	1.0543
L5	-0.8605	0.0307	-28.00	0.000	-0.9208	-0.8003
/sigma	0.0043	0.0001	34.47	0.000	0.0040	0.0045

Obs.	ll (null)	ll (model)	df	AIC	BIC	Wald Chi2 (11)	Prob > Chi2
480	.	1932.337	13	-3838.673	-3784.414	251586.52	0

Figure I.1: Line Plot of the Japanese Consumer Price Index between January 1974 and January 2014

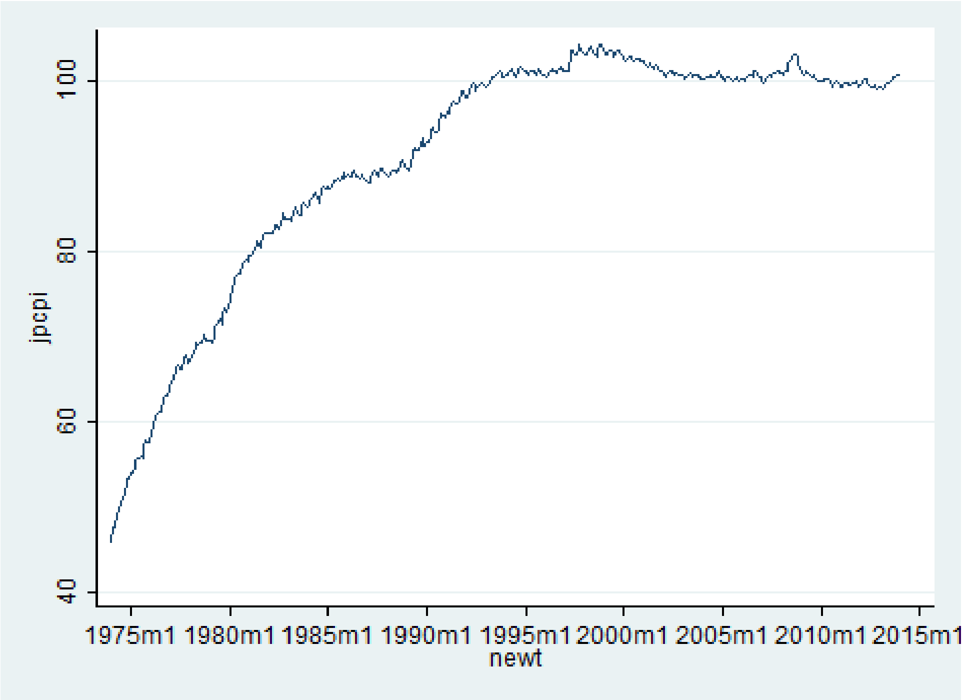


Figure I.2: Line Plot of the Natural Logarithm of the Japanese Consumer Price Index between January 1974 and January 2014

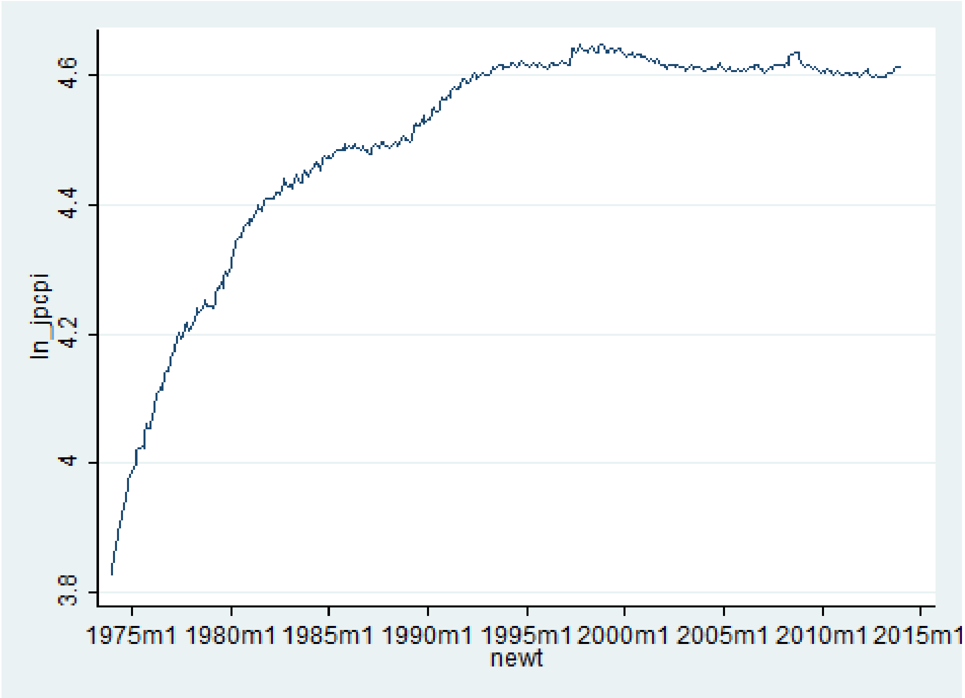


Figure I.3: Line Plot of the First Difference of the Natural Logarithm of the Japanese Consumer Price Index between January 1974 and January 2014

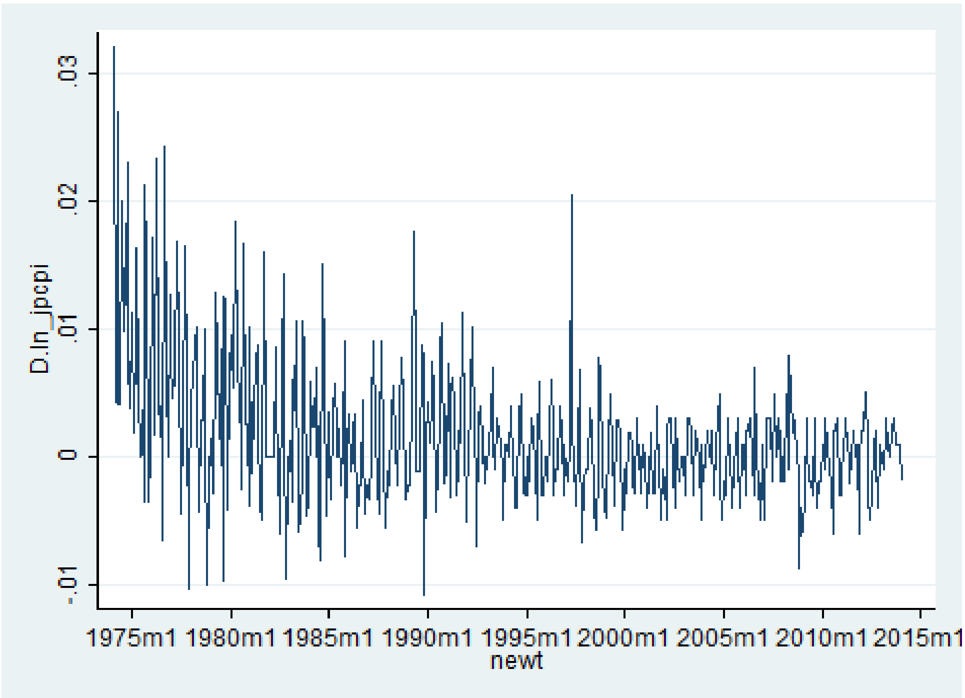


Figure I.4: Graph of Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the Japanese Consumer Price Index between January 1974 and January 2014

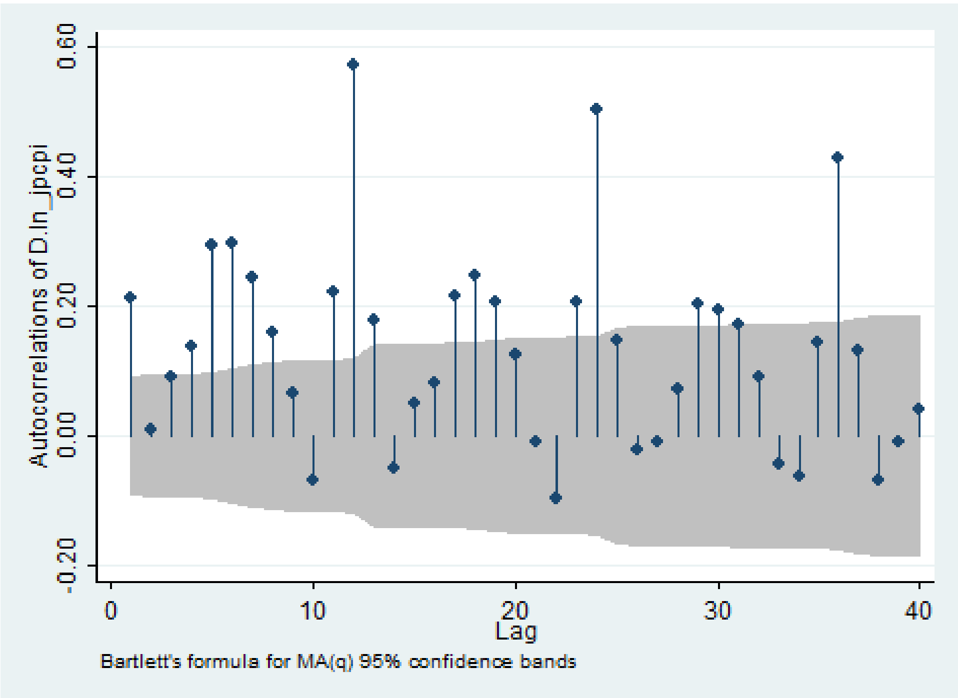
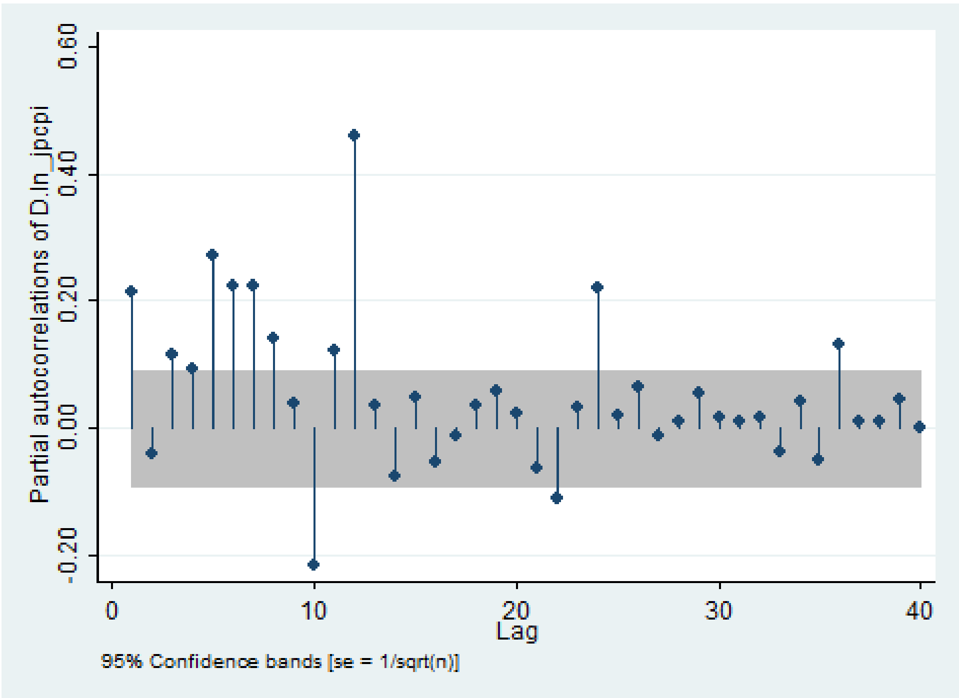


Figure I.5: Graph of Partial Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the Japanese Consumer Price Index between January 1974 and January 2014



APPENDIX J

ARIMA(2,1,2) Model Selection - Producer Price Index, Japan

The appropriate ARIMA model used to derive predicted values of the Japanese Producer Price Index was selected based on different possible model specifications in Stata. The model selected has an Autoregressive Order (p) of 2, an Integrated (difference) Order (d) of 1, and a Moving-average Order (q) of 2 - resulting into an ARIMA(2,1,2) model. No independent variable was specified in the model. The table and figures in this Appendix can be used to understand the accuracy of the ARIMA(2,1,2) model specified. All figures and results were obtained using Stata 13.

Table J.1: ARIMA (2,1,2) Regression Japan PPI

	Coefficient	Standard Error	z	P >|z|	Lower 95%	Upper 95%
ln_ppi						
_cons	0.0007	0.0007	0.99	0.322	-0.0007	0.0020
ARMA						
ar						
L1	-0.1647	0.0353	-4.67	0.000	-0.2338	-0.0955
L2	0.8175	0.02834	28.83	0.000	0.7619	0.8730
ma						
L1	0.6327	0.0471	13.42	0.000	0.5403	0.7251
L2	-0.3412	0.0389	-8.77	0.000	-0.4175	-0.2649
/sigma	0.0036	0.0001	60.55	0.000	0.0035	0.0037

Obs.	ll (null)	ll (model)	df	AIC	BIC	Wald Chi2 (4)	Prob > Chi2
480	.	2020.503	6	-4029.006	-4003.964	1424.05	0

Figure J.1: Line Plot of the Japanese Producer Price Index between January 1974 and January 2014

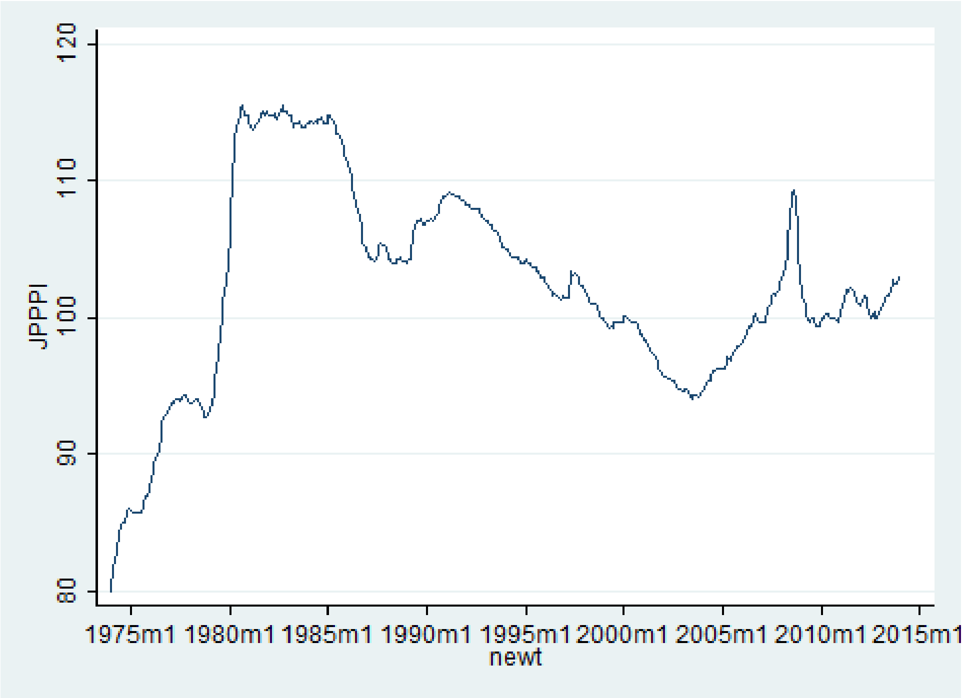


Figure J.2: Line Plot of the Natural Logarithm of the Japanese Producer Price Index between January 1974 and January 2014

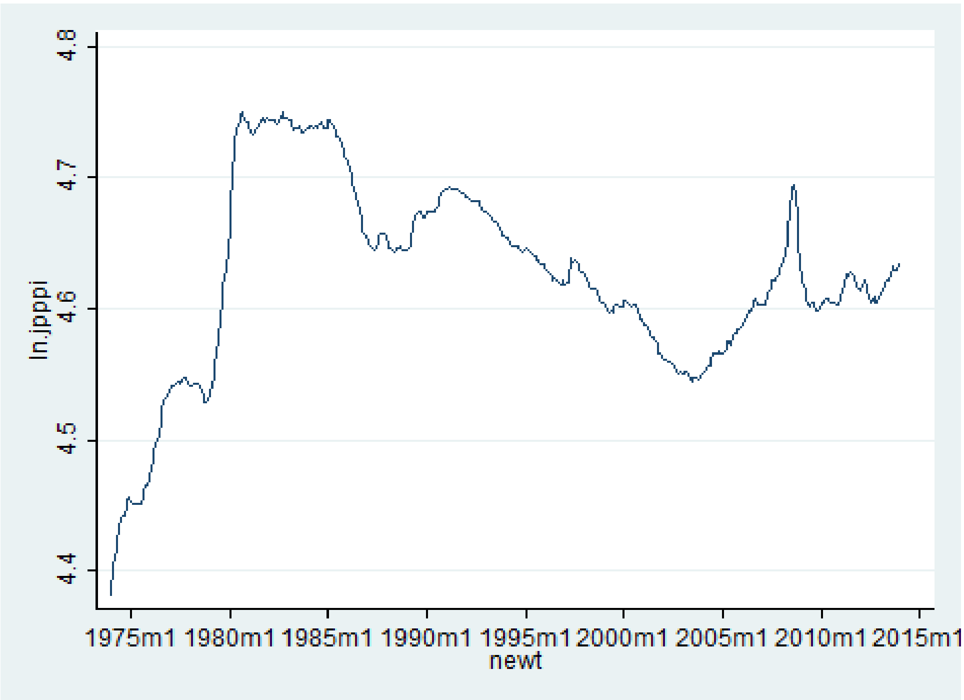


Figure J.3: Line Plot of the First Difference of the Natural Logarithm of the Japanese Producer Price Index between January 1974 and January 2014

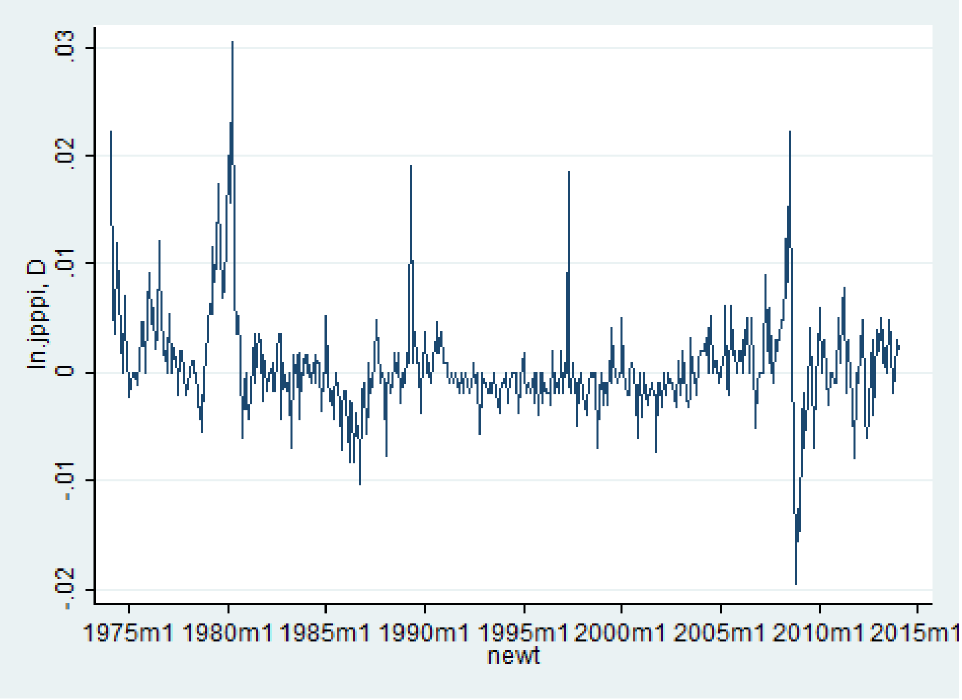


Figure J.4: Graph of Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the Japanese Producer Price Index between January 1974 and January 2014

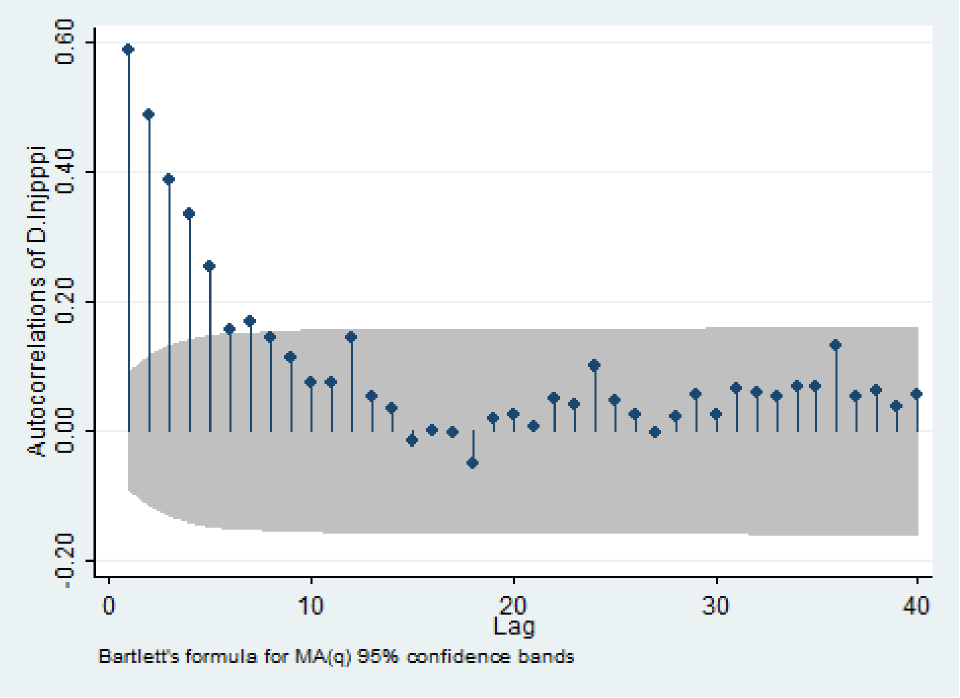
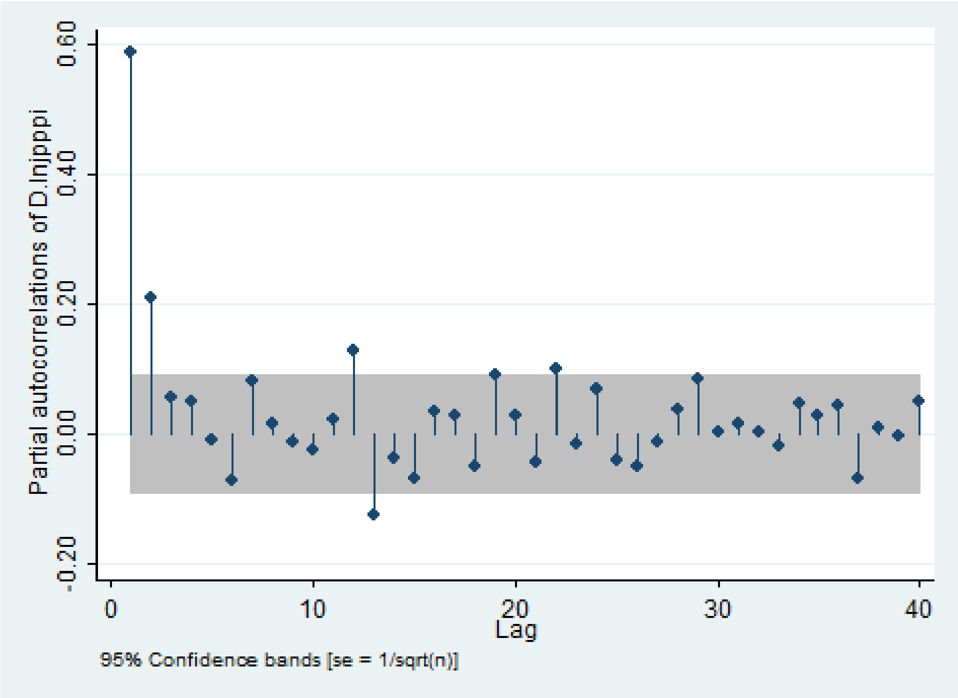


Figure J.5: Graph of Partial Autocorrelations with Confidence Intervals of the First Difference of the Natural Logarithm of the Japanese Producer Price Index between January 1974 and January 2014



APPENDIX

K

Figures: Gold and Inflation - Japan

Plotting the Trace Statistic of the Johansen (1991, 1995) test allows a visualisation of the cointegration relationship between gold and the inflation series considered. If the blue line is below the horizontal black line, the two series are cointegrated. In case the blue line is above the horizontal black line, there is no evidence for cointegration.

Figure K.1: The nominal Japanese CPI and Gold in ¥ between 1974 and 2014

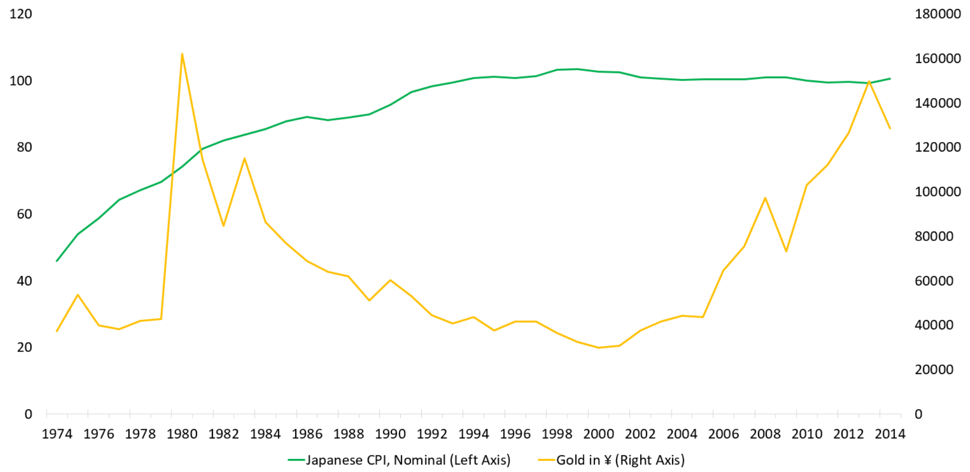


Figure K.2: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal Japanese CPI (Scaled by the 5% Critical Value) - All Parameters

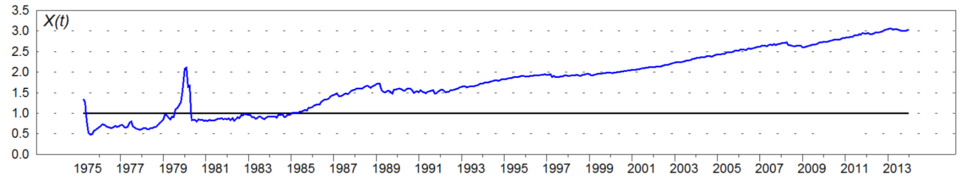


Figure K.3: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted Japanese CPI (Scaled by the 5% Critical Value) - All Parameters

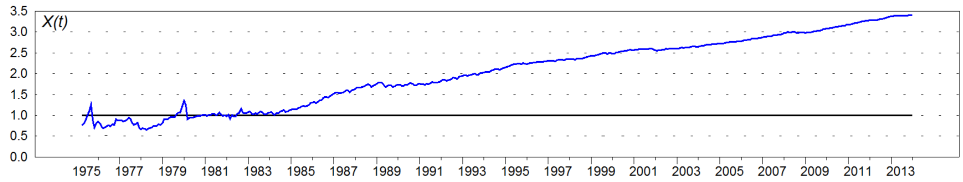


Figure K.4: Japanese CPI Surprise Index and Gold between 1974 and 2014

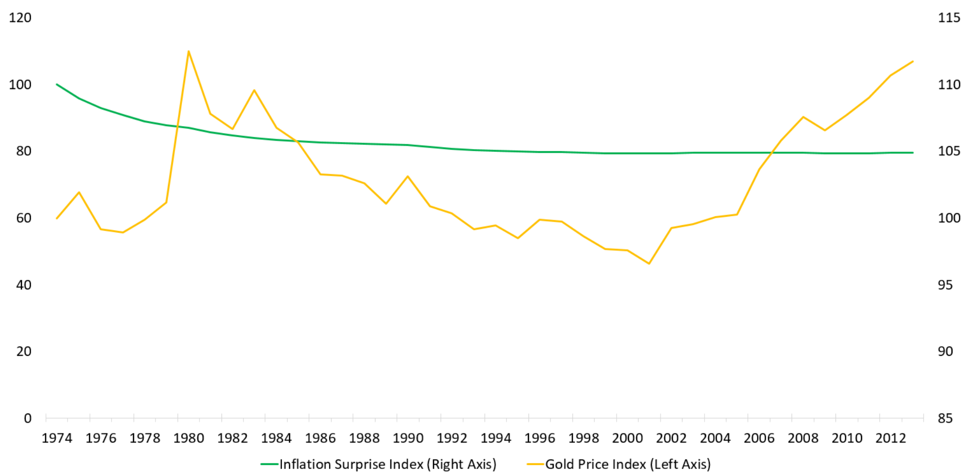


Figure K.5: The nominal Japanese PPI and Gold in ¥ between 1974 and 2014

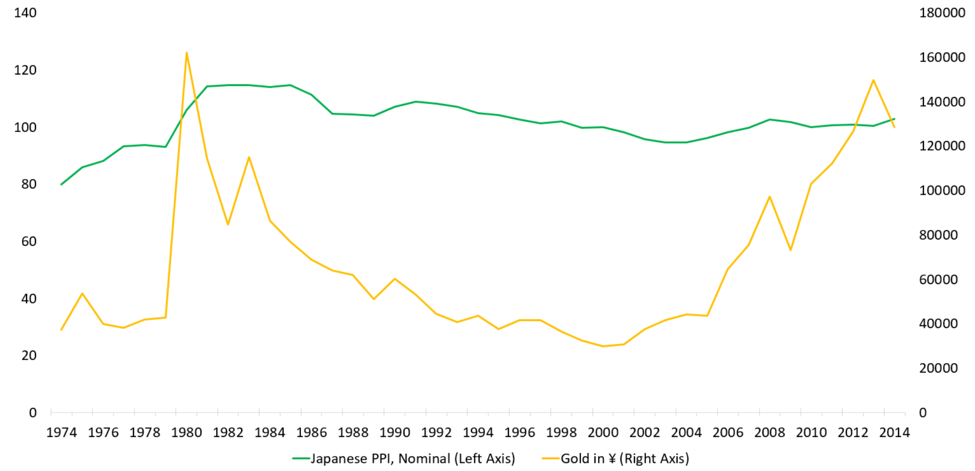


Figure K.6: Recursive Plot of Johansen's Trace Statistic for Gold and the Nominal Japanese PPI (Scaled by the 5% Critical Value) - All Parameters

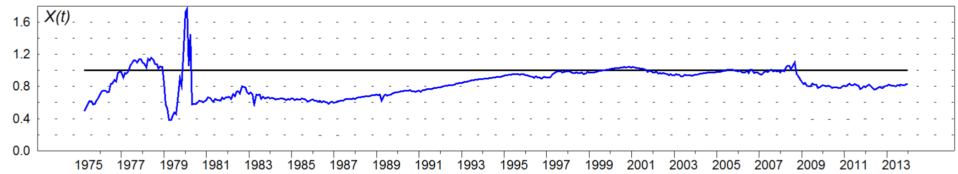


Figure K.7: Recursive Plot of Johansen's Trace Statistic for Gold and the Predicted Japanese PPI (Scaled by the 5% Critical Value) - All Parameters

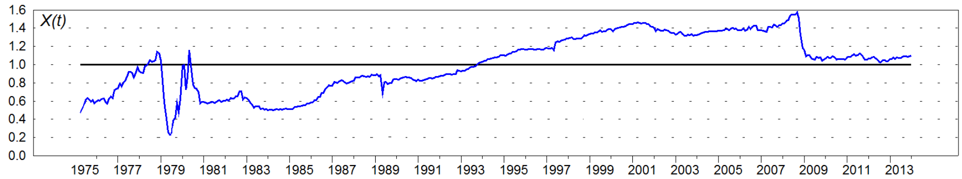


Figure K.8: Japanese PPI Surprise Index and Gold between 1974 and 2014

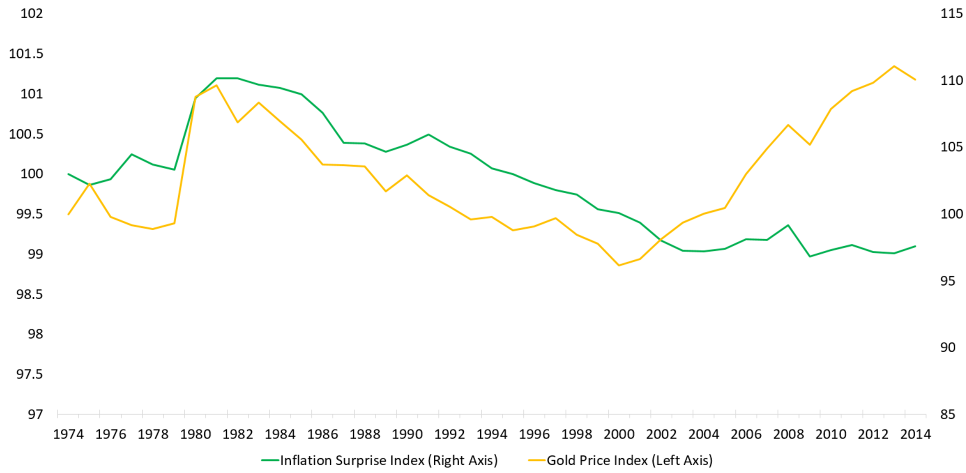


Figure K.9: Japanese Narrow Money and Gold in ¥ between 1974 and 2014

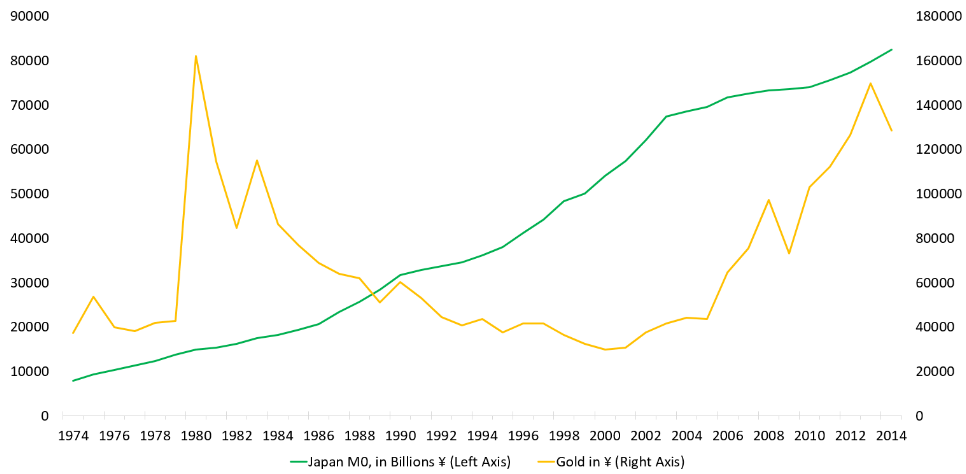
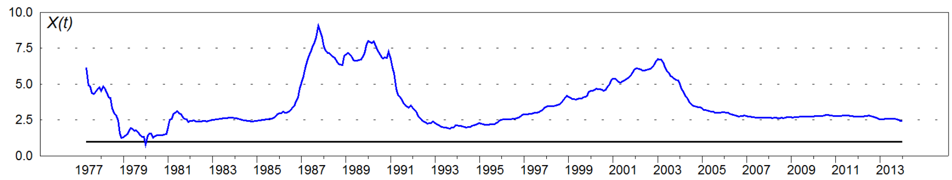


Figure K.10: Recursive Plot of Johansen's Trace Statistic for Gold and Japanese Narrow Money (Scaled by the 5% Critical Value) - All Parameters



APPENDIX L

FIGURES: SILVER AND INFLATION - JAPAN

Plotting the Trace Statistic of the Johansen (1991, 1995) test allows a visualisation of the cointegration relationship between silver and the inflation series considered. If the blue line is below the horizontal black line, the two series are cointegrated. In case the blue line is above the horizontal black line, there is no evidence for cointegration.

Figure L.1: The nominal Japanese CPI and Silver in ¥ between 1974 and 2014

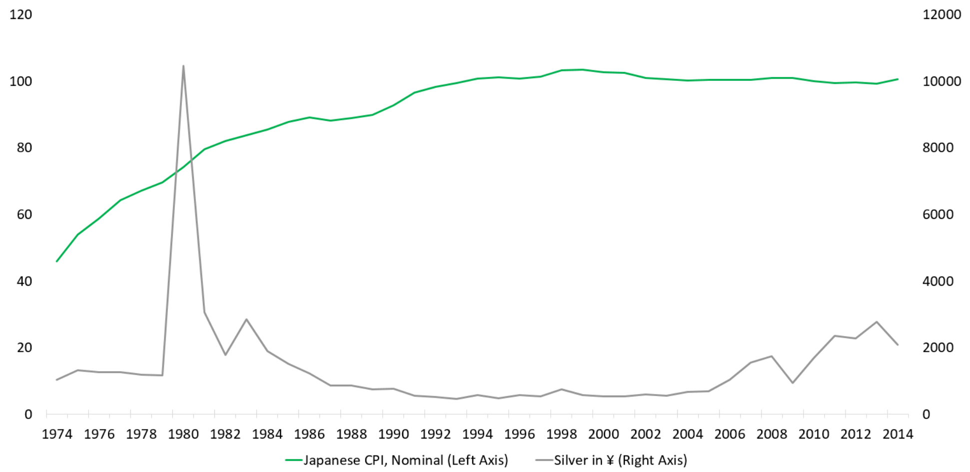


Figure L.2: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal Japanese CPI (Scaled by the 5% Critical Value) - Long-Run Parameters

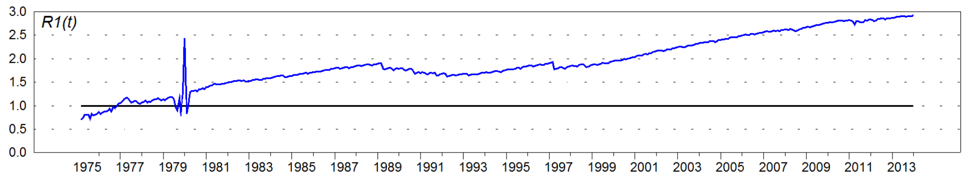


Figure L.3: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal Japanese CPI (Scaled by the 5% Critical Value) - All Parameters

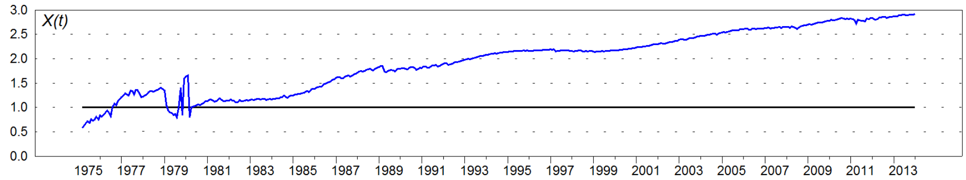


Figure L.4: The nominal Japanese PPI and Silver in ¥ between 1974 and 2014

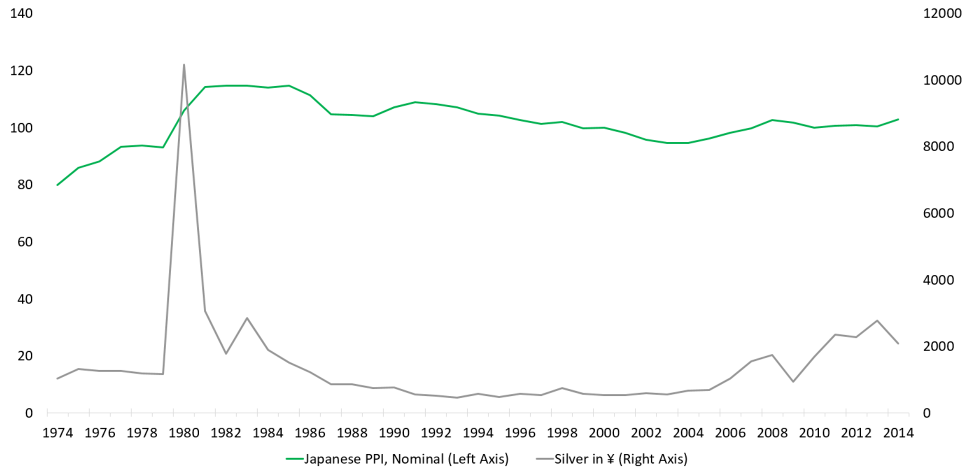


Figure L.5: Recursive Plot of Johansen's Trace Statistic for Silver and the Nominal Japanese PPI (Scaled by the 5% Critical Value) - All Parameters

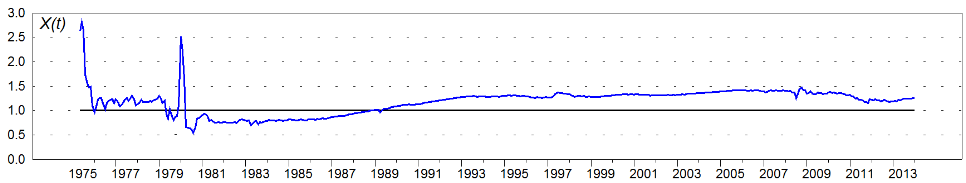


Figure L.6: Japanese Narrow Money and Silver in ¥ between 1974 and 2014

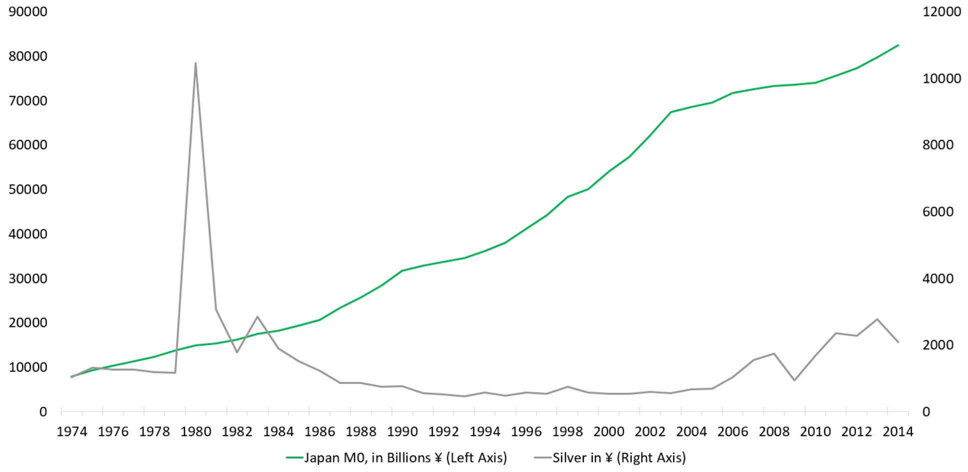
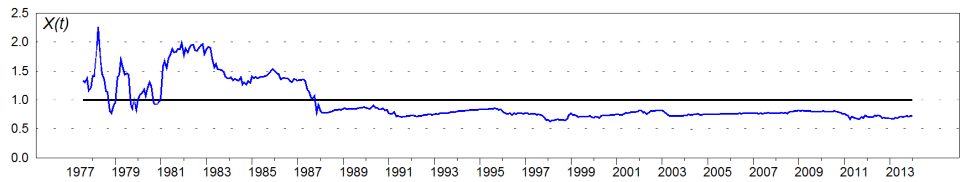


Figure L.7: Recursive Plot of Johansen's Trace Statistic for Silver and Japanese Narrow Money (Scaled by the 5% Critical Value) - All Parameters



Appendix M

Extreme Bounds Analyses Results for Gold

The Extreme Bounds Analysis in the spirit of Leamer (1983), Granger and Uhlig (1990) and Sala-I-Martin (1997) allows to run a very high number of linear regressions and identify which variables are robustly cointegrated with gold and which are not. The graphical results allow to quickly understand if a variable is positively or negatively cointegrated with the price of gold by looking at the density distribution. If more than 90% of the regressors are positive, the variable is positively cointegrated with the price of gold. A majority of negative regressors indicate that a high value of the variable is associated with a low price of gold.

Figure M.1: Naive Extreme Bounds Analysis Results for Gold - Model 0: No Fixed Variable

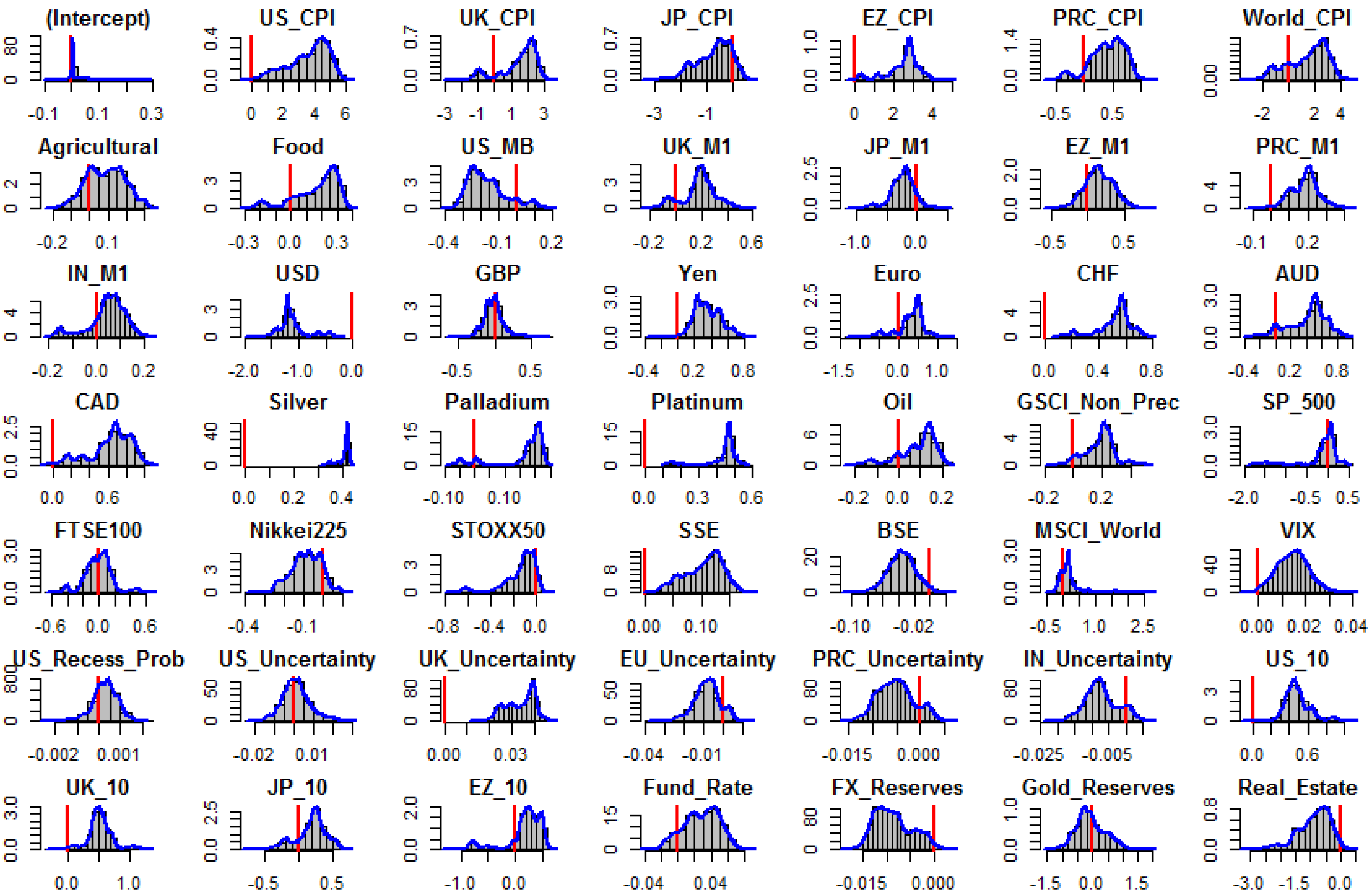


Figure M.2: Sophisticated Extreme Bounds Analysis Results for Gold - Model 1: Fixing Silver

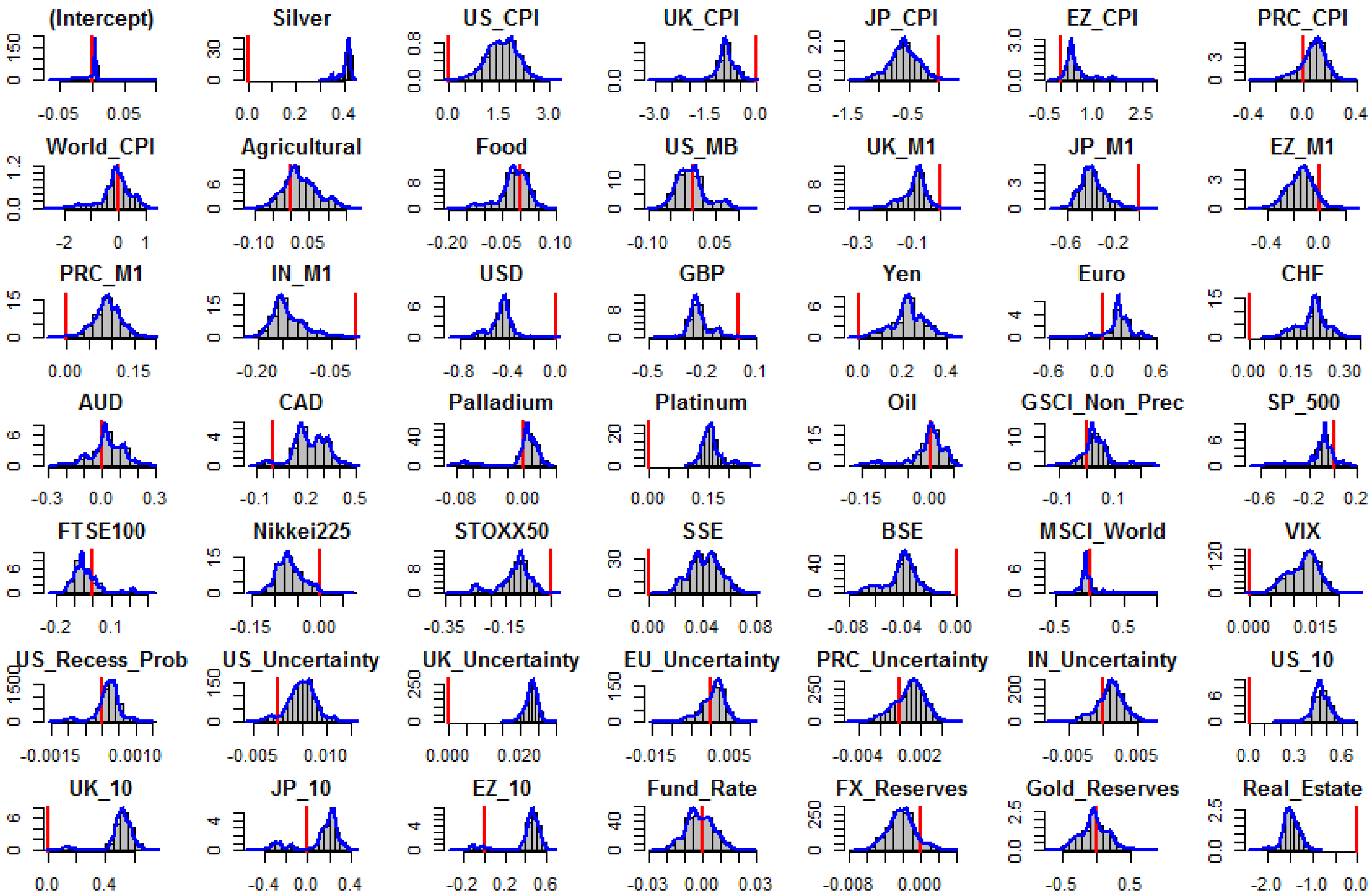


Figure M.3: Sophisticated Extreme Bounds Analysis Results for Gold - Model 2: Fixing Silver, Platinum and Palladium

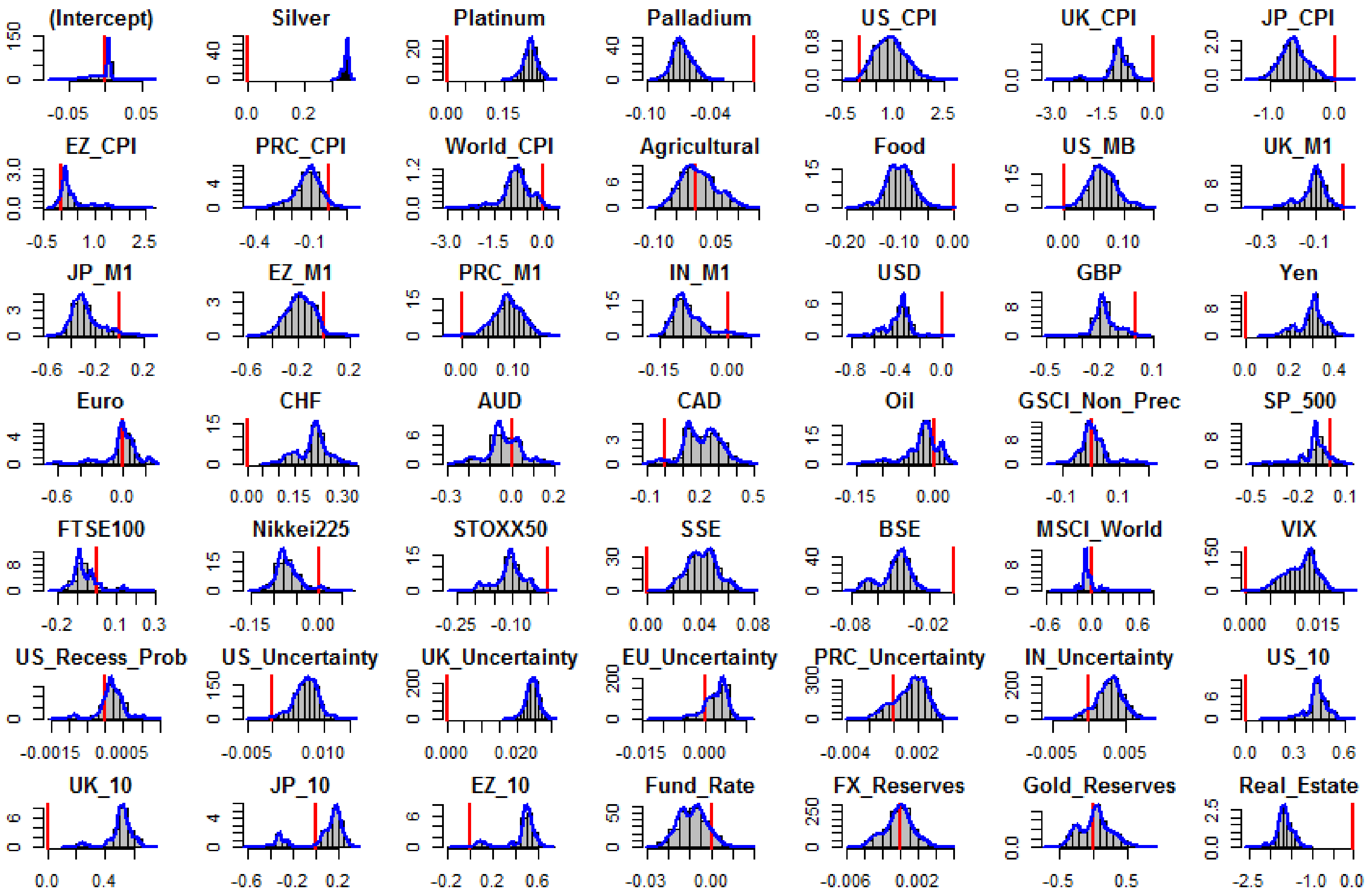


Figure M.4: Sophisticated Extreme Bounds Analysis Results for Gold - Model 3: Fixing Silver, Platinum, Palladium and Non-Precious Metals

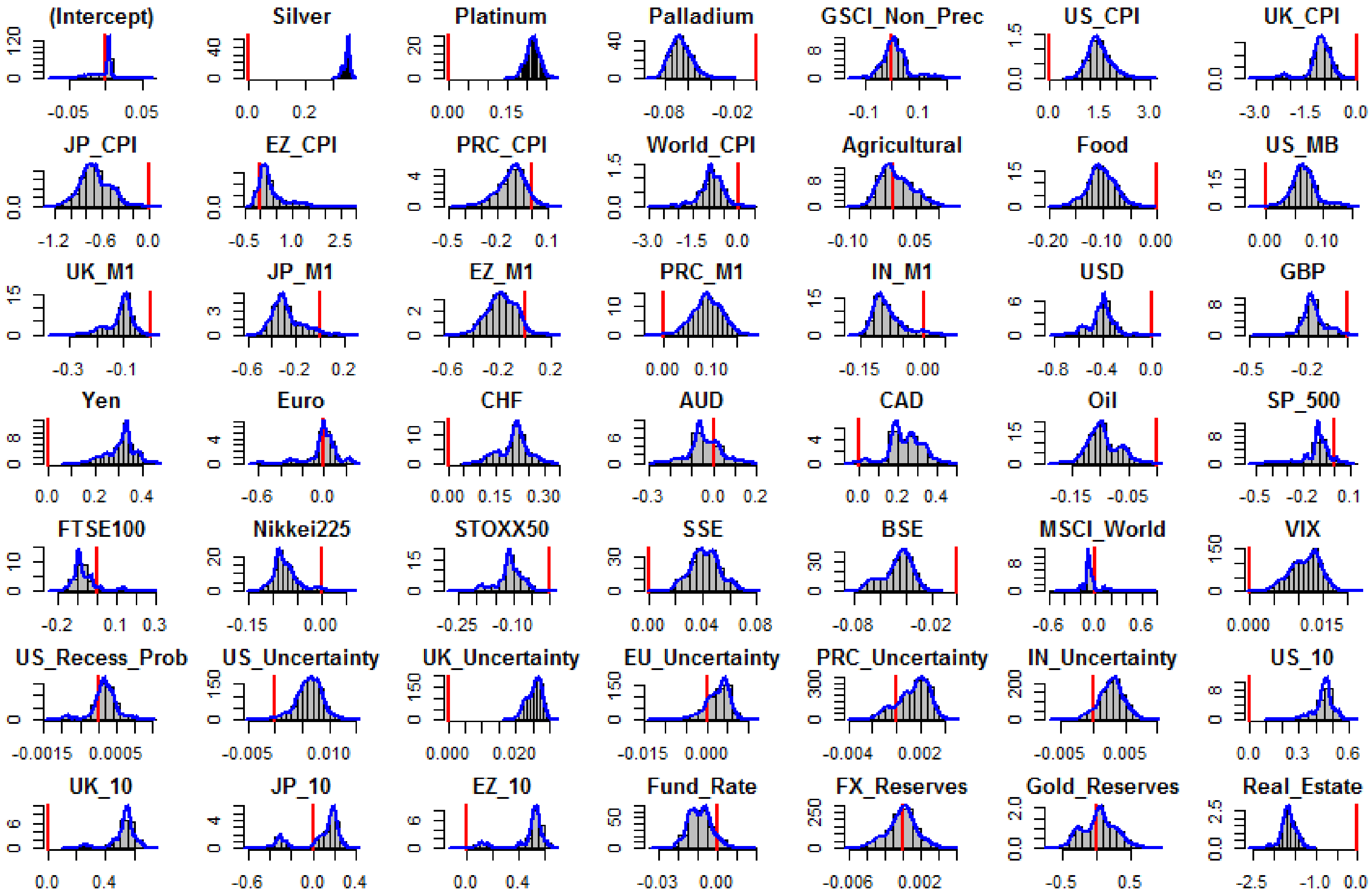


Figure M.5: Sophisticated Extreme Bounds Analysis Results for Gold - Model 4: Fixing Oil

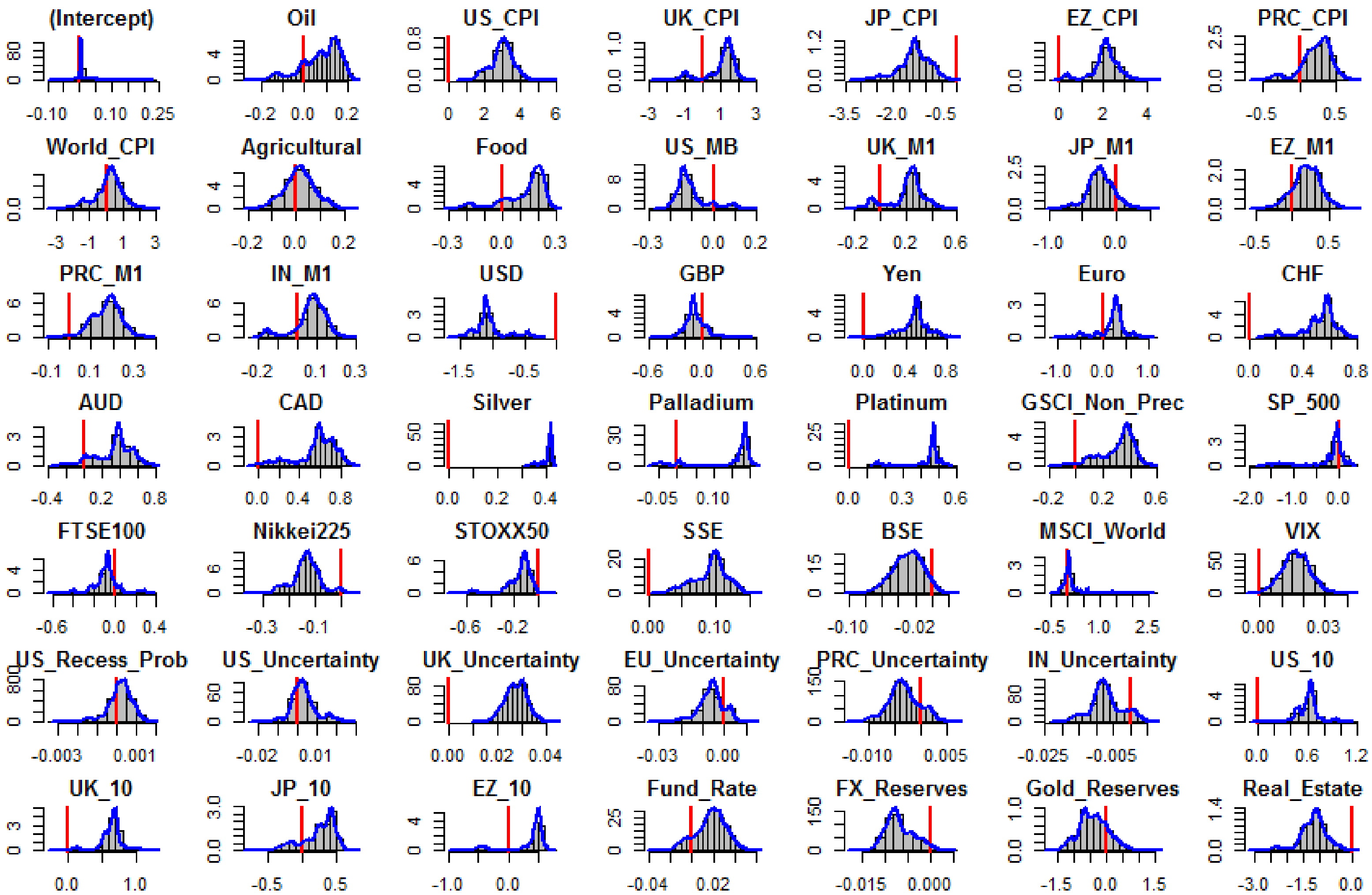


Figure M.6: Sophisticated Extreme Bounds Analysis Results for Gold - Model 5: Fixing the US Dollar

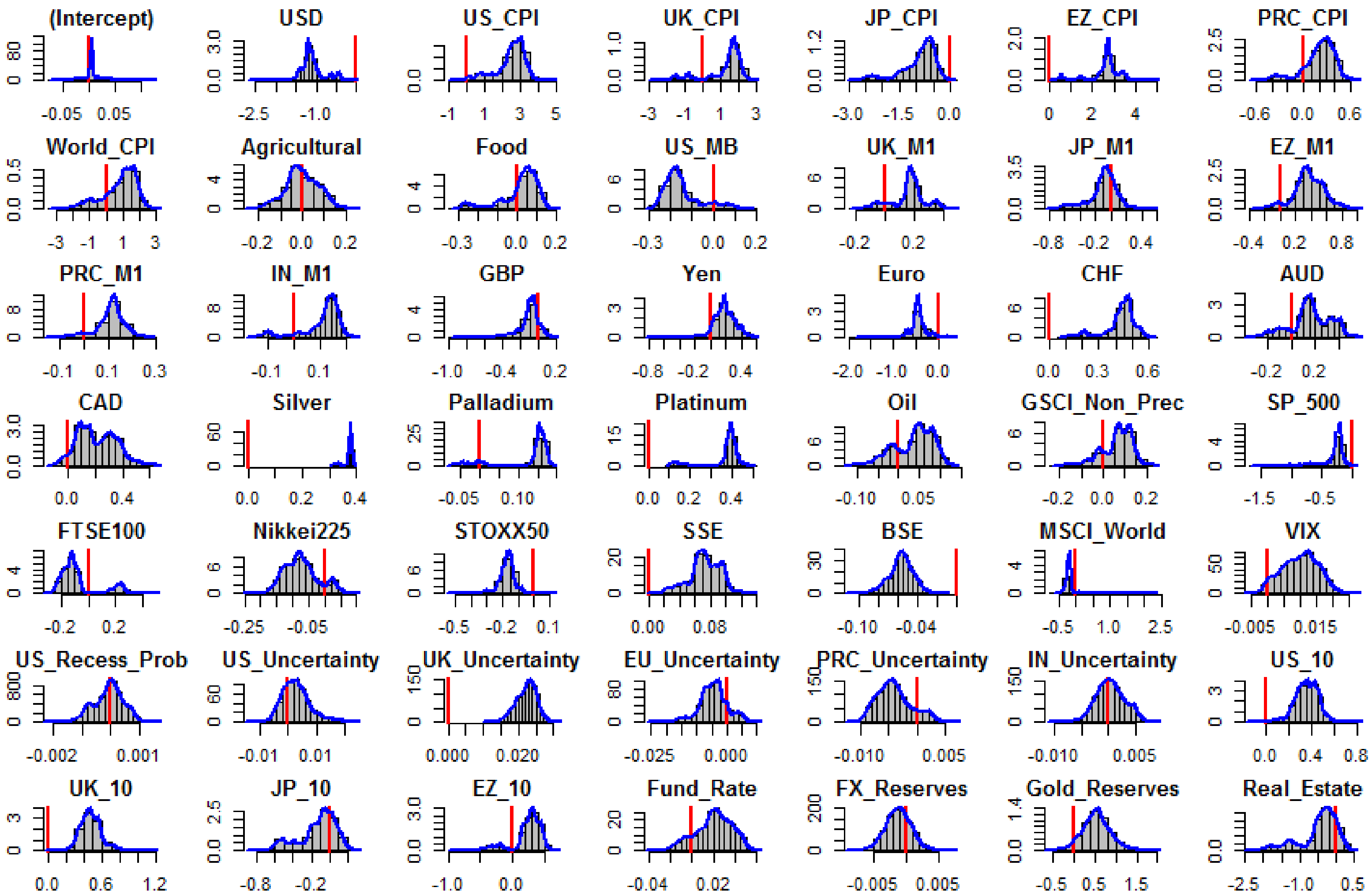


Figure M.7: Sophisticated Extreme Bounds Analysis Results for Gold - Model 6: Fixing Currencies Identified in the Unconstrained Model

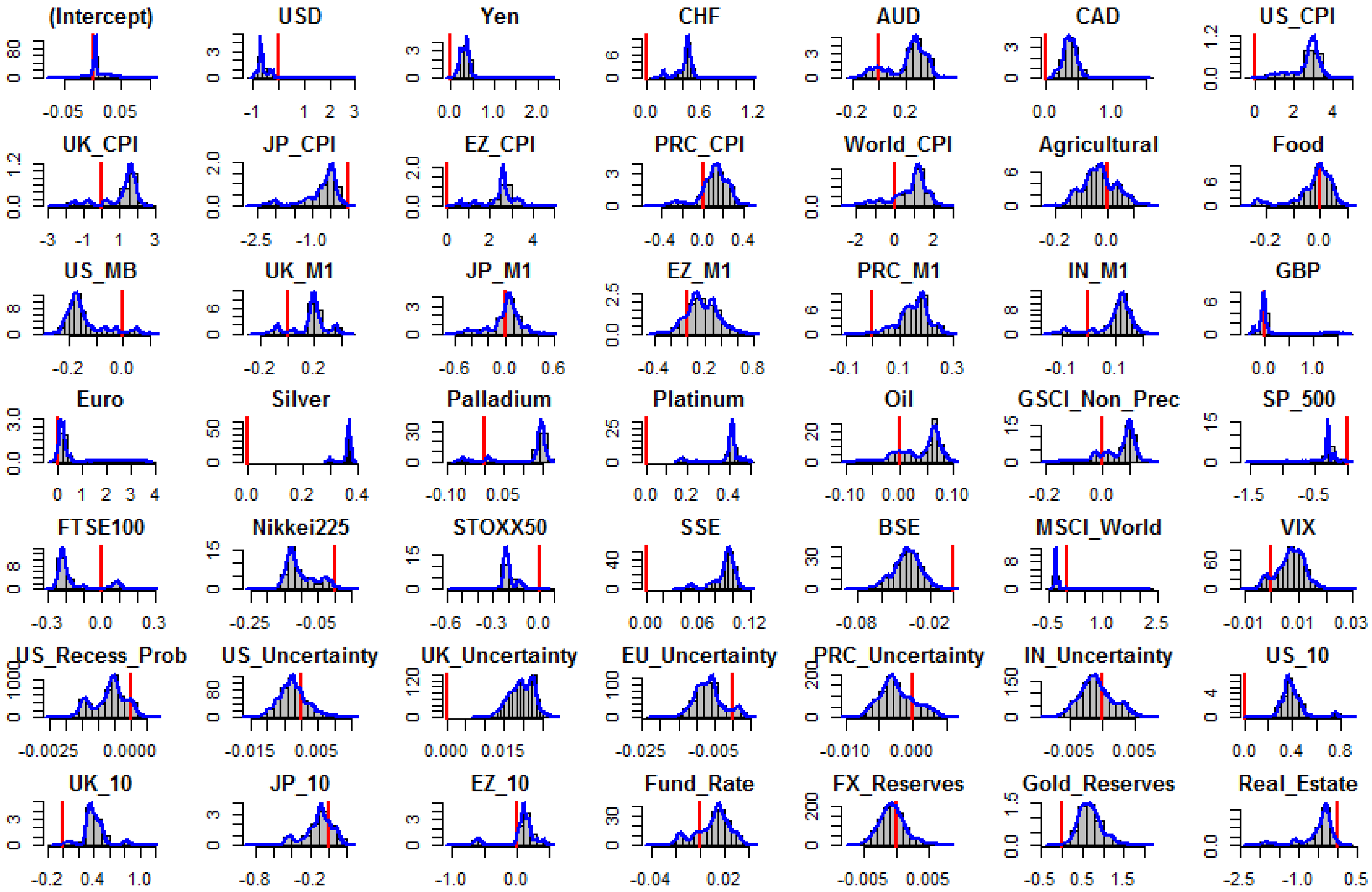


Figure M.8: Sophisticated Extreme Bounds Analysis Results for Gold - Model 7: Fixing all Currencies

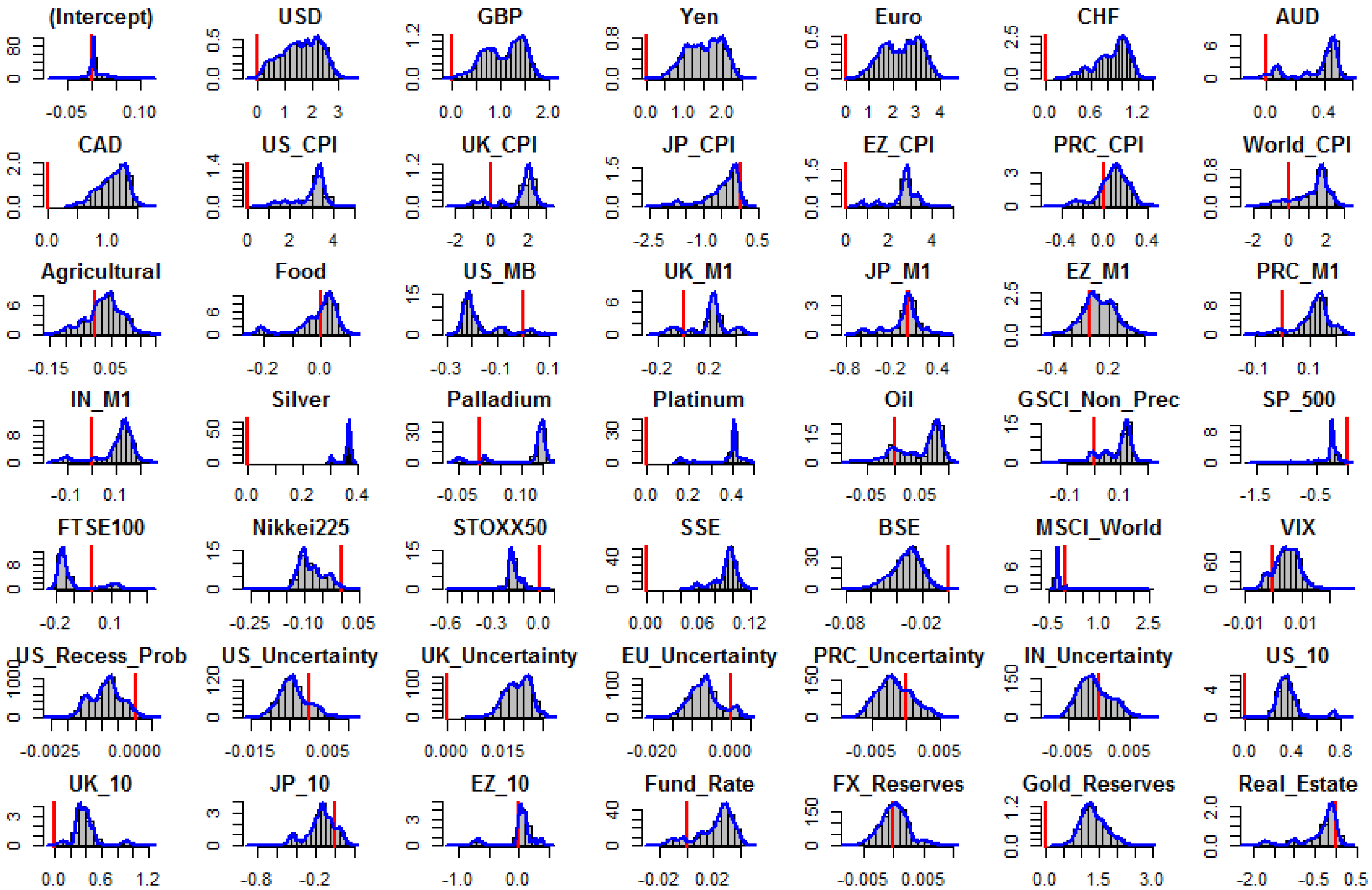


Figure M.9: Sophisticated Extreme Bounds Analysis Results for Gold - Model 8: Fixing Consumer Price Indices

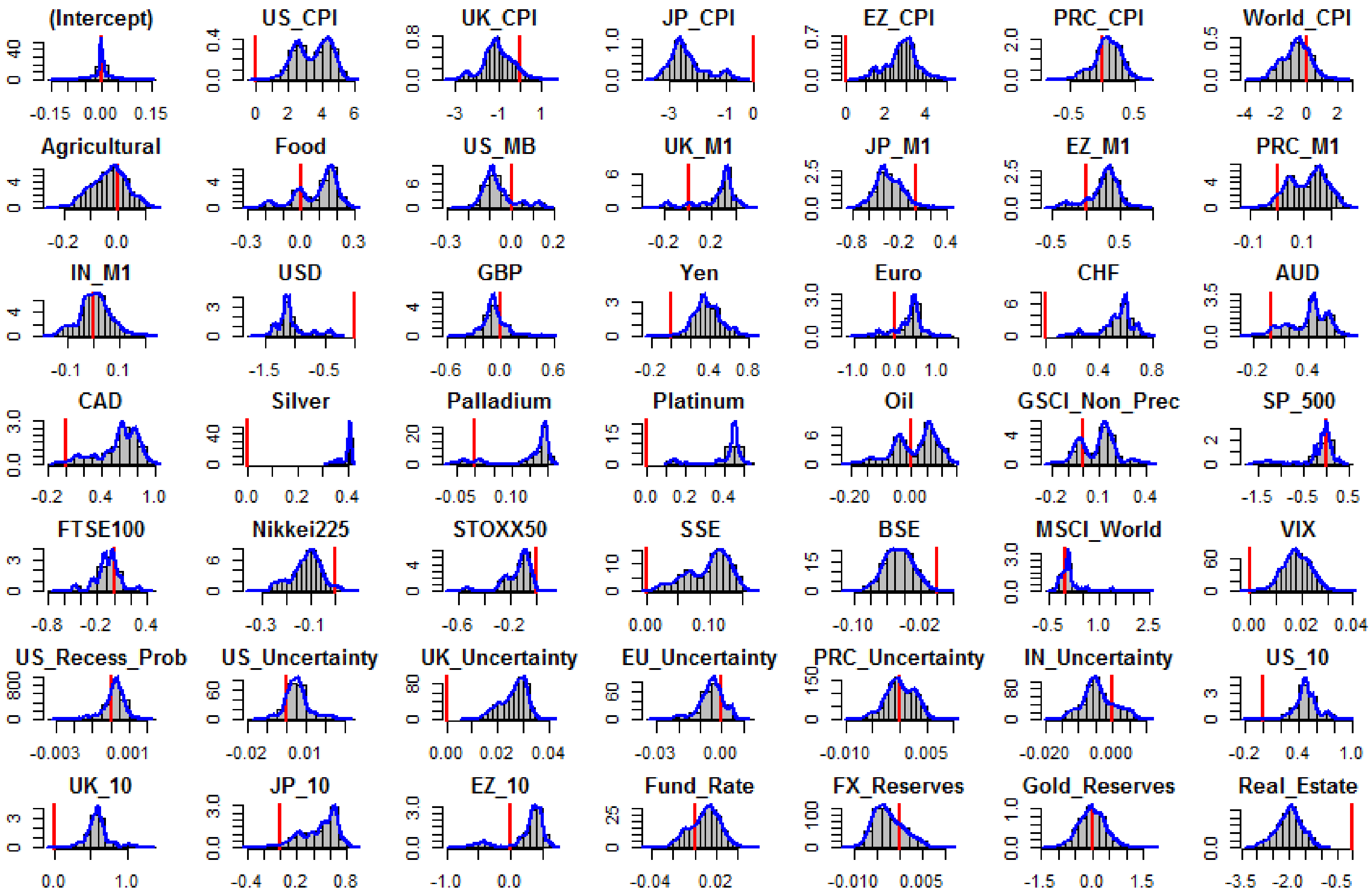


Figure M.10: Sophisticated Extreme Bounds Analysis Results for Gold - Model 9: Fixing Money Supply

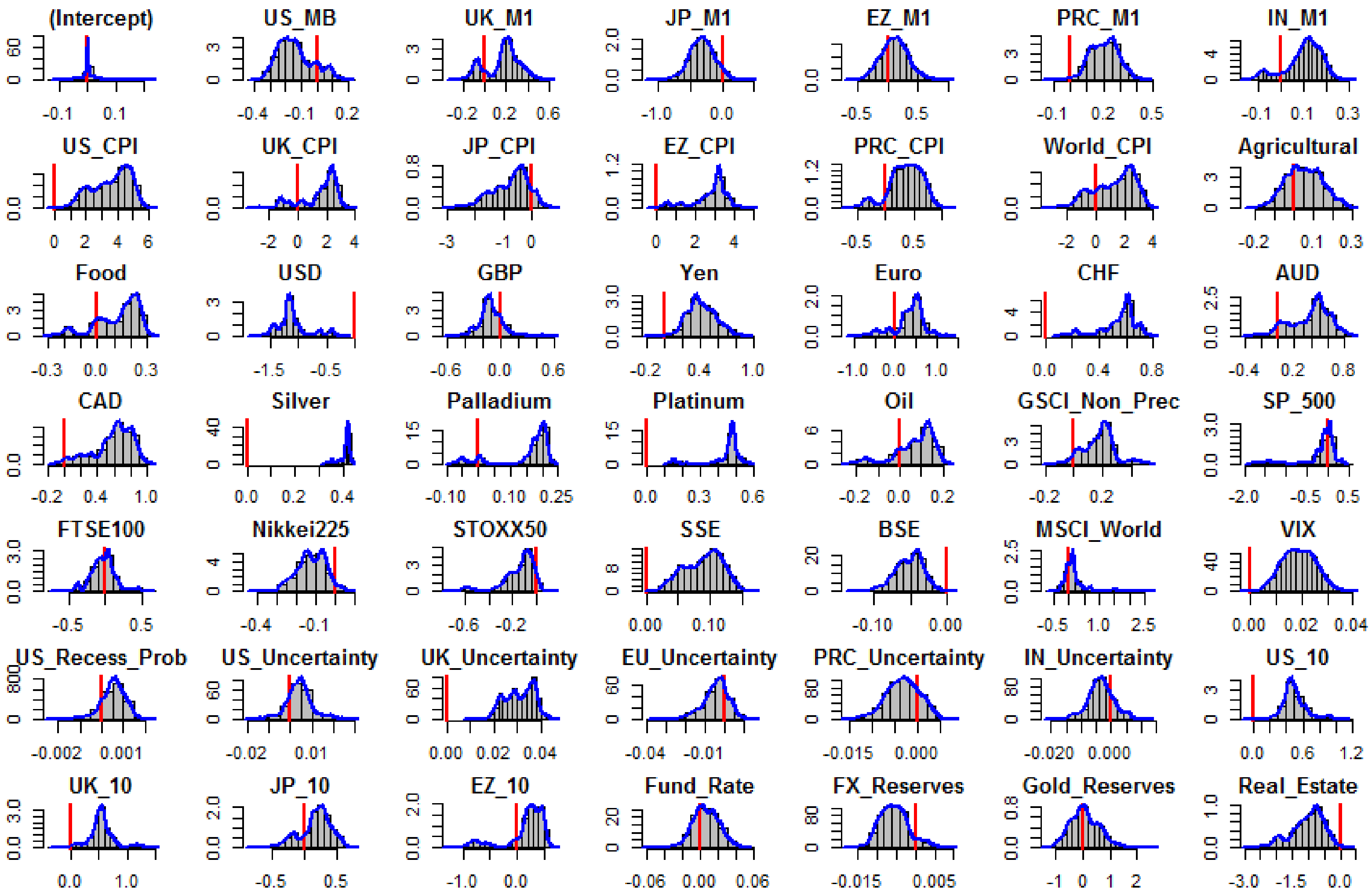


Figure M.11: Sophisticated Extreme Bounds Analysis Results for Gold - Model 10: Fixing Economic Indicators Identified in the Unconstrained Model

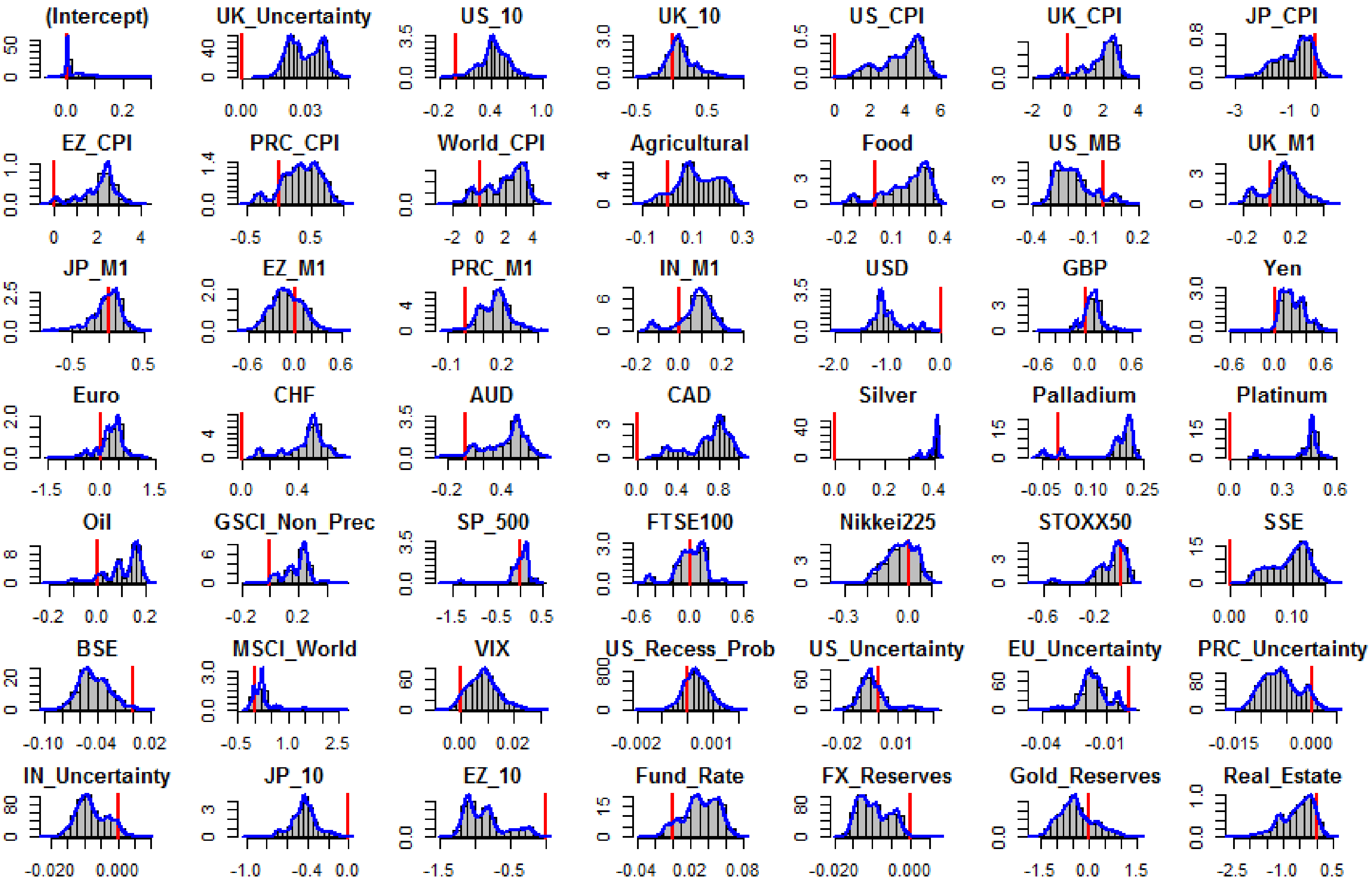
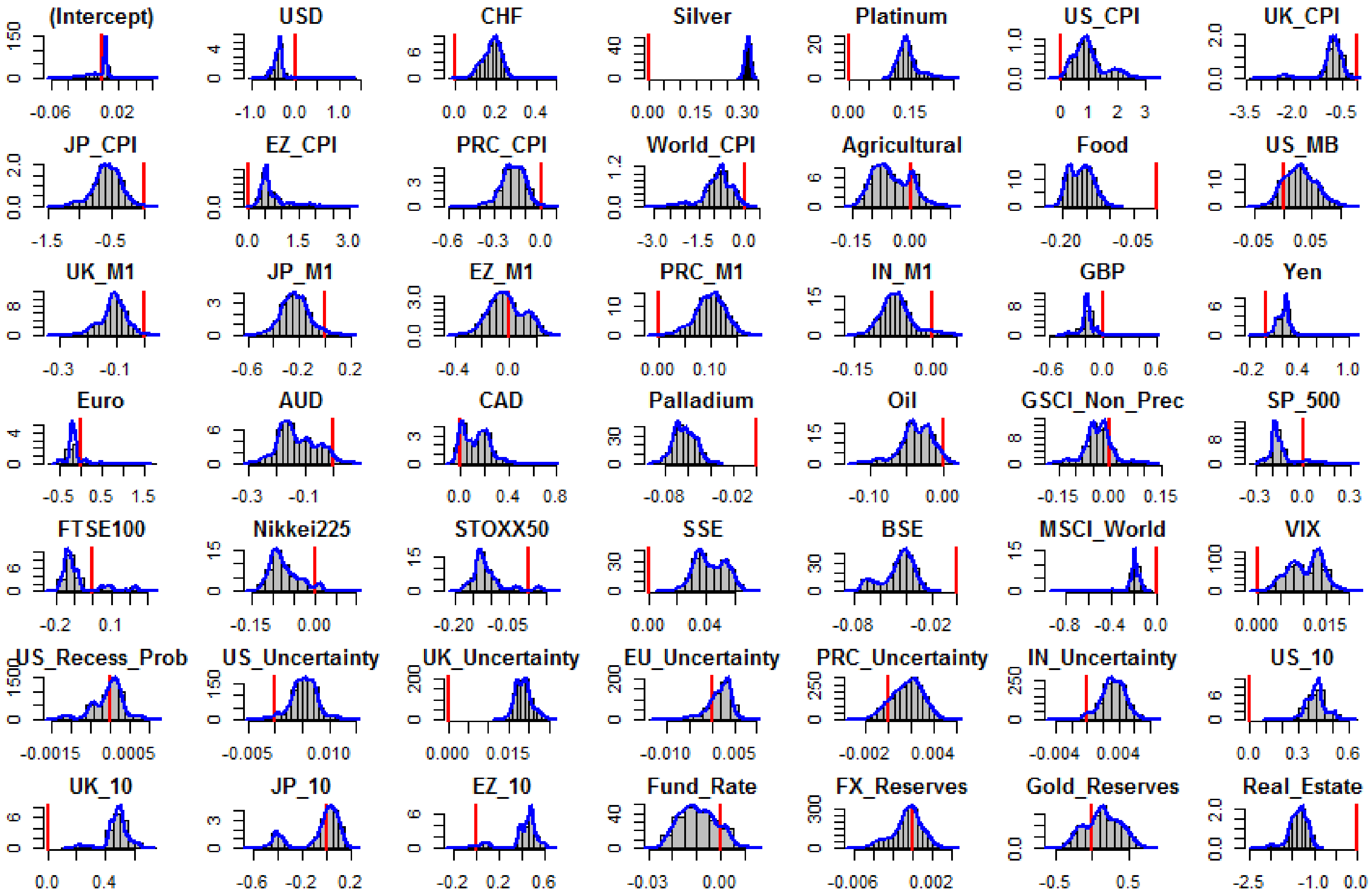


Figure M.12: Sophisticated Extreme Bounds Analysis Results for Gold - Model 11: Fixing the Variables Identified at the 99% Confidence Interval



APPENDIX N

Extreme Bounds Analyses Results for Silver

The Extreme Bounds Analysis in the spirit of Leamer (1983), Granger and Uhlig (1990) and Sala-I-Martin (1997) allows to run a very high number of linear regressions and identify which variables are robustly cointegrated with silver and which are not. The graphical results allow to quickly understand if a variable is positively or negatively cointegrated with the price of silver by looking at the density distribution. If more than 90% of the regressors are positive, the variable is positively cointegrated with the price of silver. A majority of negative regressors indicate that a high value of the variable is associated with a low price of silver.

Figure N.1: Naive Extreme Bounds Analysis Results for Silver

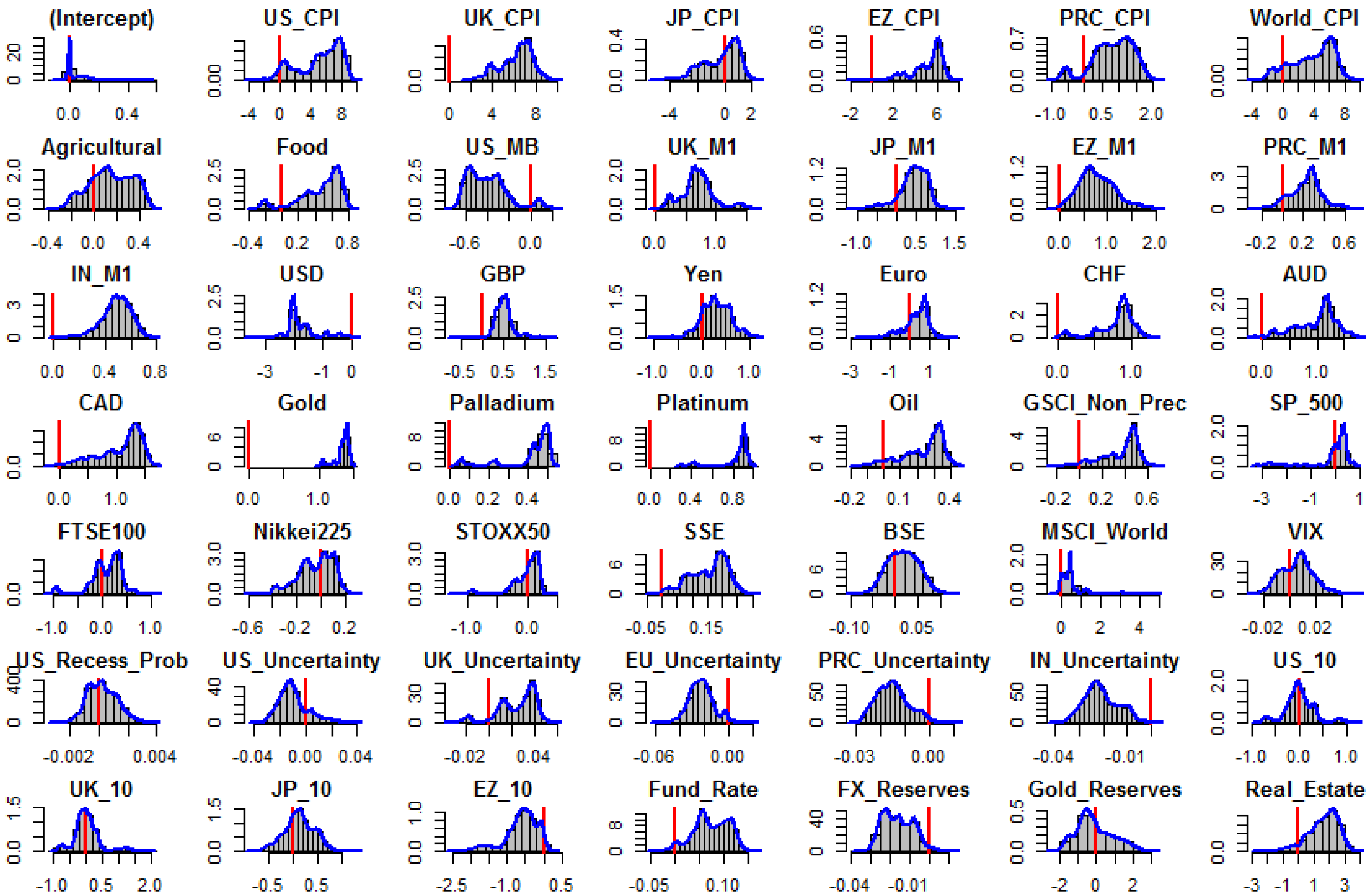


Figure N.2: Sophisticated Extreme Bounds Analysis Results for Silver - Model 1: Fixing Gold

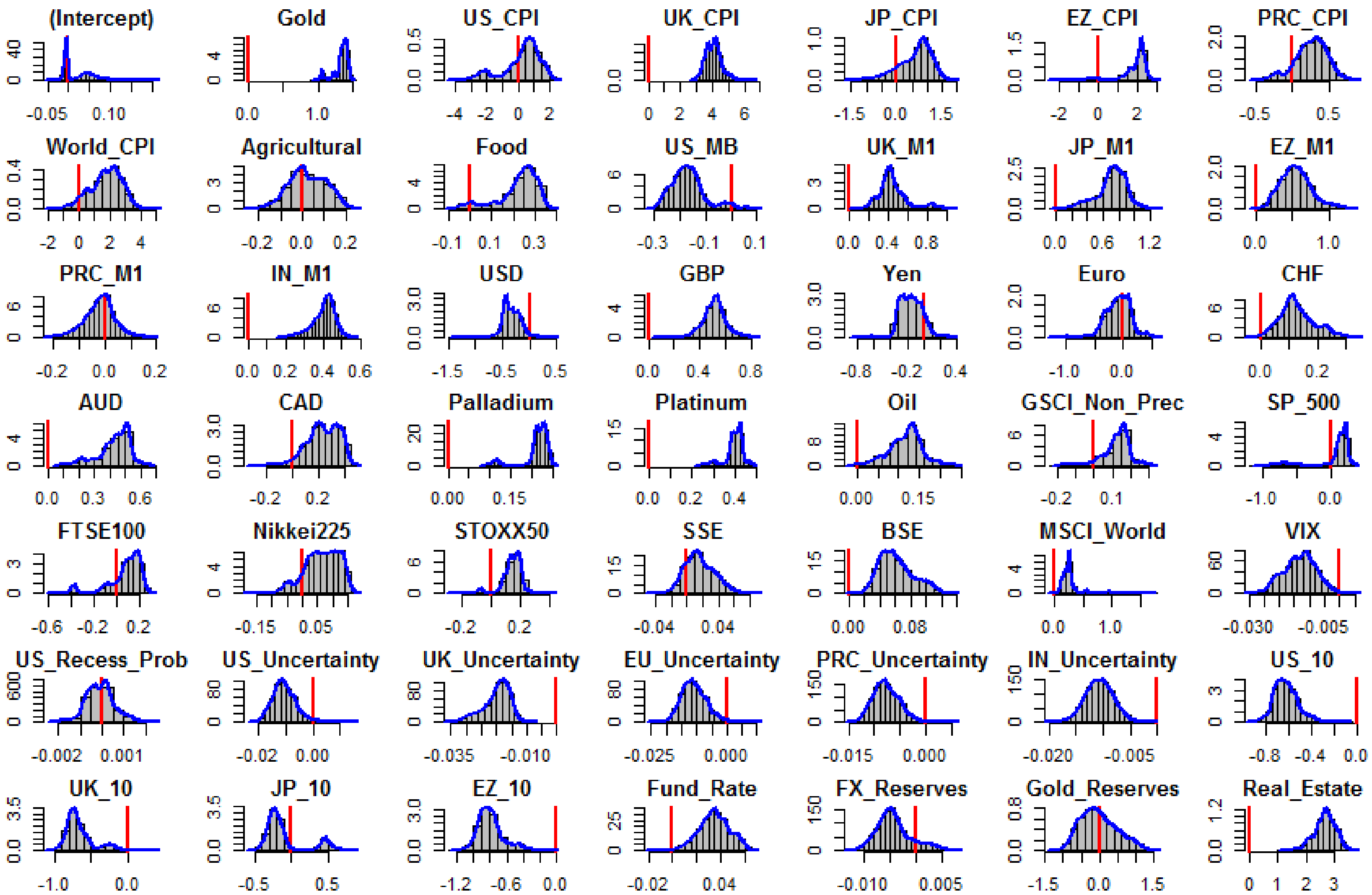


Figure N.3: Sophisticated Extreme Bounds Analysis Results for Silver - Model 2: Fixing White Precious Metals

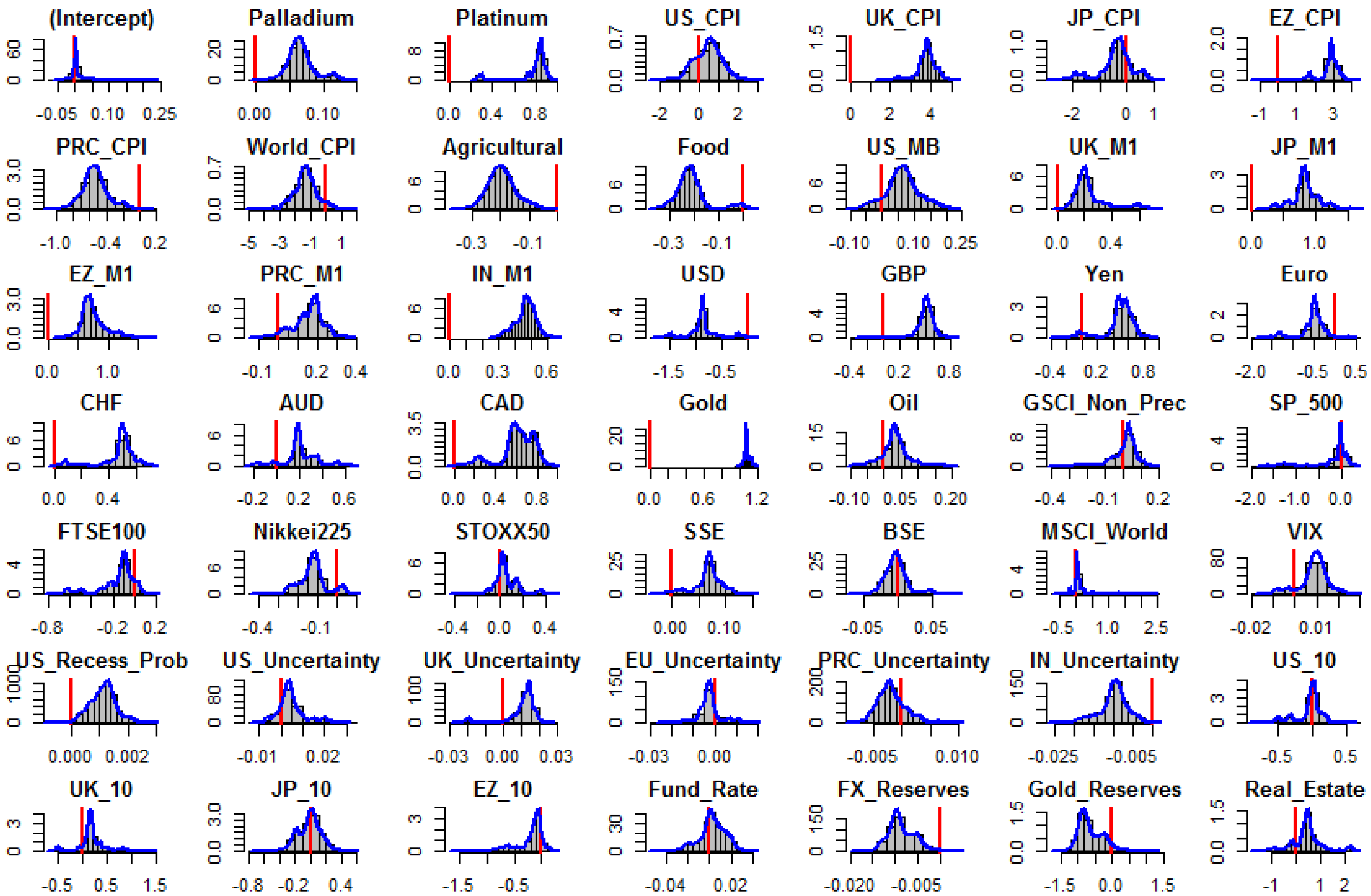


Figure N.4: Sophisticated Extreme Bounds Analysis Results for Silver - Model 3: Fixing all Precious Metals

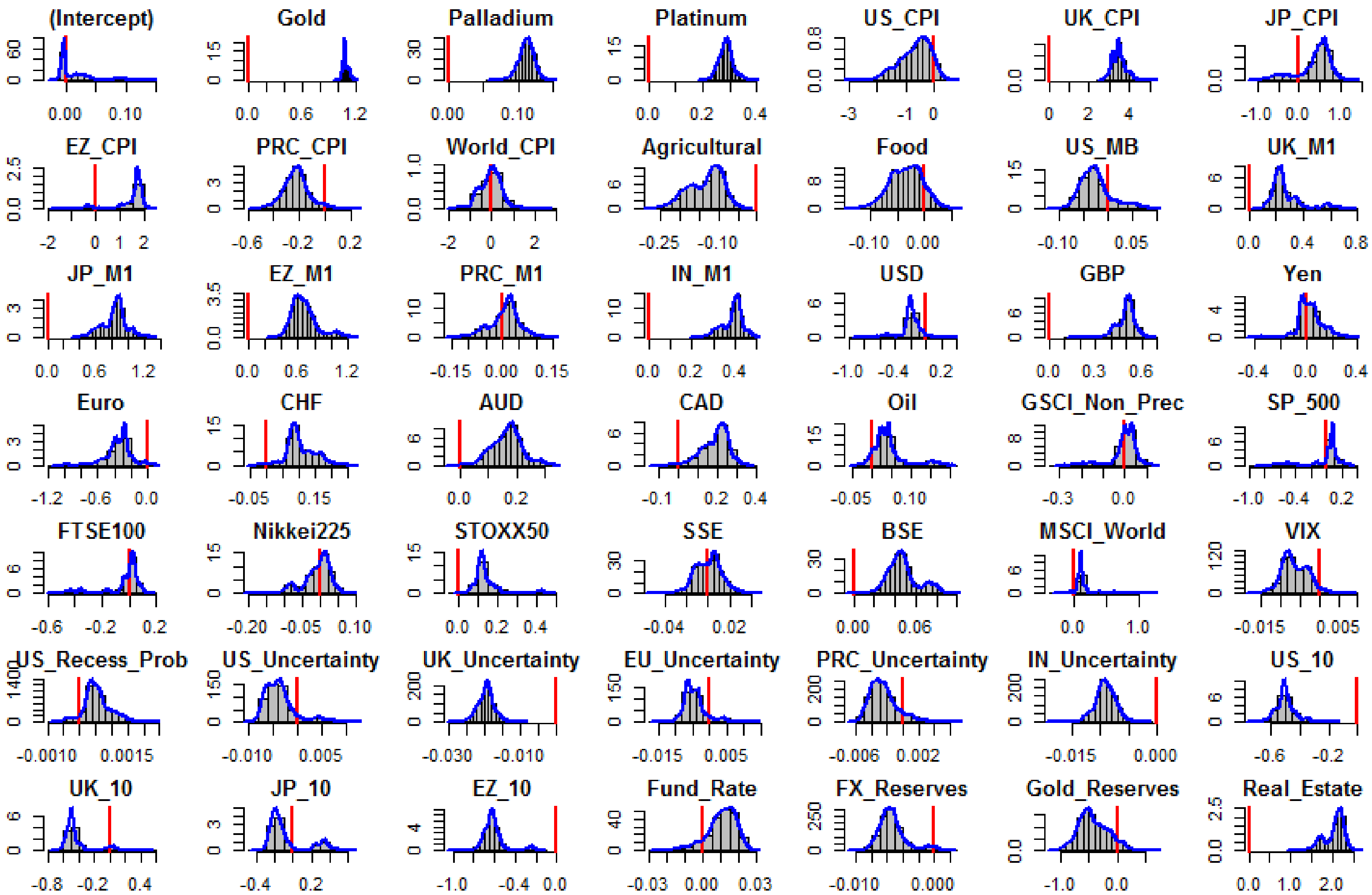


Figure N.5: Sophisticated Extreme Bounds Analysis Results for Silver - Model 4: Fixing Precious and Non-Precious Metals

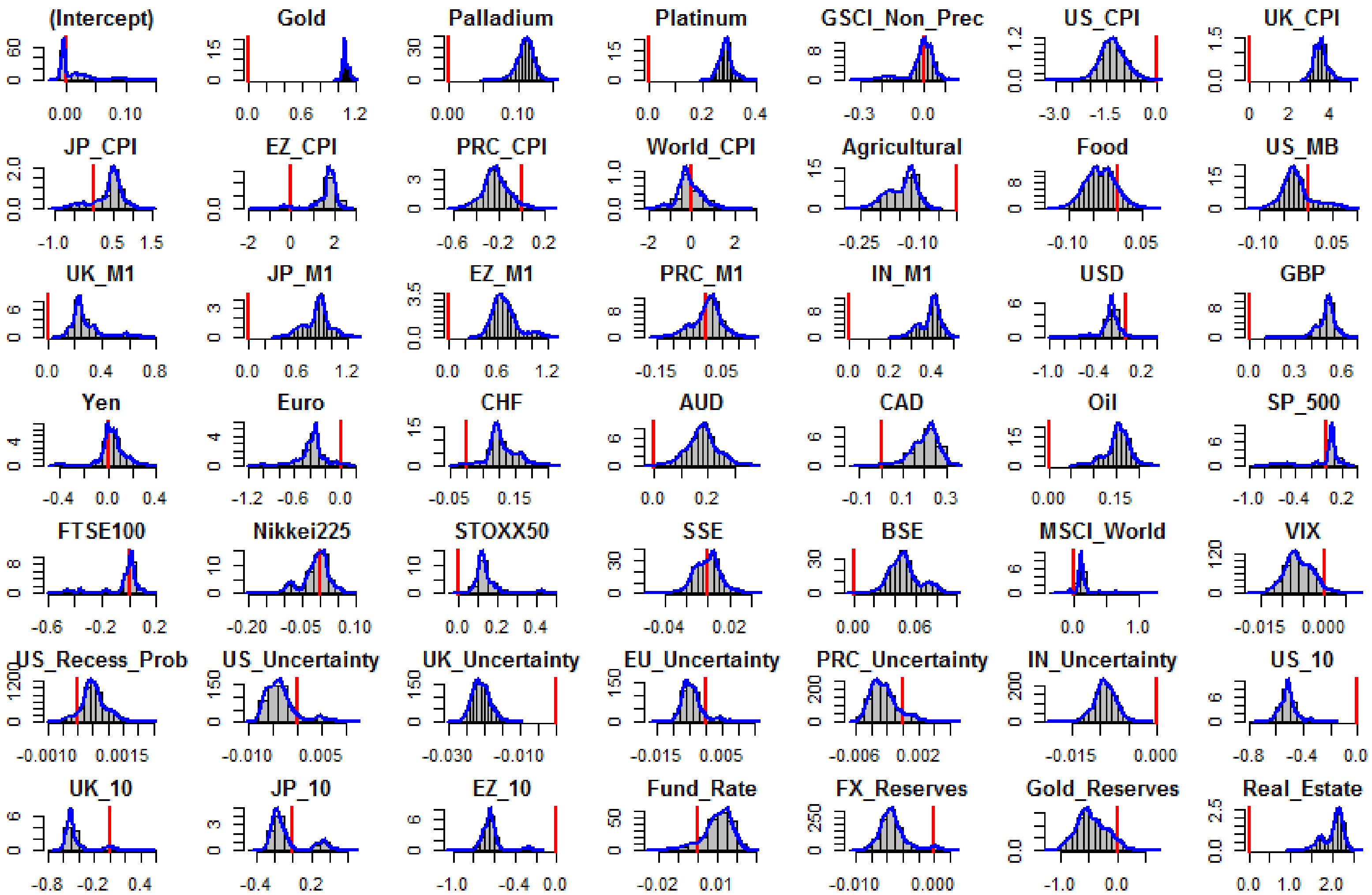


Figure N.6: Sophisticated Extreme Bounds Analysis Results for Silver - Model 5: Fixing Oil

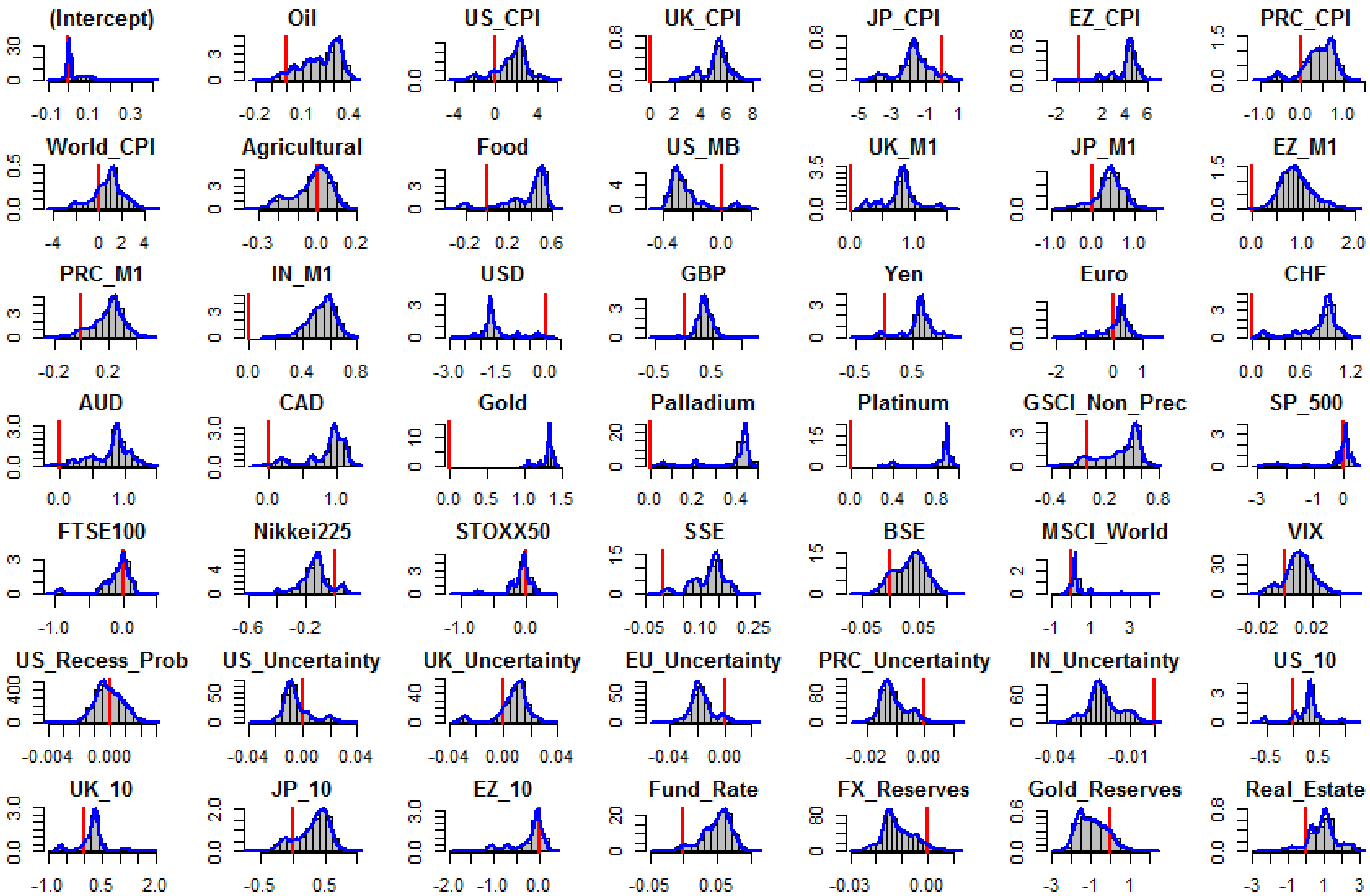


Figure N.7: Sophisticated Extreme Bounds Analysis Results for Silver - Model 6: Fixing the US Dollar

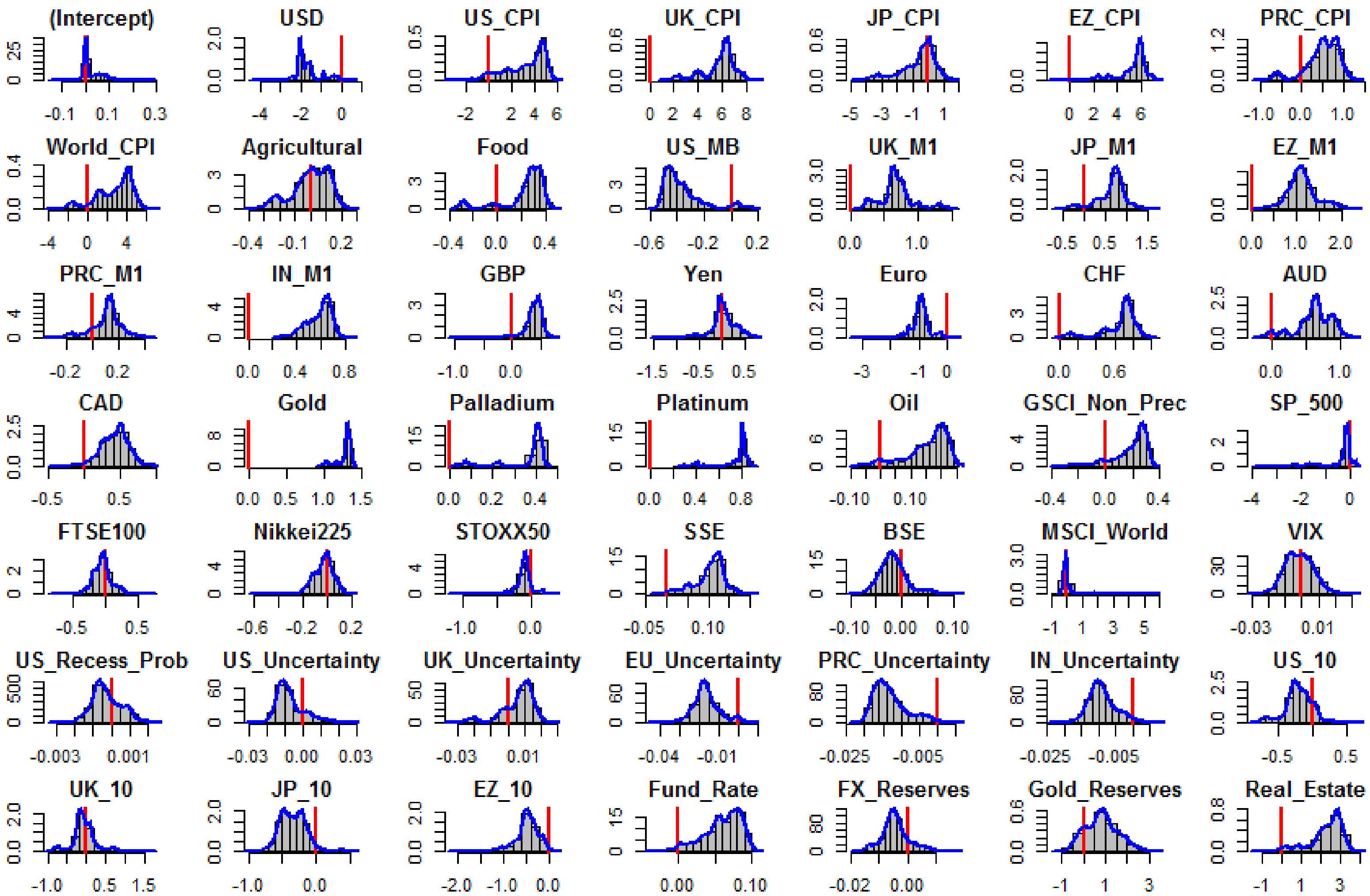


Figure N.8: Sophisticated Extreme Bounds Analysis Results for Silver - Model 7: Fixing Currencies Identified in the Unconstrained Model

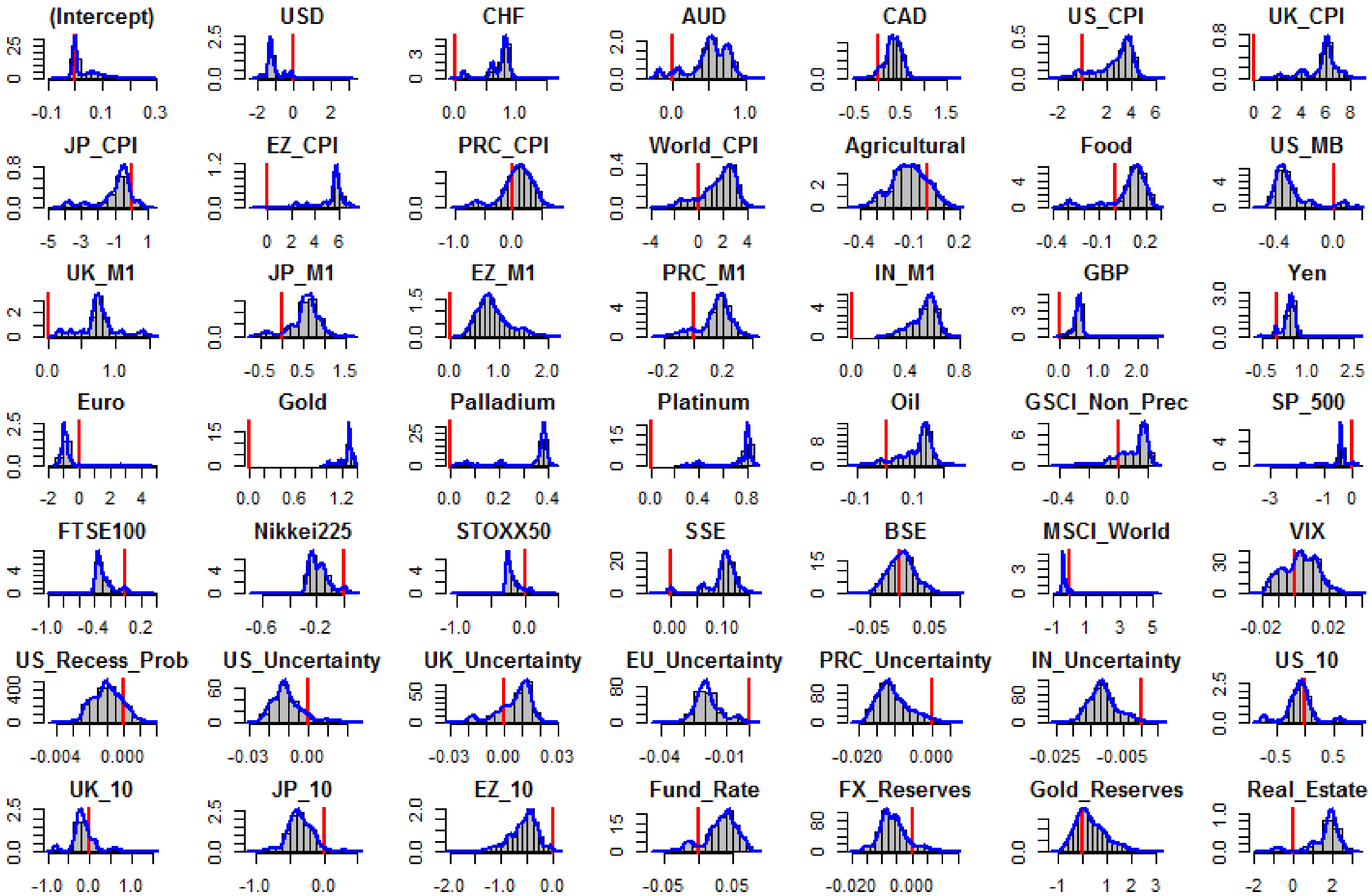


Figure N.9: Sophisticated Extreme Bounds Analysis Results for Silver - Model 8: Fixing all Currencies

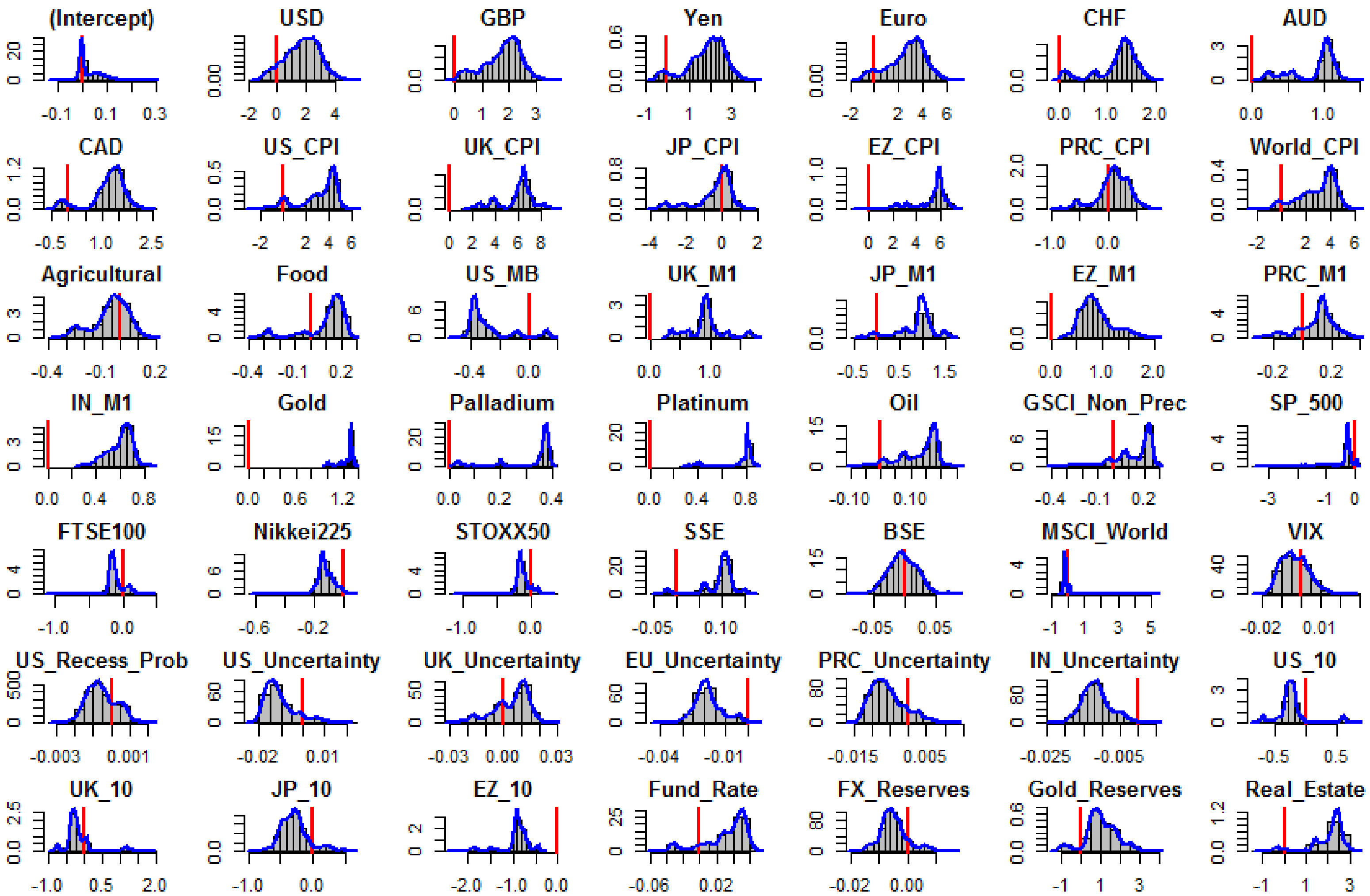


Figure N.10: Sophisticated Extreme Bounds Analysis Results for Silver - Model 9: Fixing Consumer Price Indices

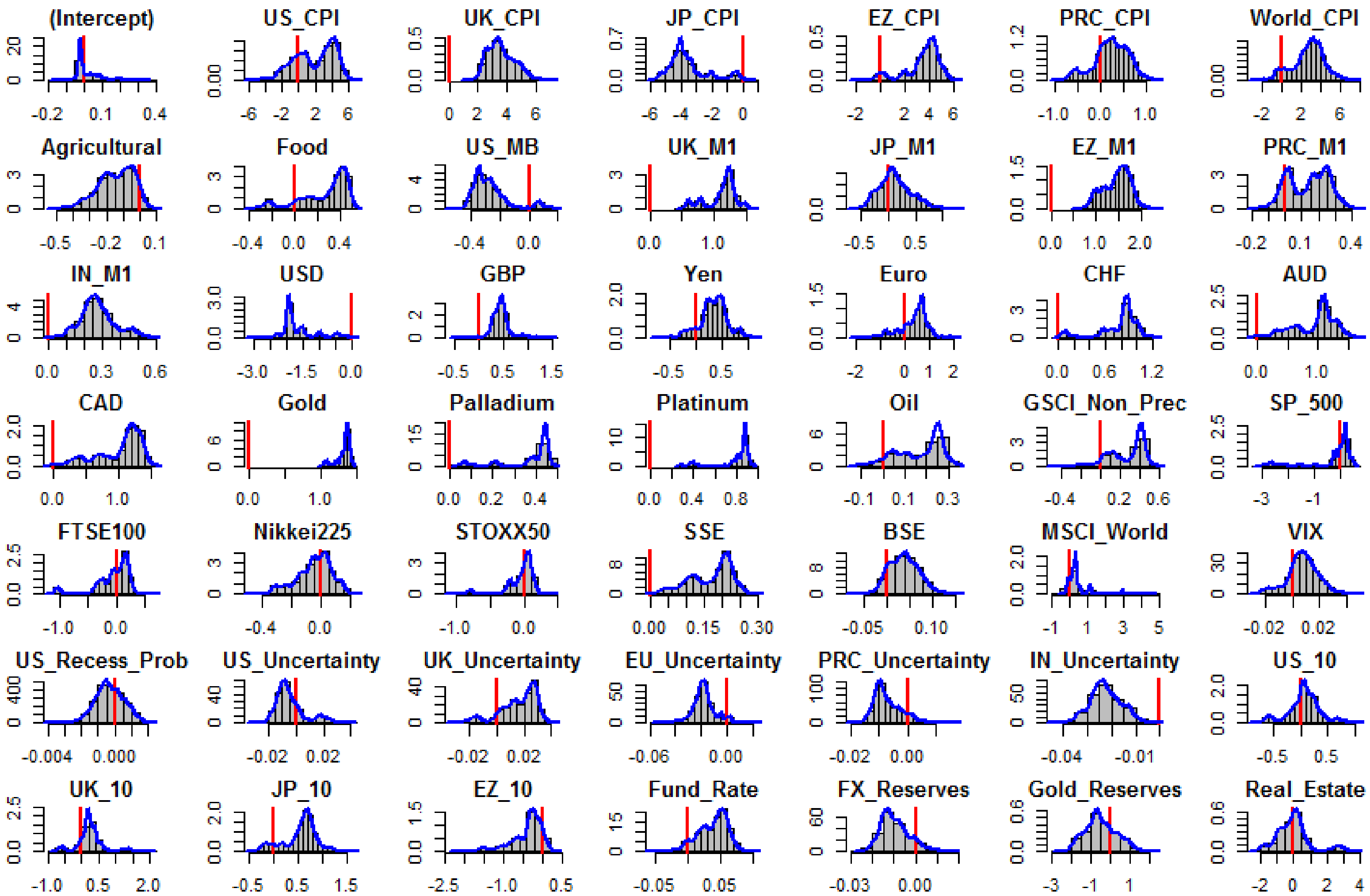


Figure N.11: Sophisticated Extreme Bounds Analysis Results for Silver - Model 10: Fixing Money Supply

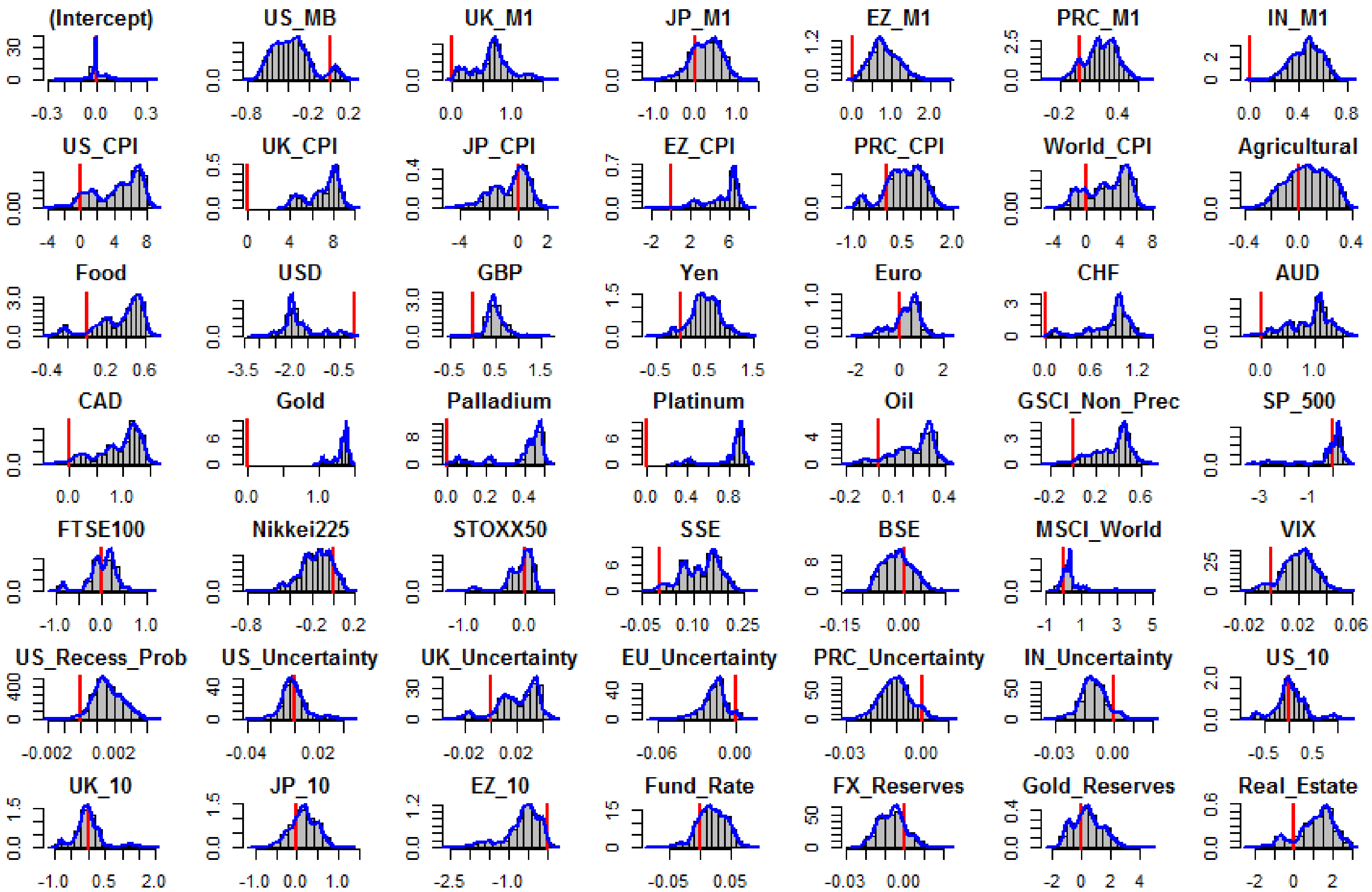
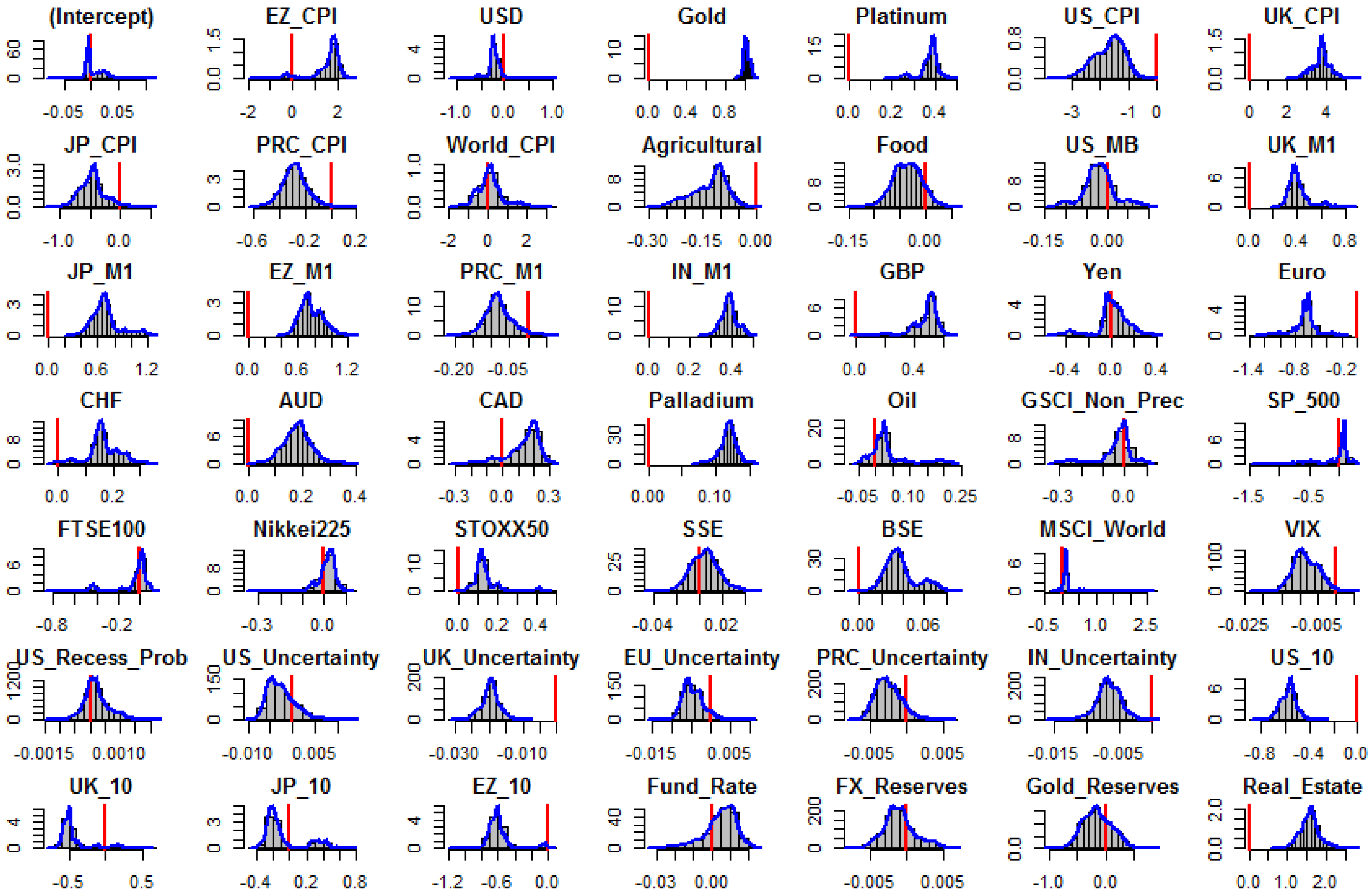


Figure N.12: Sophisticated Extreme Bounds Analysis Results for Silver - Model 11: Fixing the Variables identified at the 99% Confidence Interval



APPENDIX O

Unconstrained Extreme Bounds Analyses for Platinum, Palladium and Oil

The Extreme Bounds Analysis in the spirit of Leamer (1983), Granger and Uhlig (1990) and Sala-I-Martin (1997) allows to run a very high number of linear regressions and identify which variables are robustly cointegrated with platinum, palladium and oil, and which are not. The graphical results allow to quickly understand if a variable is positively or negatively cointegrated with the price of the three commodities by looking at the density distribution. If more than 90% of the regressors are positive, the variable is positively cointegrated with the price of the commodity. A majority of negative regressors indicate that a high value of the variable is associated with a low price of the commodity.

Table O.1: Naive Extreme Bounds Analysis Results for Platinum

Variable	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**	**Variable**	**Type**	**CDF (beta ≤ 0)**	**CDF (beta > 0)**
(Intercept)	fixed	39.971	60.029	Oil**	focus	4.884	95.116
US_CPI**	focus	2.985	97.015	GSCI_Non_Prec***	focus	0.162	99.838
UK_CPI*	focus	7.846	92.154	S&P_500	focus	17.685	82.315
JP_CPI	focus	44.232	55.768	FTSE100	focus	15.025	84.975
EZ_CPI**	focus	4.166	95.834	Nikkei225	focus	28.192	71.808
PRC_CPI**	focus	3.521	96.479	STOXX50	focus	52.686	47.314
World_CPI**	focus	2.419	97.581	SSE*	focus	9.376	90.624
Agricultural*	focus	5.271	94.729	BSE	focus	36.811	63.189
Food***	focus	0.007	99.993	MSCI_World*	focus	5.092	94.908
US_MB***	focus	99.846	0.154	VIX	focus	56.898	43.102
UK_M1	focus	14.531	85.469	US_Recess_Prob	focus	64.687	35.313
JP_M1	focus	76.242	23.758	US_Uncertainty	focus	85.471	14.529
EZ_M1	focus	45.240	54.760	UK_Uncertainty	focus	28.135	71.865
PRC_M1	focus	39.610	60.390	EU_Uncertainty*	focus	93.650	6.350
IN_M1	focus	50.830	49.170	PRC_Uncertainty*	focus	90.644	9.356
USD***	focus	99.191	0.809	IN_Uncertainty	focus	88.117	11.883
GBP	focus	56.627	43.373	US_10	focus	42.065	57.935
Yen	focus	79.912	20.088	UK_10	focus	68.457	31.543
Euro***	focus	0.793	99.207	JP_10	focus	37.806	62.194
CHF	focus	12.261	87.739	EZ_10	focus	86.056	13.944
AUD***	focus	0.040	99.960	Fund_Rate**	focus	3.299	96.701
CAD*	focus	7.560	92.440	FX_Reserves	focus	77.403	22.597
Silver***	focus	0.001	99.999	Gold_Reserves	focus	42.245	57.755
Palladium***	focus	0.000	100	Real_Estate	focus	16.056	83.944
Gold***	focus	0.020	99.980				

Figure O.1: Naive Extreme Bounds Analysis Results for Platinum

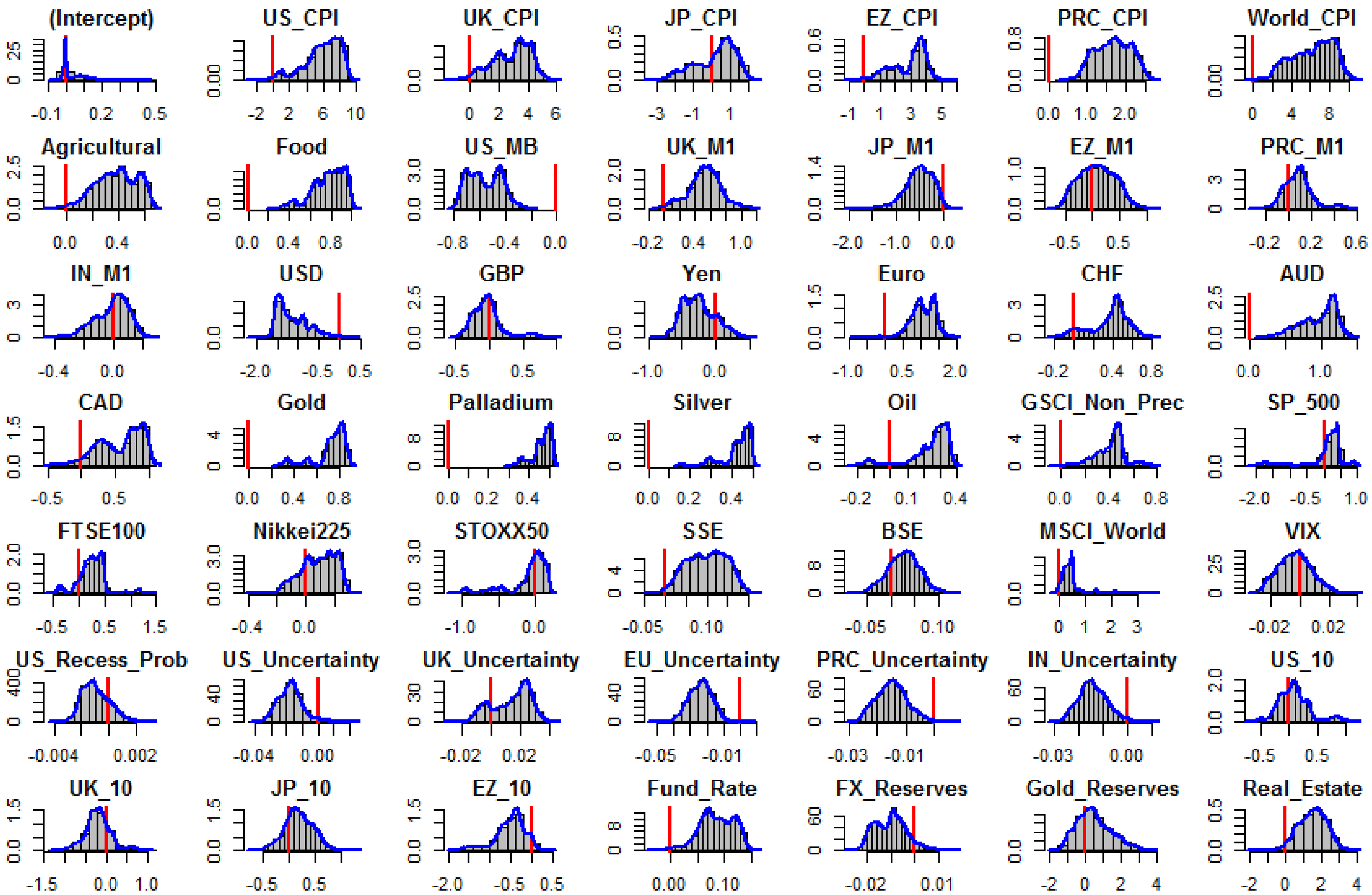


Table O.2: Naive Extreme Bounds Analysis Results for Palladium

Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)	Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)
(Intercept)	fixed	37.183	62.817	Oil**	focus	4.442	95.558
US_CPI	focus	25.064	74.936	GSCI_Non_Prec***	focus	0.557	99.443
UK_CPI	focus	20.029	79.971	S&P_500	focus	10.490	89.510
JP_CPI	focus	50.846	49.154	FTSE100	focus	11.558	88.442
EZ_CPI	focus	20.188	79.812	Nikkei225*	focus	7.655	92.345
PRC_CPI	focus	15.027	84.973	STOXX50	focus	44.577	55.423
World_CPI	focus	12.660	87.340	SSE*	focus	6.643	93.357
Agricultural**	focus	1.096	98.904	BSE	focus	55.936	44.064
Food**	focus	1.142	98.858	MSCI_World**	focus	3.920	96.080
US_MB	focus	87.428	12.572	VIX	focus	83.558	16.442
UK_M1	focus	10.544	89.456	US_Recess_Prob	focus	80.635	19.365
JP_M1	focus	65.609	34.391	US_Uncertainty	focus	80.501	19.499
EZ_M1	focus	80.229	19.771	UK_Uncertainty*	focus	7.819	92.181
PRC_M1	focus	50.301	49.699	EU_Uncertainty	focus	82.436	17.564
IN_M1	focus	21.279	78.721	PRC_Uncertainty*	focus	94.170	5.830
USD	focus	89.702	10.298	IN_Uncertainty	focus	48.193	51.807
GBP	focus	31.197	68.803	US_10	focus	77.920	22.080
Yen	focus	63.365	36.635	UK_10	focus	85.046	14.954
Euro	focus	30.551	69.449	JP_10	focus	58.307	41.693
CHF*	focus	9.348	90.652	EZ_10	focus	66.788	33.212
AUD***	focus	0.786	99.214	Fund_Rate*	focus	8.977	91.023
CAD	focus	13.563	86.437	FX_Reserves	focus	23.275	76.725
Silver**	focus	1.428	98.572	Gold_Reserves	focus	21.833	78.167
Gold*	focus	7.702	92.298	Real_Estate	focus	42.278	57.722
Platinum***	focus	0.000	100				

Figure O.2: Naive Extreme Bounds Analysis Results for Palladium

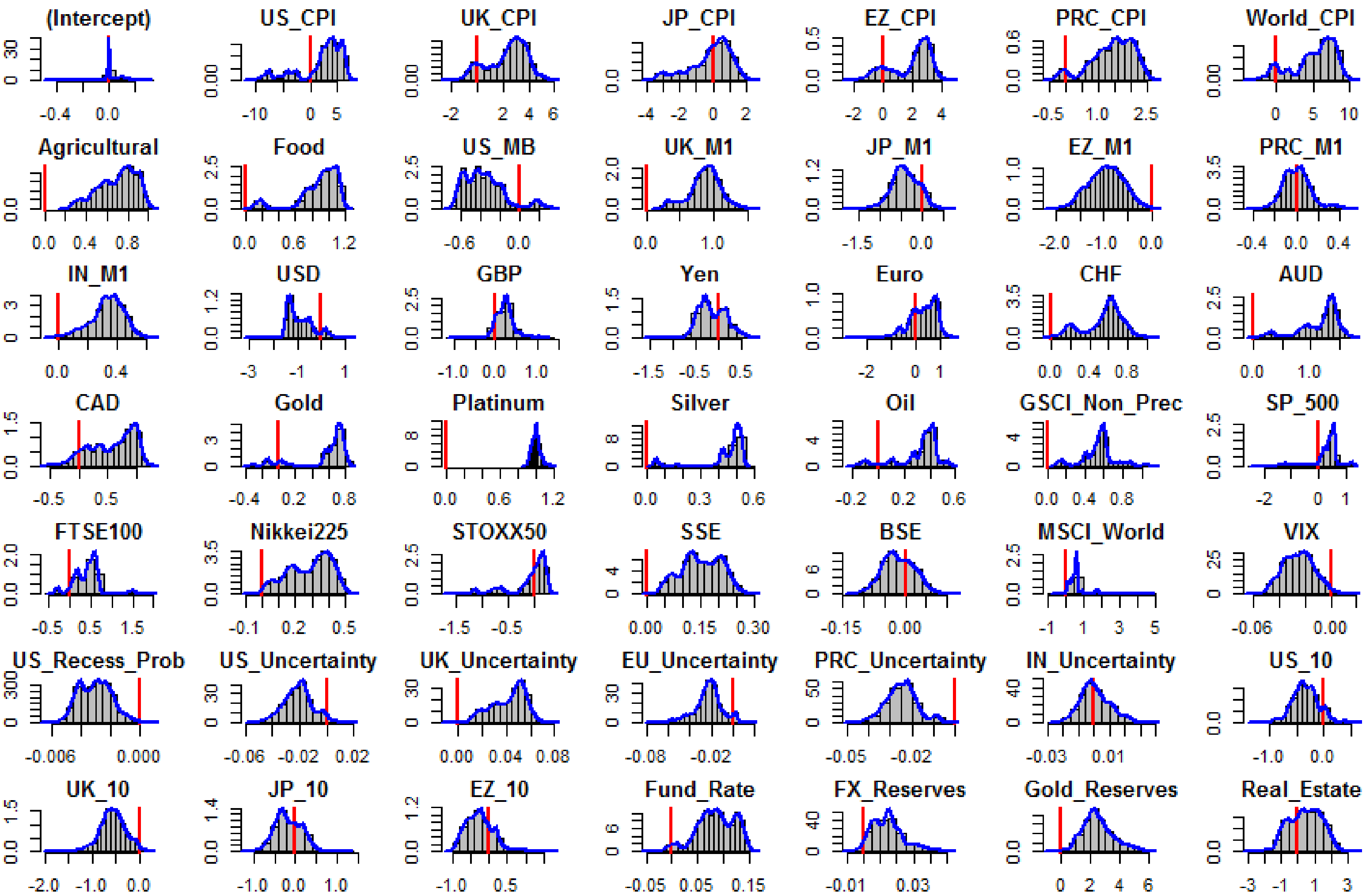
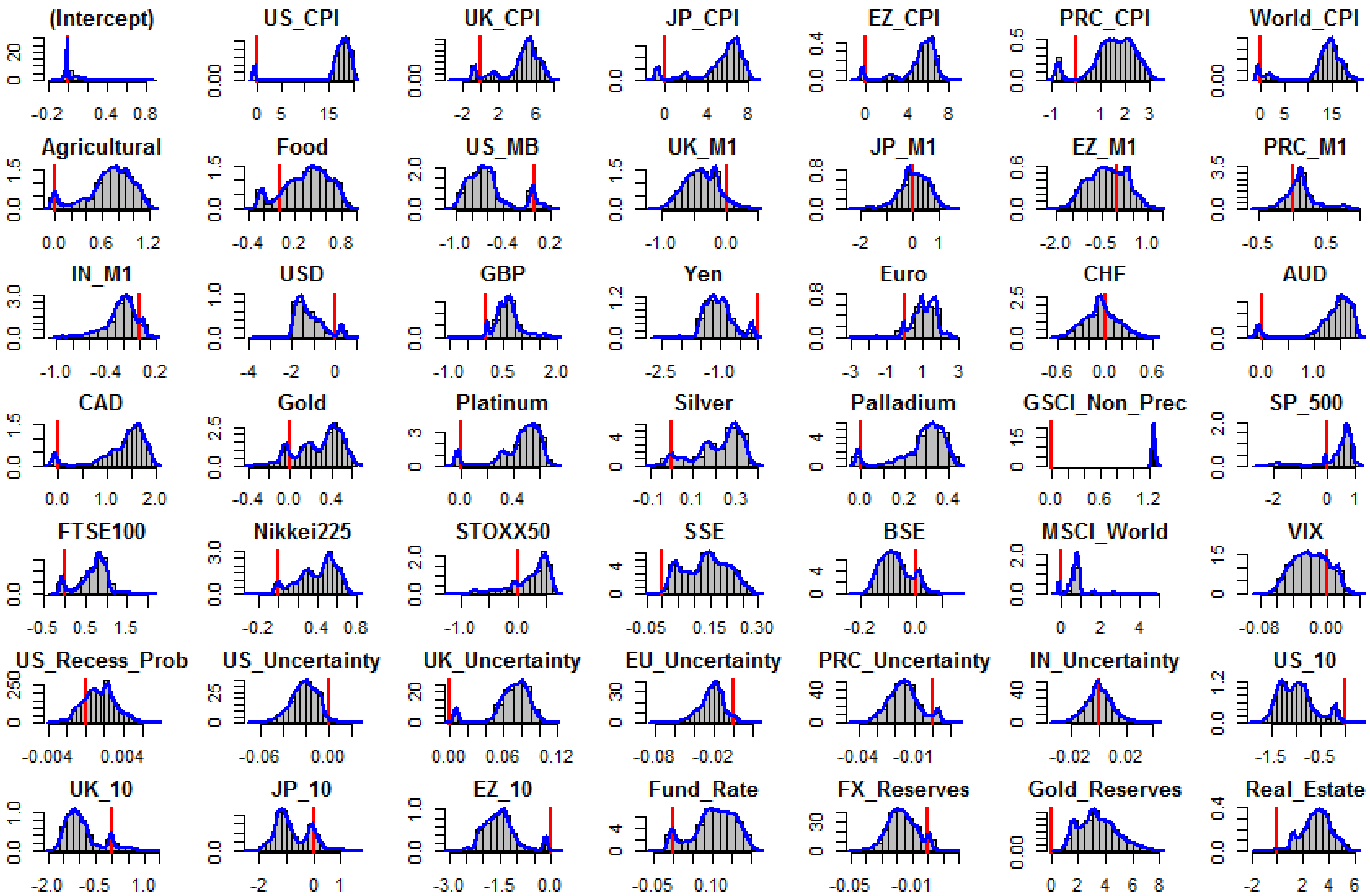


Table O.3: Naive Extreme Bounds Analysis Results for Oil

Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)	Variable	Type	CDF (beta ≤ 0)	CDF (beta > 0)
(Intercept)	fixed	40.045	59.955	Gold	focus	14.634	85.366
US_CPI**	focus	4.549	95.451	GSCI_Non_Prec***	focus	0.000	100
UK_CPI*	focus	9.735	90.265	S&P_500	focus	13.413	86.587
JP_CPI*	focus	6.818	93.182	FTSE100*	focus	7.832	92.168
EZ_CPI**	focus	4.815	95.185	Nikkei225*	focus	5.795	94.205
PRC_CPI	focus	14.393	85.607	STOXX50	focus	24.133	75.867
World_CPI*	focus	5.923	94.077	SSE*	focus	8.567	91.433
Agricultural**	focus	4.405	95.595	BSE	focus	73.850	26.150
Food	focus	16.923	83.077	MSCI_World*	focus	6.116	93.884
US_MB*	focus	93.978	6.022	VIX	focus	71.532	28.468
UK_M1	focus	73.758	26.242	US_Recess_Prob	focus	32.593	67.407
JP_M1	focus	46.757	53.243	US_Uncertainty	focus	83.070	16.930
EZ_M1	focus	59.661	40.339	UK_Uncertainty**	focus	1.388	98.612
PRC_M1	focus	37.190	62.810	EU_Uncertainty	focus	85.013	14.987
IN_M1	focus	68.983	31.017	PRC_Uncertainty	focus	81.739	18.261
USD*	focus	92.111	7.889	IN_Uncertainty	focus	49.359	50.641
GBP*	focus	9.101	90.899	US_10**	focus	97.645	2.355
Yen***	focus	99.384	0.616	UK_10	focus	89.622	10.378
Euro*	focus	6.927	93.073	JP_10	focus	80.198	19.802
CHF	focus	57.014	42.986	EZ_10**	focus	98.401	1.599
AUD**	focus	4.374	95.626	Fund_Rate*	focus	7.814	92.186
CAD**	focus	4.151	95.849	FX_Reserves	focus	80.759	19.241
Silver*	focus	6.113	93.887	Gold_Reserves	focus	12.114	87.886
Palladium**	focus	4.442	95.558	Real_Estate*	focus	5.927	94.073
Platinum**	focus	4.884	95.116				

Figure O.3: Naive Extreme Bounds Analysis Results for Oil



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