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Essays in Option Pricing

Thesis submitted to Trinity College, Dublin
In fulfilment of the requirements for the degree of
Doctor of Philosophy (Ph. D.)

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Declaration

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In loving memory of Nana and Grandad.

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0.2 Summary

In this thesis I explore option valuation from a theoretical standpoint and also from an empirical perspective. In particular, I address the issue of irreversible decision making under uncertainty (real options) applied to a firm's optimal voluntary disclosure policy.

In Chapter 2 I conduct theoretical research which utilises a real options approach to valuing a firm's voluntary disclosure policy. I derive a threshold, using real options analysis, on the manager's belief that disclosing information will impact positively upon the firm value. I further show that the model I describe provides a violation to the Modigliani–Miller theorem of investment financing.

In Chapter 3 I extend the analysis outlined in Chapter 2 to estimate the impact of competition on the timing of corporate voluntary disclosure. In a competitive environment, a firm's decision over when to disclose is not only driven by the sunk cost of making a disclosure and the direct effect of doing so on current and future payoffs through the market's reaction, but also by an indirect effect of imperfect competition. By disclosing, a firm affects its rival's payoffs and thus its disclosure timing decision which, in turn, affects the firm's own payoffs.

In particular, I examine the impact of competition, in a duopoly framework, on the voluntary disclosure policy of firms. Each firm is assumed to have invested in a specific product and the manager of each firm must then decide when to optimally disclose its involvement in the product to the market, while taking into consideration the disclosure strategy of the other firm. A preemption, attrition, or synergy equilibrium is found, depending on the trade-off between first and second mover advantages and, also on the advantage from simultaneous disclosure.

In Chapter 4, I extend the benchmark model of disclosure described in Chapter 2 to account for the possibility that the manager is faced with a corporate control

challenge, with the ensuing possibility of dismissal, if his disclosure policy is too intransparent for the shareholder's satisfaction. I derive the manager's disclosure threshold, adjusted for the fact that he is faced with the threat of a corporate control challenge, and I find that the manager's threshold under corporate control is always lower than the threshold when no such corporate control challenge is imposed. The result is intuitive, and it corroborates broadly with anecdotal evidence on voluntary disclosure theory. Furthermore, the greater the probability the manager is faced with a control challenge, the more transparent is the disclosure policy he chooses to adopt, and the lower the agency costs the shareholder may incur as a result of delegating the disclosure decision to the manager.

In Chapter 5 I extend the familiar geometric Brownian motion and log-normal jump diffusion models of option pricing and I derive a new specification, termed the Gamma-Beta jump diffusion (GBJD) model, which separates the "good" news from the "bad" news components. This specification is comprised of a Gamma distribution to model the upward jumps, or "abnormal" movements in the underlying assets, and a Beta distribution to model the downward jumps. The purpose of this new model specification is to deepen the intuitive realism behind the other more popular specifications.

The aim of this chapter is to go beyond the log-normal jump diffusion process introduced by Merton [35] and, through a selection analysis, assess whether the fit of the model to the data will be enhanced, and importantly, whether its forecasting accuracy will be improved as a result of distinguishing between the upward and downward abnormal price movements. Using a sample of securities and indices, I compare the fit and the predictive power of the three model specifications. I find that for both, the GBJD specification, which separates the news components, is the preferred model for the sample series that are examined.

Contents

Chapter 1

Introduction

"For the things of this world cannot be made known without a knowledge of mathematics". Roger Bacon (c. 1214-1294)

1.1 Opening Notes

In this thesis I explore option valuation from a theoretical standpoint and also from an empirical perspective. In particular, I address the issue of irreversible investment under uncertainty (real options) applied to a firm's voluntary disclosure policy. Voluntary disclosure relates to the announcements that are made by firms outside of their legal and regulatory requirements.

The economic analysis of disclosures at its fundamental level investigates voluntary disclosures. Even though provision of information, such as a publicly traded company's financial statements, is mandatory, the economic approach is motivated by the observation that it is only possible to assess the effect of mandatory disclosures relative to the disclosures that would have arisen in the absence of such regulation.

Archival and interview based evidence suggests that firms communicate with the external marketplace substantially through the information released by means of corporate announcements. Such announcements send desired signals that both inform investors perceptions and guide their expectations. Although announcements are a commonplace characteristic of modern corporations, to date, there is no strategic management theory (to my knowledge) which places announcements at the core of the management and strategic decision making process. This is in spite of the fact that Heil and Robertson [22] noted some time ago that the time for such a theory is long overdue. I seek to address this need in Chapter 2 by introducing a theory of strategic disclosure and illustrating how, once conceptualised as (real) options, a framework is provided under which they can be valued and better understood.

Similar to most investment decisions, the decision to disclose information has three important characteristics. Firstly, the disclosure is irreversible; that is, once the information has been released to investors, it cannot be taken back. Secondly, there is uncertainty over the future impact of the disclosure on the share price of the firm in that the firm's manager does not know, in advance, how the shareholders will interpret the information when released. Thirdly, in the case of voluntary disclosure, the manager of the firm has some discretion over when to release the information. These three characteristics allow one to plausibly interpret voluntary disclosure as a (real) option and, together, they interact to determine the optimal voluntary disclosure policy of the firm.

In principle, a firm can make an announcement about anything it chooses, and thus, the range of announcement applications is endless. Examples of such announcements include competitive pricing strategies, new product introductions, various mergers, acquisitions and other alliances, and a range of detailed structural changes within the firm. However, in practice, firms tend to make announcements only about key strategic and organisational events that could impact substantially on their value and success (see Bayus et al. [3]).

I further show, in Chapter 2, that the (benchmark) model of disclosure provides an example of a violation to the Modigliani–Miller theorem on irrelevance of capital structure on firm value. The theorem asserts that the mix of debt and equity financing does not have any impact on the overall value of an investment project. With respect to the disclosure setting, I show that this assertion does not hold true when some of the disclosure cost is financed with debt. In particular, the limited liability aspect of debt dominates the loss to the firm from compensating the lender for expected default losses, and consequently, the optimal disclosure threshold for the manager is lower. As such this is an interesting example where excess risk taking by managers due to limited liability protection of debt financing actually has a positive social effect since it encourages managers to adopt a more transparent disclosure policy.

With respect to the model set-up, there is an asymmetry of information between the manager, who holds all of the information about the firm, and the shareholder who gains no information until disclosure has taken place at the manager's discretion. I address this aspect of the problem in Chapter 4. In particular, I extend the benchmark model described in Chapter 2 to account for the possibility that the manager is faced with a corporate control challenge, with the ensuing possibility of dismissal, if his disclosure policy is too far mis-aligned with the shareholder's utility maximising policy. My main finding is that the threat of a corporate control challenge imposed upon the manager leads to a more transparent disclosure policy being adopted by the firm.

Another aspect of the disclosure problem is that firms may not always have the option to delay or withhold its information disclosure. There can be occasions which make it imperative for a firm to disclose quickly, such as in the face of competition. They must then try to preempt disclosure by competitors, which could have a negative impact on their own profit, relative to the profit of a competing firm. Hence, there is a non-exclusivity feature inherent in a real option which is not associated with its financial counterpart. If, on the other hand, delay is feasible, the risk of disclosure by competing firms, is a cost to delay. The manager of the firm must weigh this cost against the benefit(s) of waiting for new information when deciding on what their optimal disclosure strategy ought to be. In such a setting, one must conduct a game-theoretic analysis of equilibrium disclosure strategies.

In Chapter 3 I extend the analysis outlined in Chapter 2 to estimate the impact of competition on the timing of corporate voluntary disclosure. In a competitive environment, a firm's decision over when to disclose is not only driven by the sunk cost of making a disclosure and the direct effect of doing so on current and future payoffs through the market's reaction, but also by an indirect effect of imperfect competition. By disclosing, a firm affects its rival's payoffs and thus its disclosure timing decision which, in turn, affects the firm's own payoffs.

In terms of real option applications concerned with competitive equilibrium in exercise policies, the literature is relatively scant. Furthermore, the application of game theory to continuous-time models is not very well developed, and can be quite difficult to implement. However, from the literature that does exist, the generalisation of the real option approach to include competitive equilibrium exercise strategies appears to provide very different implications from the standard monopolistic setting. For example, one of the most well known results in the real options literature is the invalidation of the classical net present value (NPV) rule of investment. However, the inclusion of competitive access to an investment opportunity leads to a rapid erosion in the value of the option to wait, making the standard NPV rule a much more accurate description of the actual investment threshold. My results in Chapter 3 corroborate with this standard result.

The research in Chapter 3 most closely resembles Thijssen et al. [53] from the perspective of real options analysis. However, the crucial difference is that they assume that the value of an unprofitable outcome from option exercise is always zero, while I do not make such an assumption and allow for a negative impact from option exercise. By not relaxing the negative impact assumption, my research makes a noteworthy contribution in that I show how a new equilibrium emerges whereby preemption is nonsensical. This so-called "synergistic" equilibrium implies that the optimal strategies of a firm is to never announce, or else to do so only at the same time as its competitor.

In Chapter 5 I extend the familiar geometric Brownian motion (GBM) and log-normal jump diffusion (LJD) models of option pricing by deriving a new specification, termed the Gamma-Beta jump diffusion (GBJD) model, in which I distinguish the "good" news from the "bad" news components. This specification is comprised of a Gamma distribution to model the upward jumps, or "abnormal" movements in the underlying assets, and a Beta distribution to model the downward jumps. I compare this new specification with the GBM and LJD in terms of model fit and forecasting adequacy and find that the GBJD is the preferred specification for both criteria for the return series examined.

Jumps arise for many reasons, such as sudden financial turmoil, as witnessed globally in August 2007, litigation issues, or incomplete accounting information. Hence, searching for models that account for such jumps are becoming increasingly important in terms of financial modelling. In extant literature, a wide range of continuous-time models have been constructed by choosing different theoretical structures for the drift, the diffusion, and the jump component of the process (for example, stochastic volatility and mean reversion). The point of such models is to improve derivative pricing and portfolio optimisation through reducing the deviation between model and reality.

While much of the literature has focussed primarily on improving the fit of these specifications with the data, to my knowledge, there has been very little effort, if indeed any, to assess their predictive power. The aim of my research in Chapter 5 is to go beyond the log-normal jump diffusion process introduced by Merton [35] and, through a selection analysis, by assuming a different distributional choice to model the jump component, in particular a Gamma Distribution for the "good" news component and a Beta Distribution for the "bad" news component, whether the fit of the model will be enhanced, and importantly, whether its forecasting accuracy will be improved.

I use daily returns data for the ISEQ, FTSE 100 and S&P 500 indices and also from a number of stocks included in one or other of these indices, in conjunction with cumulant moment matching to fit the models. As expected, the GBM specification does not provide a better fit over the jump diffusion specifications for any of the return series examined. This is consistent with economic intuition. The GBJD is superior to the LJD for eight of the returns series, with the LJD beating the GBJD for only four cases. This provides strong support for the GBJD specification in terms of model fit.

From a forecasting adequacy perspective, the GBJD specification also appears to perform better than the other two specifications. Overall, the results for forecasting adequacy of the models are not very informative. However, the GBJD has a greater predictive power for five of the twelve returns series studied, whereas the GBM and LJD have greater predictive power for only three and four of the twelve series respectively.

Chapter 2

Valuing Voluntary Disclosure using a Real Options Approach

2.1 Introduction

Corporate voluntary disclosure has become an important element of capital market dynamics (Wen [56]) in that it conveys value-relevant information for market pricing. As well as this, it typically contains information related to a firm's activities which may not be immediately stated in accounting reports. The issue has become increasingly topical and important in the aftermath of some major corporate scandals such as Enron, WorldCom and others. Such events have raised concerns over the transparency of U.S. firms, in particular, the quality of their financial reporting and disclosures (see Dempster [8]). This chapter demonstrates how a real options approach to valuation can contribute to our understanding of corporate disclosure, and in particular, *voluntary* corporate disclosure which is concerned with those announcements willingly made by firms which are outside their legal and regulatory requirements.

One of the earliest findings in the disclosure literature, provided by Grossman and Hart [19] and Grossman [18], has become known as the "unravelling result". If the managers of firms, holding private information, choose not to disclose their information to outside investors, then the investors will discount the value of the firm down to the lowest possible value consistent with whatever voluntary disclosure is made. Once the managers realise this, they will have an incentive to make full disclosure. Dye [11], however, challenges this result and provides a reasoning for why it may not always hold. He shows that the qualitative features of an optimal disclosure policy for management may take the form of a policy dependent on a cutoff in which management disclose only if the information is sufficiently good, otherwise they withhold disclosure. His reasoning is due to the uncertainty of investors about the firm's information endowment; that is, investors may not be able to distinguish between managers holding undisclosed information from managers being uninformed. In such a setting, investors seeing non-disclosure must temper their inferences concerning the likelihood of a manager having observed bad news and opting not to disclose by the fact that non-disclosure may have arisen due to managers being uninformed. Since these early seminal contributions by Grossman [18] and Dye [11], a large body of work has emerged on corporate voluntary disclosure. Verrecchia [54] provides an extensive survey on such voluntary disclosure models.

The economic analysis of disclosures at its fundamental level investigates voluntary disclosures. Even though provision of information, such as a publicly traded company's financial statements, is mandatory, the economic approach is motivated by the observation that we can only assess the effect of mandatory disclosures relative to the disclosures that would have arisen in the absence of such regulation.

A positive interpretation of carefully timed announcements is that they provide an opportunity for managers to communicate to the marketplace that they are aware of, and up to date with, current investor demands and interests. For example, Subramani and Walden [49], in their study of the market impact of e-commerce announcements, argue that the reason for the significant positive abnormal returns that they found were in part because investors viewed announcement of such initiatives as favourable signals of certain firm attributes.

Importantly, across various streams of research investigating corporate disclosure, there is a growing recognition that the various announcements that firms make have an inherent strategic value in their power to influence external perceptions directly and firm performance indirectly (see Bettis [5]).

In principle, a firm can make an announcement about anything it chooses, and thus, the range of announcement applications is endless. Examples of such announcements include competitive pricing strategies, new product introductions, various mergers, acquisitions and other alliances, and a range of detailed structural changes within the firm. However, in practice, firms tend to make announcements only about key strategic and organisational events that could impact substantially on their value and success (see Bayus et al. [3]).

In this chapter voluntary disclosure of information relating to the state of the firm to the marketplace is viewed as a (real) option held by the firm's manager. This interpretation links the two strands of literature; real options on one hand with corporate voluntary disclosure on the other. Exercising the option to disclose information is a strategic decision on the part of the firm, which implies that the manager will only do so if he is sufficiently certain that the payoffs are positive; that is, that the option is deep enough in the money. The payoff to the disclosure option is measured as the impact of market response to the information on the value of the firm. This reflects the standard corporate practice to (partly) renumerate managers based upon the firm's stock market performance. This, effectively, aligns the manager's incentives with potential sellers of the firm's equity. They, after all, are interested in firm value to be as high as possible.

I also adapt the model to show that it provides an example of a violation to the Modigliani–Miller theorem on irrelevance of capital structure on firm value. The theorem asserts that the mix of debt and equity financing does not have any impact on the overall value of an investment project. With respect to the current setting, I show that this assertion does not hold true when some of the disclosure cost is financed with debt. To the extent that debt reduces the manager's share of the disclosure cost, the disclosure threshold is lower, and to the extent that limited liability lowers the manager's downside risk from making a disclosure, the disclosure threshold is lower. However, the lender anticipates a likelihood that the manager will default on his debt obligation, and sets a coupon to (partly) offset expected losses. To the extent that a higher coupon decreases the profitability to the manager from making a disclosure, the disclosure threshold is higher. While one may intuitively expect that after compensating the lender for expected default losses, the net effect of such debt financing on the optimal disclosure threshold is zero, I show in Section 2.4 that the net effect is negative in that the threshold is lower, and this is owing to the impact from limited liability.

From a modelling point of view, my paper is most closely related to Thijssen et al. [52] and Subarwal [48]. The model of the arrival of imperfect signals over time follows that of Thijssen et al. [52]. That paper analyses the problem of a firm with the opportunity to invest in a project which has an uncertain profitability and does not feature the debt financing issue that is central to my paper. Additionally, they assume that there is no negative impact on firm value through exercising their investment option. However, making such an assumption in my set-up is not realistic. If the manager makes an announcement, the shareholders may react negatively and respond by selling off some of their investment in the firm. This implies that disclosure may, indeed, have a direct negative impact on firm value. This results in a lower threshold than the threshold under their set-up. Subarwal [48] shows how the ideas regarding the value of the option to wait provide a violation of the Modigliani–Miller theorem, but he deals with uncertainty using the standard framework of real options literature (see Dixit and Pindyck [9]), whereas in my model, uncertainty is resolved over time and thus, standard stochastic calculus tools cannot be used.

The chapter is organised as follows; I describe the benchmark model and I solve for the optimal stopping problem for the disclosure threshold in the next section. In Section 2.3 I discuss some important properties associated with the optimal disclosure threshold. I analyse the model from another dimension in Section 2.4; namely if some of the disclosure cost is financed with debt, and Section 2.5 finally concludes. All proofs are outlined in the Appendix.

2.2 Model

2.2.1 Background and Motivation

Consider a firm which has invested in a new product or technology, and the objective for the manager of the firm is to determine at what point to disclose this information to the market, such that his own current expected (discounted) utility from wealth is maximised. I assume that the product is still in the developmental stage and signals regarding the progress of the development, which are indicative of the potential profitability of the product for the firm, are obtained by the manager at random points in time. Disclosing the signals is analogous to revealing the firm's involvement in the product to the market. Furthermore, it is important to assume that the firm can choose to abandon its investment at any point, before it launches the product. Thus, by choosing not to make an announcement, if the firm then abandons the investment, the market may never learn that such an investment took place. This implies another option for the manager; namely a disinvestment option. However, taking account of the value of such an option is beyond the scope of this chapter.

The manager of the firm is uncertain about how the private information he holds will be perceived by the market. The more positive are the signals he obtains, the more likely the market will interpret the information favourably. Hence, each time a signal is obtained, the manager updates his belief as to the likely market response in a Bayesian way. The assumption of response uncertainty is necessary to prevent (extremely) high returns from being disclosed, an act that would initiate the unravelling process described by Grossman and Hart [19]. This source of uncertainty differs with Dye [11] in the sense that he assumes the uncertainty arises because the market is unsure what, if any, information the manager has obtained.

There are several reasons why such response uncertainty may arise. One such reason is that the market can interpret the disclosed information in different ways. In Dutta and Trueman [10], response uncertainty arises because firms do not know how investors will interpret the firm's private information. They present the disclosure of order backlog as an example. Investors can interpret a high-order backlog favourably if they believe that it signals high demand for the firm's product. Alternatively, they can interpret a high-order backlog unfavourably if they believe that it signals problems with the firm's production facilities or a manager's lack of control over operations. In terms of the current story, the disclosure of the signals (that is, the disclosure that the firm has invested in a new product) may be interpreted favourably by the market in that it signals growth and innovation within the firm through newer and more improved products. Alternatively, such news may be interpreted unfavourably as the market views the investment as a costly and risky venture with little chance of success.

I further assume that all disclosures are (ex post) verifiable; that is, a manager will not issue mis-leading information in an attempt to alter the market's perception of his firm's prospects. Stocken [47] examines in detail the credibility of a manager's disclosure of privately observed nonverifiable information. His main finding is that a manager will almost always endogenously truthfully disclose his private information because if the market perceives lack of credibility in the disclosure, it will ignore it and this can lead to deeper problems for the firm in the future.

In this model, disclosure is costly and this cost cannot be recouped once the disclosure option has been exercised. For example, there may be some direct costs associated with producing and disseminating information; that is, information may need to be disclosed or certified by a third party such as an accounting firm. I note that these costs are direct and do not relate to the (indirect) proprietary costs that are typically referred to in the disclosure literature such as the cost of revealing firm sensitive information to competitors. There also exists an exogenous opportunity cost of waiting for more, and possibly better, information signals to arrive. By waiting for further signals, the manager can be more certain of the overall profitability of the firm (owing to the new investment), which will reduce the likelihood of misinforming the market and thereby damaging his reputation. These costs of announcing the information, and therefore exercising the disclosure option, could greatly outweigh the benefit of disclosure.

Furthermore, I assume that a fraction of the firm is owned by the manager. Therefore, the manager's compensation depends upon the firm's activities, and as such, he is compensated with a fraction of the option to disclose. If the manager's compensation does not depend on the disclosure option itself, then in the absence of some form of control, the manager should not have any preference for the timing of disclosure. I assume that the manager's preferences are quasi-linear in his share in the firm's value and, therefore, the manager acts to maximise firm value. In this way, the incentives of the manager are aligned with those of a shareholder whose only aim is to maximise firm value. This is consistent with the typical principal-agent set-up of Mas-Colell et al. [32].

2.2.2 Model Set-up

I assume that the firm has invested in a project and receives (private) information regarding the project's profitability. The manager has, at any time, the option to voluntarily disclose the information at a sunk cost $I \geq 0$. The manager is uncertain about market reaction to the disclosure. The market reaction to the disclosed information can be either good ($\gamma = 1$) or bad ($\gamma = 0$) resulting in a change in firm value of $V^P > I$ or $V^N < 0$, respectively. Over time, the manager receives information, the arrivals of which follow a Poisson process with parameter $\mu > 0$. Information is interpreted by the manager as either increasing the likelihood of a positive market response or decreasing it. Each batch of information, however, is an imperfect signal which reflects the true market reaction with probability $\theta \in (1/2, 1)$.[1] In this set-up, the number of signals indicating a positive market reaction net of the number of signals indicating a negative market reaction is a sufficient statistic for the manager's optimal disclosure policy. At time t this number of signals is denoted by $s_t \in \mathbb{Z}$. Under the assumptions regarding the arrival and precision of information, s_t evolves over time according to

$$ds_t = \begin{cases} 1 & \text{w.p. } [1_{(\gamma=1)}\theta + 1_{(\gamma=0)}(1-\theta)]\mu dt \\ 0 & \text{w.p. } 1 - \mu dt \\ -1 & \text{w.p. } [1_{(\gamma=1)}(1-\theta) + 1_{(\gamma=0)}\theta]\mu dt. \end{cases} \tag{2.1}$$

Suppose that the manager has a prior over the probability of a positive market reaction equal to $p_0 \in (0, 1)$. If, at time $t \geq 0$, the manager observes s_t, then his

[1]This assumption is made without loss of generality. A choice of $\theta = \frac{1}{2}$ implies that the signal is pure noise, since the initial prior is not revised. Furthermore, a choice of $\theta = 0.2$ is as informative as a choice of $\theta = 0.8$ since the same analysis may be carried out for $1 - \theta$.

posterior probability of a favourable market response follows from an application of Bayes' rule:

$$
\begin{aligned}
p_t := \mathbb{P}(V^P|s_t) =& \frac{\mathbb{P}(s_t|V^P)\mathbb{P}(V^P)}{\mathbb{P}(s_t|V^P)\mathbb{P}(V^P) + \mathbb{P}(s_t|V^N)\mathbb{P}(V^N)} \\
=& \frac{\theta^{s_t}}{\theta^{s_t} + \zeta(1-\theta)^{s_t}},
\end{aligned}
\tag{2.2}
$$

where $\zeta = (1 - p_0)/p_0$ is the prior odds ratio. Note that p_t is a monotonically increasing function in s_t, and that the inverse function is given by

$$
s_t := s(p_t) = \frac{\log\left(\frac{1-p_t}{p_t}\right) - \log(\zeta)}{\log\left(\frac{1-\theta}{\theta}\right)}. \tag{2.3}
$$

This implies that one can either work with the number of net signals or the posterior belief. In the following I use both approaches intermittently, depending on analytical convenience.

If the manager discloses the information at time $t \geq 0$, then, conditional on the prior p_0, the expected change in the firm's value equals

$$
U(s_t) := p(s_t)V^P + (1 - p(s_t))V^N - I. \tag{2.4}
$$

Assuming that the manager discounts future payoffs at a constant rate $r > 0$, his problem can be formulated as an optimal stopping problem,

$$
U^*(s_t) = \sup_{\tau \geq t} \mathbb{E}_t\left[e^{-r\tau}U(s_\tau)\right], \tag{2.5}
$$

where $\mathbb{E}_t$ denotes the expectation conditional on all information available up to and including time t, and the supremum is taken over stopping times.

Problem (2.5) has an analytical solution, which takes the form of a threshold policy: the manager should disclose the information as soon as the posterior belief exceeds a certain threshold belief p^*. Adapting the arguments in Thijssen et al. [52] to my setting, this threshold is derived fully in subsection 2.2.3.

2.2.3 Derivation of the Optimal Disclosure Policy

The critical value of the conditional belief in a positive market response to an announcement, denoted $p^* = p(s^*)$, is the point at which the manager is indifferent between disclosing the information and withholding it. That is, if $p_t > p^*$, the manager is confident that there will be a positive trading response to the announcement if disclosed. On the other hand, if $p_t < p^*$, the manager is not confident enough in a positive response and waits for more information to arrive.

In order to solve for p^*, the approach taken is to solve the optimal stopping problem (2.5) by examining two scenarios. The *stopping value*, denoted by $U(s_t)$ and given by (2.4), is the expected return to the firm from disclosing the information to the market immediately. This is the first scenario examined. Such a situation can arise for two reasons. Firstly, the signals the manager obtains regarding the firm's prospects (as a result of its investment) are generally all positive, and the manager wishes to inform the market of this. Alternatively, the signals may not be overwhelmingly positive, but the manager is aware that the market, on observing non-disclosure, may interpret this as the firm being in a worse state than it actually is. Hence, the manager decides to disclose information to the market to prevent the value of the firm being discounted too low. This is consistent with the observation by Healy and Palepu [21] that "voluntary disclosure theory hypothesises that managers use corporate disclosures to reduce the likelihood of undervaluation".

The alternative scenario is that it is optimal not to disclose immediately, but to wait for more signals to arrive. The value of the option, known as the *continuation value*, denoted by $C(s_t)$, represents the discounted expected value of the next piece of information.

Under this scenario I assume that it is not optimal for the manager to disclose the information immediately, but to wait for more signals, even if the most recent signal is positive, since overall, the signals are poor, and an announcement would (most likely) be interpreted negatively by the shareholders, leading to a downward revision in the market's valuation of the firm.

Since there are no cash-flows accruing from the disclosure option, $C(s_t)$ should satisfy the Bellman equation over a small interval of time dt,

$$C(s_t) = e^{-rdt}\mathbb{E}_t[C(s_{t+dt})]. \tag{2.6}$$

This equation says that the value of the option at time t should equal its discounted expected value at time $t + dt$, where the time interval dt becomes infinitesimally small. In a small time interval dt, no information is received by the manager with probability $1 - \mu dt$. On the other hand, information arrives with probability μdt. If information arrives, the value of the option jumps, either to $C(s_t + 1)$ if the information is deemed to signal a positive market reaction, or $C(s_t - 1)$ otherwise. Assuming that the current number of net signals is s_t (and, hence, that the current posterior belief in a positive market reaction is $p(s_t)$), this implies that (2.6) becomes

$$\begin{aligned} C(s_t) =&(1 - rdt)\Big\{(1 - \mu dt)C(s_t) + \mu dt\Big[p(s_t)[\theta C(s_t + 1) + (1 - \theta)C(s_t - 1)] \\ &+ (1 - p(s_t))[\theta C(s_t - 1) + (1 - \theta)C(s_t + 1)]\Big]\Big\} + o(dt). \end{aligned} \tag{2.7}$$

Substituting for $p(s_t)$ using (2.2), dividing by dt and taking the limit $dt \downarrow 0$, the following difference equation is obtained:

$$\hat{C}(s_t + 1) - \frac{r + \mu}{\mu}\hat{C}(s_t) + \theta(1 - \theta)\hat{C}(s_t - 1) = 0, \tag{2.8}$$

where

$$\hat{C}(s_t) := (\theta^{s_t} + \zeta(1 - \theta)^{s_t})C(s_t).$$

Equation (2.8) has a general solution given by

$$\hat{C}(s_t) = A_1\beta_1^{s_t} + A_2\beta_2^{s_t},$$

where A_1 and A_2 are constants and $0 < \beta_2 < 1 - \theta < \theta < \beta_1$ are the solutions to the fundamental quadratic:

$$\Psi(\beta) \equiv \beta^2 - \left(\frac{r}{\mu} + 1\right)\beta + \theta(1-\theta) = 0. \tag{2.9}$$

Therefore, the value of the disclosure option equals

$$C(s_t) = \frac{A_1\beta_1^{s_t} + A_2\beta_2^{s_t}}{\theta^{s_t} + \zeta(1-\theta)^{s_t}}.$$

Imposing several boundary conditions then leads to a solution for the unknowns A_1, and A_2. First of all, if $s_t \to -\infty$, the probability of the posterior belief ever reaching p^* goes to zero and, hence, the option becomes worthless. So, it should hold that $\lim_{s_t \to -\infty} C(s_t) = 0$. Since $0 < \beta_2 < 1 - \theta$ this implies that $A_2 = 0$. A second condition is that the value of the option should be continuous at s^*. The third boundary condition is another continuity condition that stems from the realisation that the point $s^* - 1$ is special. In deriving $C(s_t)$ it was (implicitly) assumed that after receiving the next signal disclosure still does not take place. But, for $s_t \in [s^* - 1, s^*)$, the manager knows that if the next signal indicates a positive market reaction, then disclosure should take place. Denoting the option value in the range $[s^* - 1, s^*)$ by CU, I show it to be given by

$$\begin{aligned} CU(s_t) =& \frac{\mu}{r+\mu}\Big\{[p(s_t)\theta + (1-p(s_t))(1-\theta)]U(s_t+1) \\ &+ [(1-p(s_t))\theta + (1-\theta)p(s_t)]C(s_t-1)]\Big\}. \end{aligned} \tag{2.10}$$

So, the value of the disclosure option is

$$U^*(s_t) = 1_{(s_t < s^*-1)}C(s_t) + 1_{(s^*-1 \leq s_t < s^*)}CU(s_t) + 1_{(s_t \geq s^*)}U(s_t).$$

This is a *free-boundary problem*, for which the constant A_1 and threshold s^* can be found by the continuity conditions $C(s^* - 1) = CU(s^* - 1)$ and $CU(s^*) = U(s^*)$. Solving in terms of $p^* := p(s^*)$ gives

$$p^* = \left[\frac{V^P - I}{I - V^N}\Pi + 1\right]^{-1}, \tag{2.11}$$

where

$$\Pi = \frac{\left(\beta_1(r+\mu) - \mu\theta(1-\theta)\right)\left(\frac{r}{\mu}+1-\theta\right) - \mu\theta(1-\theta)\beta_1}{\left(\beta_1(r+\mu) - \mu\theta(1-\theta)\right)\left(\frac{r}{\mu}+\theta\right) - \mu\theta(1-\theta)\beta_1} \tag{2.12}$$

and $\beta_1 > \theta$ is the larger (real) root of the quadratic equation (2.9).

I note that there is no guarantee that there exists an integer $s_t \in \mathbb{Z}$ such that $p^* = p(s_t)$. In other words, the optimal disclosure threshold in terms of net signals can be any real number. Since signals are integers this implies that the manager should wait until the posterior probability, driven by (2.2), exceeds p^*. In other words, the disclosure threshold in terms of net signals is $s^* = \lceil s(p^*) \rceil$.[2]

The following theorem asserts that the threshold given by (2.11) is the unique solution to the optimal stopping problem (2.5). Its proof is outlined in Appendix A.

Theorem 1. *The optimal stopping problem for the manager, $U^*(s_t) = \sup_{\tau \geq t} \mathbb{E}_t[e^{-r\tau}U(s_\tau)]$, is solved by*

$$U^*(s_t) = \begin{cases} U(s_t) & \text{if } s_t \geq s^* \\ \frac{\mu}{r+\mu}\left(\frac{\theta p(s_t)}{p(s_t+1)}U(s_t+1) + \left[\frac{r}{\mu(1-\theta)}\frac{U(s^*)}{p(s^*)} + \frac{U(s^*-1)}{p(s^*-1)}\right] \times \right. & \\ \left. (1-\theta)(\frac{\beta_1}{\theta})^{s_t-s^*}p(s_t)\right) & \text{if } s^*-1 \leq s_t < s^* \\ \left(\frac{\beta_1}{\theta}\right)^{s_t-s^*+1} p(s_t)\left[\frac{r}{\mu(1-\theta)}\frac{U(s^*)}{p(s^*)} + \frac{\Lambda(s^*-1)}{p(s^*-1)}\right] & \text{if } s_t < s^*-1. \end{cases} \tag{2.13}$$

where $U(s_t)$ is given by (2.4), $p(s_t)$ is given by (2.2) and $s^* := s(p^*)$, given by (2.3), is the critical number of positive in excess of negative signals above which the manager will disclose, and withhold his information otherwise.

Additionally, the optimal stopping time, τ^*, is given by

$$\tau^* = \inf\{t \geq 0 | s_t \geq s^*\}.$$

[2] For $s_t \in \mathbb{R}$, $\lceil s(p^*) \rceil := \min\{k \in \mathbb{N} | k \geq s_t\}$.

2.3 Properties of the Optimal Disclosure Policy

In this section I provide an insight into the main features that emerge from the manager's disclosure policy. The following proposition shows that the policy under the current (real options) approach gives a more stringent criterion on disclosure than the classical NPV approach demands; that is, the manager will wait longer before disclosing than under the NPV approach. The more stringent criteria is supported by Dixit and Pindyck [9], and the reasoning is that the classical NPV approach does not incorporate the opportunity cost of waiting for more informative signals to arrive through exercising the option immediately.

The manager's belief threshold under the classical NPV rule (disclose at the first time when the PV exceeds the cost of disclosure) is given by

$$p_{NPV} = \frac{I - V^N}{V^P - V^N}. \tag{2.14}$$

The proof that $p^* > p_{NPV}$ proof can be found in Appendix B.

Proposition 1. *The real options approach leads to a well-defined threshold probability, p^*, and requires a more stringent criteria on the timing of disclosure than the classical NPV approach would demand.*

The result of a comparative static analysis of the threshold, p^*, with respect to the model's key economic variables is given in the following proposition, the proof of which is obtained through simple calculus and is, therefore, omitted.

Proposition 2. *The threshold belief in a positive market response, p^*, decreases with V^P and V^N, and increases with I.*

These results are intuitive and are driven by the manager's policy to maximise firm value.

Similar to my paper, Suijs [50] shows that the unravelling argument leading to full disclosure need not apply when the firm is uncertain about investor response. In that paper, the firm's objective is to acquire as much of the investor's capital as possible. He assumes that the investor can invest in the firm, a risk-free asset, or some alternative risky investment project. While I do not make this assumption directly, implicit in my set-up is that any profit from disclosure is obtained through acquiring capital investment when the response to the disclosed information is positive. A lack of information may induce investors to opt for alternative investment opportunities. Therefore, the greater the impact an announcement will have on the positive value of the firm, that is, the higher V^P, the less time the manager will wait before he exercises his option to disclose the information. This is consistent with Suijs [50] who finds that a stronger positive response makes disclosure a more attractive option (to non-disclosure), and therefore, the firm can be less certain about the market reaction being positive for disclosure to be optimal.

Conversely, the greater the impact an announcement will have on a negative trading response, that is, the lower V^N, the longer the firm will wait before making a disclosure. Unlike Thijssen et al. [52], $V^N \neq 0$, and therefore, if the investors learn of bad news about the firm's stock, they will sell off some of their shareholdings and this lowers the valuation of the firm. Thus, it is straightforward to see why the firm conceals information that is likely to have a strong negative impact on the stock price. This is again corroborated by Suijs [50] who points out that a stronger negative response makes disclosure less attractive compared with nondisclosure, and thus, the firm must be more certain about being a good firm for disclosure to be optimal. However, if the news is unlikely to have a very strong negative impact, the manager will be more likely to disclose the information to prevent the market from inferring that the firm is in a worse state than it actually is. Graham et al. [17] conduct a comprehensive survey that asks CFOs to describe their choices related to reporting accounting numbers and voluntary disclosure and find that one advantage for releasing bad news is that it can help a firm to develop a reputation for providing timely and accurate information. CFOs place a great deal of importance on acquiring such a reputation: 92% of their survey respondents believe that developing a reputation for transparent reporting is a key factor motivating voluntary disclosures.

The greater the cost of making an announcement, the longer the manager chooses to wait before making an announcement. This is owing to the fact that if the (direct) costs of, say, preparing or disseminating information are high, the manager requires more time to confirm the accuracy of the information signals. By so doing, he obtains a stronger conviction about how the market will react to the news and the likelihood of making a wrong disclosure decision is reduced.

The comparative static result with respect to signal quality suggests that the more informative are the signals, the longer the manager will wait before disclosing his information; that is, the higher θ, the higher p^*. The proof of the following proposition can be found in Appendix C.

Proposition 3. *The threshold belief in a positive market response, p^*, increases with θ.*

In the context of my model, the more informative are the signals, the less uncertainty the manager has regarding the impact from his disclosure choice. However, the comparative static result with respect to θ appears to be at odds with the intuitive and, indeed, widely accepted result in real options literature, that an increase in uncertainty should have an inhibiting effect on disclosure. In other words, standard results (Dixit and Pindyck [9], McDonald and Siegel [33], etc.) imply that we would expect that the more informative are the signals, the earlier disclosure will occur. However, in the standard framework, all of the uncertainty inherent in the model is captured by one parameter, namely the variance, whereas in my model, the uncertainty arises not only through the quality of the information signal, θ, but also through the (random) arrival times of the information signals, μ, and more specifically, the manager's uncertainty regarding how the market will interpret the information if disclosed. This latter effect is a latent variable, and thus cannot be measured. While a higher quality signal will reduce the manager's uncertainty as to the likely market response, for reasons discussed in Section 2.2.1, it will never be eliminated entirely. It is the combination of these effects that drive the uncertainty in this model and thus, obtaining an unambiguous conclusion on what the uncertainty effect should be is not trivial.

In order to understand why a negative relationship exists between the information quality of signals and the optimal disclosure threshold, p^*, I examine the probability that disclosure will take place (i) when the true state of the world is a negative market response and (ii) when the true state of the world is a positive market response. An increase in this probability corresponds with a lower disclosure threshold. My reasoning for examining the probability of disclosure is motivated by Sarkar [41] who suggests that in order to gauge the overall effect of uncertainty on the level of investment, one can look at the probability that investment will take place within a specified time period. I note, however, that Sarkar [41] examines the investment-uncertainty relationship for the standard real options model where uncertainty is constant over time.

Firstly, I assume that the true state of the world is a negative market response ($\gamma = 0$). The probability that the threshold, s^*, is reached, and thus that the manager will disclose is given by

$$P^{(s^*)}(s_t) := \left(\frac{\theta}{1-\theta}\right)^{s_t - s^*}, \tag{2.15}$$

where $s_t < s^*$. I give the derivation of this result in Appendix F. Since $s_t < s^*$, the probability of disclosure decreases when the quality of the signals increases.

Intuitively this is sensible: if the true state of the world is a negative market response and if the signal quality is high, implying the manager is obtaining accurate, but negative signals, the likelihood he will disclose quickly decreases and the disclosure threshold, p^*, will be higher.

On the other hand, if the true state of the world is a positive market response ($\gamma = 1$), the probability that the manager will disclose before a finite time T is given by

$$\widetilde{P}^{(s^*)}(s_t) := \int_0^T f_{s^*}(t)dt, \tag{2.16}$$

where $f_s(t)$ is the *unconditional* density of first passage times and is given by

$$f_s(t) = \left(\frac{\theta}{1-\theta}\right)^{-\frac{s_t}{2}} \frac{s_t}{t} I_{s_t}\left(2\mu\sqrt{\theta(1-\theta)}t\right) e^{-\mu t}. \tag{2.17}$$

$I_{s_t}(\cdot)$ denotes the modified Bessel function with parameter s_t (see Appendix F).

I demonstrate in Figure 2.1 that this probability is an increasing function of θ.[3] Hence, when the true state of the world is a positive market response, and the information quality is high, the probability that disclosure will occur increases, or equivalently, fewer positive (over negative) signals are required to make disclosure an attractive option. This is intuitive.

However, concerning the comparative statics with respect to θ, Proposition 3 asserts that p^* increases in θ. This arises from the fact that for certain combinations of θ with the other parameter values, a low value of s^* can be associated with a high value of p^* (see Figures 2.2 and 2.3), that is, the threshold belief is reached after fewer positive signals have been obtained. This can occur if, for example, one highly accurate and very positive signal is obtained. s_t will only change by $+1$, but the likely impact of such information on the firm's value through a positive market

[3]The parameterisation is as follows; $V^P = 15$, $V^N = -10$, $I = 5$, $r = 0.04$ and $\mu = 4$. This parameterisation is used for all figures in this chapter, unless otherwise stated.

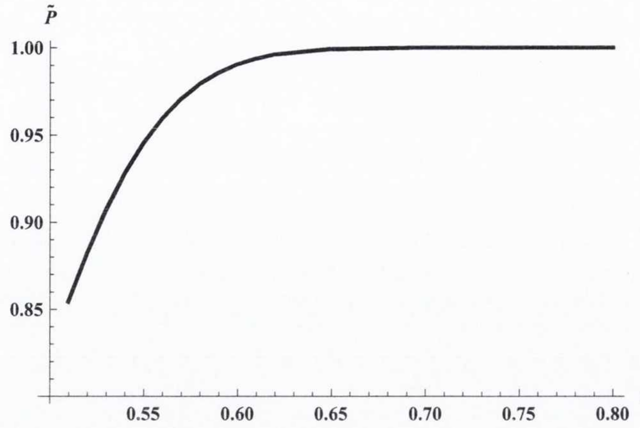

Figure 2.1: Probability of disclosure for $\gamma = 1$.

response may be so strong that the manager's belief variable p_t will "jump" upwards by an amount such that p^* is reached.

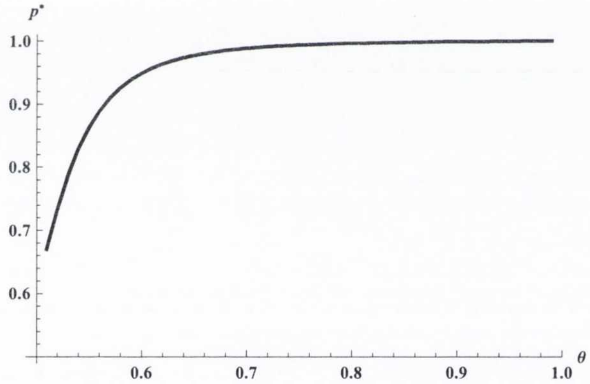

Figure 2.2: Comparative statics for p^* with respect to θ

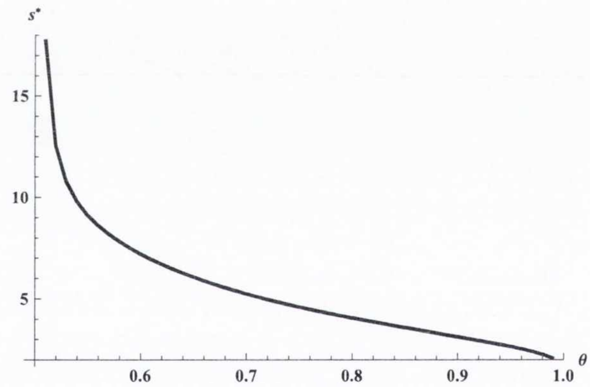

Figure 2.3: Comparative statics for s^* with respect to θ

Finally, it is possible to say something about the frequency of information arrival on the optimal disclosure policy. Unfortunately, it is not possible to determine the direction of the relationship between p^* and the arrival rate, μ, unambiguously. Therefore, I use numerical simulation results to ascertain the direction of the relationship. From Figure 2.4, we see that p^* is increasing in the arrival rate (for one set of parameter values). I repeatedly carried out these computations for a wide range of parameter values, and can confirm that this result is robust to a wide choice of values. Hence, for reasonable parameter values, I can conclude that p^* increases in μ which, in turn, implies that it decreases in the expected time between signal arrivals.[4]

Einhorn and Ziv [12] examine corporate voluntary disclosures in a multi-period setting. They conclude that inter-temporal dynamics occur because a firm's use of their private information is assumed to be history dependent.

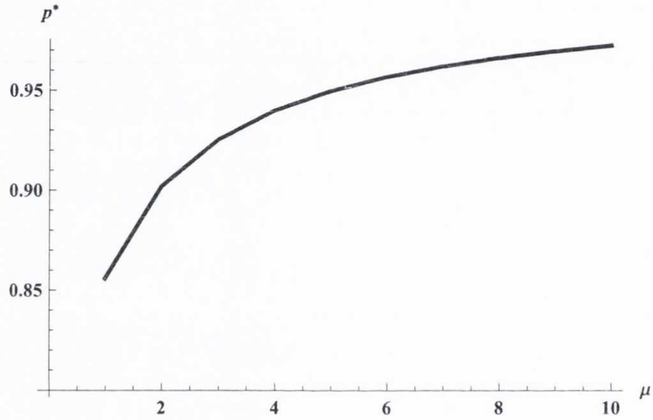

Figure 2.4: Comparative statics of μ with $\theta = 0.6$ and $r = 0.04$, fixed.

Their multi-period model demonstrates that by providing current disclosure, the manager increases the firm's implicit commitment to provide similar disclosures in the future. Thus, in the absence of disclosure, the market is likely to infer that the manager possesses negative information which they consider too unfavourable to disclose and will consequently revise down their expected valuation of the firm accordingly. My model supports their result, and goes a step further by showing that in the absence of disclosure as a direct consequence of receiving few, or no, signals (as opposed to receiving bad information), the manager will opt to disclose at a

[4]Dixit and Pindyck [9] show that $\mathbb{E}[T] = \int_0^\infty \mu T e^{-\mu T} dT = \frac{1}{\mu}$.

lower threshold in an attempt to temper the market's uncertainty and to prevent it from inferring that the firm must be withholding some negative information. The result is further supported by anecdotal evidence. Graham et al. [17] find that executives believe that lack of clarity, or a reputation for not consistently providing timely and accurate information, can lead to under-pricing of a firm's stock. Their survey evidence suggests that 48.8% of CFOs use voluntary disclosures to correct an undervalued price. Moreover, Healy and Palepu [21] observe that managers use corporate disclosures to reduce the likelihood of undervaluation.

2.4 Debt and Voluntary Disclosure

In this section I present an example of a situation where the Modigliani–Miller theorem on the irrelevance of capital structure is violated. In practice, exceptions to the theorem are widely observed in many areas of finance. For example, aggregate debt growth rates are known to be pro-cyclical for households and firms. With respect to the current setting of disclosure theory, Ahmed and Courtis [1] conduct an empirical study on factors affecting the level of voluntary disclosure using leverage as an explanatory variable. In particular, they show that companies with capitalisation structures showing higher proportions of fixed interest securities relative to equity are significantly associated with the release of higher quantities of informational disclosure.

Explanations for the observed violations to the theorem usually rely on some form of market imperfection, including agency costs, tax distortions, and so on. Using ideas regarding value of waiting that have been formalised in real options theory, I show that if a disclosure option resides with the manager, his optimal disclosure strategy is affected by the form of capital structure. In particular, my main finding corroborates with Ahmed and Courtis [1] in that the amount of information disclosed is positively related to leverage. While they assert that this leverage-based association may be related to corporate size, in that larger companies tend to use proportionally higher amounts of fixed interest securities as a financing technique because of the tax advantages, my reasoning is owing to the lower downside risk afforded by limited liability. However, their assertion of corporate size is only one explanation for the observed link, and this is owing to their choice of explanatory variables. However, adopting a broader interpretation of their result, there is nothing to suggest that limited liability does not play a part in establishing this causation in their setting, and thus, my model may provide an adequate theoretical explanation for their empirical result.

In terms of adapting the benchmark model, I consider how the manager's disclosure policy is affected when some of the sunk costs associated with disclosure are financed with debt. As in Section 2.2, I assume that the manager is compensated via stock options and that he is given complete discretion about the disclosure policy he adopts.

Typically, it may not be realistic to assume that some of the disclosure costs are financed with debt since the relative magnitude of such costs are too small to warrant such an assumption as being plausible. However, the disclosure aspect of whether to reveal the news about the project is still a contributor to the overall project's profitability through V^P, V^N, and I, and thus disclosure is simply a compound option (an option problem within a bigger option problem) which is beyond the scope of this section. If there is an injection of debt which generally funds the project's sunk costs, some of which are obviously made up of the sunk disclosure costs, then in that sense, debt is, at least partially, funding the disclosure. The idea for the coupon rate is similar; that is, part of the payoff from disclosure, if impact is V^P, is used to repay the debt via the coupon payment and if impact is V^N then none of the disclosure payoff goes toward the debt obligation.

The main reason for the association between debt and disclosure relates to the manager-lender conflict. Without debt, in an all equity firm, the manager incurs both upside and downside risk from making a disclosure. However, with debt, the manager's downside risk is limited, in that some of the sunk costs of disclosure are covered, and the lender is assumed to have first claim on revenues obtained from disclosure up to a fixed coupon, C, which the lender determines. This may provide the manager with *ex post* incentives to make decisions that are not in the lender's best interest. For example, the manager may opt to disclose some negative information about the prospects of the firm if he wishes to discourage other players from entering the market. Recognising this possibility, the lender demands a higher interest rate on the loan which implies a higher coupon payment.

The manager's objective is still to maximise his (discounted) expected utility from wealth, which is equivalent to maximising firm value owing to the compensation assumption, and the lender adopts a zero profit condition. The disclosure problem is then to determine an equilibrium belief level, p_d^{**}, such that, simultaneously, the manager's and the lender's objectives are satisfied, for a given level of debt. I further show how the disclosure policy changes as the debt level changes.

2.4.1 Manager's Problem

The manager gains when the firm's payoff from disclosure exceeds its debt obligation, and suffers a loss otherwise. However, he suffers far less damage if his payoff falls just short, or way short, of the debt obligation, than if all of the disclosure cost was financed with equity.

Denote by $0 < D \leq I$ the firm's only debt payment. I assume that if the response to disclosure is negative, and consequently, the impact on firm value is V^N, the firm defaults on its loan; that is, $V^N - (I - D) < 0$. In the event of a default, the payment to the lender is 0 and the manager suffers by the amount $V^N - (I - D) > V^N - I$. On the other hand, if the response is positive, the impact on firm value is V^P and I assume that the manager can meet his debt obligation. This implies that $V^P - (I - D) - C \geq 0$ and the lender is paid C while the manager retains the residual $V^P - I + D - C \geq 0$.

The expected change in value from disclosure at time t, conditional on p_0, is given by

$$\begin{aligned} U^D(s_t) =& p(s_t)(V^P - I + D - C) + (1 - p(s_t))(V^N - (I - D)) \\ =& p(s_t)(V^P - C) + (1 - p(s_t))V^N - (I - D), \end{aligned} \tag{2.18}$$

where $p(s_t)$ is given by equation (2.2).

Solving for the optimal threshold, via an optimal stopping approach (see subsection 2.2.3) yields the optimal threshold, when some of the cost is financed with debt, and this is given by

$$p_d^* = \left[\frac{V^P - C - (I - D)}{(I - D) - V^N} \Pi + 1 \right]^{-1} \tag{2.19}$$

where Π is given by equation (2.12). Moreover, (2.19) is a well-defined probability, if, and only if, $(I - D) \leq (V^P - C)$, which is satisfied.

2.4.2 Lender's Problem

In this subsection, the problem is outlined from the lender's perspective. Similar to Subarwal [48] (who adapts the more standard model of real options, (see Dixit and Pindyck [9]; McDonald and Siegel [33]) to include a competitive lending sector), I assume that the lender adopts a zero profit condition. Hence, he gets C with probability p_{l_t} and zero otherwise. Thus, his profit is given by

$$\pi_t^l = p_{l_t} C - D. \tag{2.20}$$

Note that p_{l_t} denotes the lender's belief, at time t, about the state of the firm. The lender acts to attain the zero profit condition implying

$$p_l^* = \frac{D}{C} \tag{2.21}$$

which is a well-defined probability if, and only if, $D \leq C$. This implies that he will only lend to the firm, to help them finance their disclosure policy, if he is sufficiently well compensated for the likelihood that the firm will default on its debt obligation if they adopt a very transparent disclosure policy; that is, he will only lend to the manager if he is prepared to pay a coupon which exceeds the amount of debt he is given.

2.4.3 Equilibrium

For a given level of debt, I want to find a coupon, C^*, such that $p_d^* = p_l^*$; that is, the manager's belief threshold about when to disclose is equal to the lender's belief threshold about when to lend. Equating equations (2.19) and (2.21) and solving for the coupon level C^* yields

$$C^* = \frac{D\Big((V^P - I + D)\Pi + (I - D - V^N)\Big)}{D\Pi + (I - D - V^N)} \tag{2.22}$$

implying that the equilibrium belief threshold for the manager, and indeed the lender, is given by

$$p_d^{**} = \left[\frac{V^P - C^* - (I - D)}{(I - D) - V^N}\Pi + 1\right]^{-1}. \tag{2.23}$$

The main findings from an analysis of this equilibrium threshold are given in Proposition 4 and Proposition 5 below. The proofs are outlined in Appendices D and E, respectively.

Proposition 4. *The equilibrium belief, p_d^{**}, is a well-defined probability.*

Proposition 5. *In equilibrium, the manager will disclose earlier, when some of the financing comes from debt, than if all of the disclosure was financed with equity; that is* $p_d^{**} < p^*$. *Moreover, the greater the level of debt obtained, the lower the threshold above which the manager will disclose, in equilibrium.*

Firstly considering the manager's optimal disclosure policy, it has been shown in Proposition 5 that to the extent that debt reduces the manager's disclosure cost, and that limited liability reduces his downside risk, the disclosure threshold is lower. This is owing to the fact that, with debt, the manager is likely to prefer a riskier and more transparent disclosure policy because his downside risk is limited; that is, the loss he may incur from a negative response reduces with the level of debt he obtains.

However, on the other hand, to the extent that the lender anticipates the likelihood that the response to disclosure will be negative, and thus, the manager defaults on his debt, he demands a coupon that compensates him for this risk. Thus, the manager's payoff from disclosure decreases in the coupon payment demanded, as does his belief threshold in equilibrium, p_d^{**}. Hence, the higher the coupon payment, *ceteris paribus*, the longer the manager waits before disclosing as he requires greater conviction that a positive response will ensue.

Overall, in equilibrium, one might intuitively expect that after compensating the lender for expected default losses, the net effect of such debt financing on the optimal disclosure threshold is zero. However, I find that, in fact, the net effect is negative; that is, the coupon payment demanded is not so high that the manager requires even greater conviction before disclosing that the response will be positive than if all his financing arose from equity.

My reasoning for this result is the following: The disclosure threshold is affected by three main components; the manager's share of the disclosure cost, $I - D$, the value that goes to the lender that arises directly from disclosure, and an additional impact of limited liability on the downside risk of making a disclosure. The lender's zero profit condition implies that the reduction in the manager's share of the cost is exactly offset by the value obtained by the lender. Therefore, the net effect on the disclosure policy is the impact of limited liability. With limited liability, some of the downside risk (that is, the risk of a loss in firm value owing to a negative response to disclosure) is transferred to the lender, and from the manager's perspective, his own lower tail of risk curtailed. Stated another way, in the presence of limited liability debt financing, waiting for more favourable signals is valuable, but not as much as it is in the standard case, essentially because adverse realisations to firm value after disclosure (owing to a negative market response) are marginally less costly for the firm. Hence the manager adopts a more transparent disclosure policy; that is, the optimal threshold is lower.

2.5 Conclusion

This chapter shows how adopting a real options approach can aid our understanding of corporate voluntary disclosure. The concept of a disclosure option is proposed and in this way the corporate disclosure literature is linked together with the real options literature. The decision to disclose, or withhold, information is strategic on the part of the firm. This implies that the manager will only announce the information if he is sufficiently certain that the market response to the information will have a positive impact on the value of the firm, and thus, on his own utility from wealth. I derive, and analyse, via a real options framework, an analytical expression for the manager's threshold belief in a positive market response to the disclosed information. I show that the approach taken in this chapter demands a higher threshold belief in a positive market response than under the classical NPV approach.

In an extension to the benchmark model I show that the Modigliani–Miller theorem on irrelevance of capital structure on firm value is violated in the instance of corporate disclosure. When some of the disclosure cost is financed with debt, the manager adopts a lower disclosure threshold owing to the limited liability aspect of debt which dominates the loss incurred by the manager through compensating the lender for expected default losses.

To conclude, there are two points worth noting with regard to relevant issues which are absent in the analysis. The first is that the market for voluntary disclosure is assumed to be complete; that is, the payoff to the manager from making a disclosure voluntarily may be perfectly replicated through trading with existing marketed securities. However, this assumption is at odds with reality, and therefore, an examination of the same problem, but under the assumption of incomplete markets, could have an interesting effect on the current results. The second aspect worth noting is that the manager does not face any competitive pressure whilst deciding on an optimal disclosure policy. Once again, this assumption is an abstraction from reality, and I examine this issue in detail in Chapter 3.

Appendix

A Proof of Theorem 1

Denote the stopping set by $D = \{p_t \in (0,1) | U^*(s_t) = U(s_t) \text{ and } s_t \geq s^*\}$, the continuation set by $C = \{p_t \in (0,1) | U^*(s_t) > U(s_t) \text{ and } s_t < s^* - 1\}$ and the "intermediate set" by $I = \{p_t \in (0,1) | U^*(s_t) > U(s_t) \text{ and } s^* - 1 \leq s_t < s^*\}$. In order for U^* to solve the free-boundary problem, it must hold that (i) $\mathscr{L}_{s_t} U^* = 0$ in

C, (ii) $U^*(s^*) = U(s^*)$ in I, and (iii) $U^*(s^*-1)$ in C is exactly equal to $U^*(s^*-1)$ in I (see Peskir and Shiryaev [37] pp. 143).

(i)

$$ds_t = \begin{cases} 0 & \text{w. p. } 1-\mu dt \\ 1 & \text{w. p. } \mu dt[\theta p + (1-\theta)(1-p)] \\ -1 & \text{w. p. } \mu dt[\theta(1-p) + (1-\theta)p]. \end{cases} \tag{A.1}$$

The infinitesimal generator is given by

$$\begin{aligned} \mathscr{L}_{s_t} U^*(s_t) =& \lim_{dt\downarrow 0} \frac{\mathbb{E}[U^*(s_t) - U(s_t)]}{dt} \\ =& -rU^*(s_t) + \lim_{dt\downarrow 0} \frac{1}{dt}\mathbb{E}[dU^*(s_t)]. \end{aligned} \tag{A.2}$$

But

$$\begin{aligned} \lim_{dt\downarrow 0} \frac{1}{dt}\mathbb{E}[dU^*(s_t)] =& \mu\left[\theta p(s_t) + (1-\theta)(1-p(s_t))\right] U^*(s_t+1) \\ &+ \mu\left[\theta(1-p(s_t)) + (1-\theta)p(s_t)\right] U^*(s_t-1) \\ &- \mu U^*(s_t). \end{aligned} \tag{A.3}$$

Substituting this into (A.2), and rearranging, yields

$$\begin{aligned} \mathscr{L}_{s_t} U^*(s_t) =& \Big[\frac{r}{\mu(1-\theta)}\frac{U(s^*)}{p(s^*)} + \frac{U(s^*-1)}{p(s^*-1)}\Big]\left(\frac{\beta_1}{\theta}\right)^{s_t-s^*}\frac{p(s_t)}{\theta}\times \\ &\Big(\mu\beta_1^2 - (r+\mu)\beta_1 + \mu\theta(1-\theta)\Big). \end{aligned} \tag{A.4}$$

From this it is clear that $\mathscr{L}_{s_t} U^*(s_t) = 0$ if and only if

$$\beta_1^2 - (\frac{r}{\mu}+1)\beta_1 + \theta(1-\theta) = 0. \tag{A.5}$$

Since the fundamental quadratic associated with the Bellman equation is given by (A.5), (i) is verified.

(ii) In I (where $s^*-1 \le s_t < s^*$),

$$\begin{aligned} U^*(s^*) =& \frac{\mu}{r+\mu}\Big(\theta p(s^*)\frac{U(s^*+1)}{p(s^*+1)} + \frac{r}{\mu}U(s^*) + (1-\theta)\frac{p(s^*)}{p(s^*-1)}U(s^*-1)\Big) \\ =& \frac{\mu}{r+\mu}\frac{p(s^*)}{\theta^{s^*}}\Big(U(s^*+1)(\theta^{s^*+1} + \zeta(1-\theta)^{s^*+1}) \\ &+ \theta(1-\theta)\beta_1^{s^*-1}A_1\Big), \end{aligned} \tag{A.6}$$

where

$$A_1 = \frac{1}{\theta(1-\theta)\beta_1^{s^*-1}} \left[\theta^{s^*}\left(\frac{r}{\mu} + (1-\theta)\right)(V^P - I) + \zeta(1-\theta)^{s^*}\left(\frac{r}{\mu} + \theta\right)(V^N - I)\right].$$

Using equation (2.11) to substitute for $p(s^*)$, and after some algebraic manipulation, the expression reduces to $U(s^*)$, as required.

(iii) The continuity condition is verified by the following argument:

For $s_t < s^* - 1$ (i.e. in C),

$$\begin{aligned} U^*(s^*-1) =& p(s^*-1)\left[\frac{r}{\mu(1-\theta)}\frac{U(s^*)}{p(s^*)} + \frac{U(s^*-1)}{p(s^*-1)}\right] \\ =& p(s^*-1)A_1\frac{\beta_1^{s^*-1}}{\theta^{s^*-1}} \\ =& \frac{A_1\beta_1^{s^*-1}}{\theta^{s^*-1} + \zeta(1-\theta)^{s^*-1}}. \end{aligned} \tag{A.7}$$

Alternatively, for $s^* - 1 \leq s_t < s^*$, (i.e. in I)

$$\begin{aligned} U^*(s^*-1) =& \frac{\mu\theta}{r+\mu}\left(p(s^*-1)\frac{U(s^*)}{p(s^*)}(1 + \frac{r}{\mu\beta_1}) + \frac{1-\theta}{\beta_1}\Lambda(s^*-1)\right) \\ =& \frac{\mu}{r+\mu}\Big(\left(\theta p(s^*-1) + (1-\theta)(1-p(s^*-1))\right)U(s^*) \\ & + \theta(1-\theta)\frac{A_1\beta^{s^*-2}}{\theta^{s^*-1} + \zeta(1-\theta)^{s^*-1}}\Big) \\ =& \frac{\mu}{r+\mu}\Big(\left(\theta p(s^*-1) + (1-\theta)(1-p(s^*-1))\right)U(s^*) \\ & + \left(\theta(1-p(s^*-1)) + (1-\theta)p(s^*-1)\right) \times \\ & \frac{A_1\beta^{s^*-2}}{\theta^{s^*-2} + \zeta(1-\theta)^{s^*-2}}\Big) \end{aligned} \tag{A.8}$$

By appropriate substitution for A_1 and $p(s^*)$, it can be verified that equations (A.7) and (A.8) are equal, as required. ■

B Proof of Proposition 1

First, I show that p^*, given by (2.11), is a well-defined probability.

$p^* > 0$ if, and only if, $\Pi > 0$, where Π is given by equation (2.12). If $r = 0$, from equation (2.9), $\beta_1 = \theta$, and $\Pi = 0$; i.e. the numerator of (2.12) is zero. Hence $p^* = 1 > 0$.

Finding the total derivative of the numerator of Π, denoted $n(\Pi)$, with respect to r yields:

$$\begin{aligned}\frac{\partial n(\Pi)}{\partial r} =& \frac{\partial n(\Pi)}{\partial r} + \frac{\partial n(\Pi)}{\partial \beta_1}\frac{\partial \beta_1}{\partial r} \\ =& \frac{1}{\mu}\Big(\beta_1(r+\mu) - \mu\theta(1-\theta)\Big) + \beta_1\Big(\frac{r}{\mu} + 1 - \theta\Big) \\ &+ \frac{\partial \beta_1}{\partial r}\Big((r+\mu)\left(\frac{r}{\mu} + 1 - \theta\right) - \mu\theta(1-\theta)\Big)\end{aligned}$$

This expression is positive since $r > 0$, $\beta_1 > \theta$ and, trivially, $\frac{\partial \beta_1}{\partial r} > 0$.

Therefore $n(\Pi) > 0$.

On the other hand, when $r = 0$, the denominator of Π, denoted $d(\Pi)$, is $\theta\mu^2(2\theta - 1) > 0$, since $\theta > \frac{1}{2}$ by assumption. Furthermore

$$\begin{aligned}\frac{\partial d(\Pi)}{\partial r} =& \frac{\partial d(\Pi)}{\partial r} + \frac{\partial d(\Pi)}{\partial \beta_1}\frac{\partial \beta_1}{\partial r} \\ =& \frac{1}{\mu}\Big(\beta_1(r+\mu) - \mu\theta(1-\theta)\Big) + \beta_1\Big(\frac{r}{\mu} + \theta\Big) \\ &+ \frac{\partial \beta_1}{\partial r}\Big((r+\mu)\left(\frac{r}{\mu} + \theta\right) - \mu\theta(1-\theta)\Big) > 0.\end{aligned}$$

Therefore $d(\Pi) > 0$.

This proves that $\Pi > 0$ and $p^* > 0$.

$p^* \leq 1$ if, and only if, $\Pi \geq 0$. Indeed, $\Pi \geq 0$, since $r \geq 0$, and thus $p^* \leq 1$.

Hence, p^*, given by equation (2.11), is well-defined.

Moreover, $p^* > p_{NPV}$, where p_{NPV} denotes the belief threshold when the benefits from disclosure are exactly equal to the (direct) costs incurred. Thus it is obtained by solving for p_t when $U(s_t) = 0$, such that $U(s_t)$ is given by (2.4). Hence

$$p_{NPV} = \frac{I - V^N}{V^P - V^N}. \tag{B.1}$$

An algebraic manipulation shows that $p^* > p_{NPV}$ if, and only if,

$$\Pi < 1.$$

Again, an algebraic manipulation shows that

$$\Pi < 1$$

$$\Longleftrightarrow 1 - \theta < \theta,$$

which is satisfied, since $\theta > \frac{1}{2}$. ■

C Proof of Proposition 3

From equation (2.11), it is easily obtained that $\frac{\partial p^*}{\partial \theta} > 0$ if, and only if, $\frac{\partial \Pi}{\partial \theta} < 0$, where Π is given by (2.12).

To determine the sign of $\frac{\partial \Pi}{\partial \theta}$, one only needs to compare $\frac{\partial}{\partial \theta}(\frac{r}{\mu} + 1 - \theta)$ with $\frac{\partial}{\partial \theta}(\frac{r}{\mu} + \theta)$. Since these derivatives have opposite signs, and $\beta_1(r+\mu) - \mu\theta(1-\theta) > 0$, it is indeed the case that $\frac{\partial \Pi}{\partial \theta} < 0$.

Therefore, $\frac{\partial p^*}{\partial \theta} > 0$. ■

D Proof of Proposition 4

It is easily established that p_d^{**}, given by equation (2.23), is well-defined if, and only if, $C^* \leq V^P - I + D$, where C^* is given by equation (2.22).

This condition is adhered to when

$$\frac{D\Big((V^P - I + D)\Pi + (I - D - V^N)\Big)}{D\Pi + (I - D - V^N)} \leq V^P - I + D. \tag{D.1}$$

Algebraic manipulation reduces the expression (D.1) and $C^* \leq V^P - I + D$ holds once

$$-(I - D - V^N)(V^P - I) \leq 0.$$

This is satisfied since $V^P \geq I$ and $I - D - V^N > 0$, by assumption. ∎

E Proof of Proposition 5

$p_d^{**} < p^*$ if, and only if,

$$\frac{I - V^N}{V^P - V^N} < \frac{D}{C^*}, \tag{E.1}$$

where C^* is given by equation (2.22).

After substituting for C^*, an algebraic manipulation reduces this expression to the condition that (E.1) holds if

$$\Pi > \frac{V^N - (I - D)}{V^P - V^N + D},$$

where Π is given by equation (2.12).

As shown in Proposition 1, $\Pi > 0$. Additionally, $V^N - (I - D) < 0$ and $V^P - V^N + D > 0$, by assumption. Hence, the condition is satisfied. Thus, $p_d^{**} < p^*$.

It is, therefore, trivially satisfied that $\frac{\partial p_d^{**}}{\partial D} < 0$. If $D = 0$, $p_d^{**} = p^*$. For $D > 0$, it has just been shown that $p_d^{**} < p^*$. Hence, p^{**} decreases in D. ∎

F Derivation of the Probability of Disclosure

In order to derive the probability that disclosure occurs when the true state of the world is a negative market response, I define

$$P^{s^*}(s_t) := \mathbb{P}(\exists_{t \geq 0} : s_t \geq s^* | s_0 = s_t, \gamma = 0). \tag{F.1}$$

For $s_t < s^*$, a second order linear difference equation can be obtained governing $P^{s^*}(s_t)$. (Of course, $P^{s^*}(s_t) = 1$ for $s_t \geq s^*$. From s_t, the process reaches either $s_t + 1$ or $s_t - 1$ with probabilities $1 - \theta$ and θ, respectively, given that $\gamma = 0$. Thus

$$P^{s^*}(s_t) = (1-\theta)P^{s^*}(s_t + 1) + \theta P^{s^*}(s_t - 1). \tag{F.2}$$

Using the boundary conditions that $P^{s^*}(s^*) = 1$ and $\lim_{s_t \to -\infty} P^{s^*}(s_t) = 0$, a solution for (F.2) can be obtained and is given by

$$P^{s^*}(s_t) = \left(\frac{\theta}{1-\theta}\right)^{s_t - s^*}. \tag{F.3}$$

On the other hand, the probability that disclosure will occur given the true state of the world is a positive market response is

$$\begin{aligned} \widetilde{P}^{s^*}(s_t) :=& \mathbb{P}(\exists_{t\in[0,T]} : s_t \geq s^* | s_0 = s_t, \gamma = 1) \\ =& \int_0^T f_{s^*}(t)dt, \end{aligned} \tag{F.4}$$

where $f_s(t)$ is the *unconditional* density of first passage times and is given by

$$f_{s_t}(t) = \left(\frac{\theta}{1-\theta}\right)^{-\frac{s_t}{2}} \frac{s_t}{t} I_{s_t}\left(2\mu\sqrt{\theta(1-\theta)}t\right) e^{-\mu t}. \tag{F.5}$$

$I_{s_t}(\cdot)$ denotes the modified Bessel function with parameter s_t.

This probability equals zero for $T = \infty$ since $\theta > \frac{1}{2}$. Hence $t \in [0, T]$ for $T < \infty$. Additionally the first passage times density is obtained from Feller [14].

Chapter 3

Valuing Voluntary Disclosure with Competitive Interactions using a Real Options Approach

3.1 Introduction

In Chapter 2, I propose the concept of a disclosure option, which is a real option available to a firm to voluntarily disclose information to the market. The option to disclose, or withhold, information is a strategic decision on the part of the firm, implying that the manager will only announce the information if he is sufficiently certain that the market response will have a positive impact on the firm's value. Therefore, a firm with an opportunity to make a disclosure is holding an option which is analogous to a financial option. When the manager discloses some private information to the investors, he exercises his option to disclose. By doing so, he gives up the possibility of waiting for newer information to arrive that might affect the desirability of the firm's stock, and hence, have a greater positive impact on its profitability. In this way the option to wait has value.

However, firms may not always have the option to delay or withhold its information disclosure. There can be occasions which make it imperative for a firm to disclose quickly, such as in the face of competition. They must then try to preempt disclosure by competitors, which could have a negative impact on their own profit, relative to the profit of a competing firm. Hence, there is a non-exclusivity feature inherent in a real option which is not associated with its financial counterpart. If, on the other hand, delay is feasible, the risk of disclosure by competing firms is a cost to delay. The manager of the firm must weigh this cost against the benefit(s) of waiting for new information when deciding on what his optimal disclosure strategy ought to be. In such a setting, one must conduct a game-theoretic analysis of equilibrium disclosure strategies.

I extend the analysis outlined in Chapter 2 to examine the impact of competition on the timing of corporate voluntary disclosure. In a competitive environment, a firm's decision about when to disclose is not only driven by the sunk cost of making a disclosure and the direct effect of doing so on current and future payoffs through the market's reaction, but also by an indirect effect of imperfect competition. By disclosing, a firm affects its rival's payoffs and thus its disclosure timing decision which, in turn, affects the firm's own payoffs.

This research primarily touches on two streams of literature; the literature that deals with voluntary disclosure and the literature that addresses the non-exclusivity feature inherent in a real option, in particular, the issue of imperfect competition. While corporate voluntary disclosure has become an important and topical area of research in recent years, particularly in the accounting literature (see Verrecchia [54] for a detailed discussion), there have been very few real option applications concerned with voluntary disclosure and none, as far as I am aware, concerning competitive interactions between firms in determining equilibrium exercise policies from a real options perspective. Therefore, such an analysis should provide an interesting and useful contribution to the literature.

In terms of the competitive aspect of voluntary disclosure, the literature deals with the dilemma with regard to information sharing between firms. According to Bettis [5], "much of the information that would make cash-flow more forecastable for the shareholder is the same information that is competitively valuable. Typical examples include detailed discussions of strategy, new product characteristics, market share objectives, new process innovations and plant costs and capacities". Furthermore, "the information that investors need to forecast future cash-flow with less uncertainty is the same information a competitor may be able to use to thwart the realisation of this cash-flow. Thus, information disclosure becomes a trade-off with investors and competitors working at cross purposes".

Models in which competitive issues give rise to a preference for withholding disclosures include Gal-Or [16], Li [30], and Spulber [45]. A key finding in these studies is that the particular form of competition (Bertrand versus Cournot) can have a substantial influence on the firm's ex ante preference for disclosure.

In terms of real option applications concerned with competitive equilibrium in exercise policies, the literature is relatively scant. Furthermore, the application of game theory to continuous-time models is not very well developed, and can be quite difficult to implement. However, from the literature that does exist, the generalisation of the real option approach to include competitive equilibrium exercise strategies appears to provide very different implications from the standard monopoly setting. For example, one of the most well known results in the real options literature is the invalidation of the classical NPV rule of investment. However, the inclusion of competitive access to an investment opportunity leads to a rapid erosion in the value of the option to wait, making the standard NPV rule a much more accurate description of the actual investment threshold.

This typical result is shown clearly in a basic example provided by Dixit and Pindyck [9]. The example they present is based on Smets [43] and essentially it demonstrates the tradeoff between the value of waiting and the fear of preemption by a rival which suggests the need to invest sooner. The parameters of the model determine which of these considerations holds most weight.

This paper most closely resembles Thijssen et al. [53] from the perspective of real options analysis. However, the crucial difference, in terms of technicalities, is that they assume that the value of an unprofitable outcome from option exercise is always zero, while this paper does not make such an assumption and allows for a negative impact from option exercise. By not relaxing the negative impact assumption, the current paper makes a noteworthy contribution in that it shows how a new equilibrium emerges whereby preemption is nonsensical. This so-called "synergistic" equilibrium implies that the optimal strategies of a firm is to never announce, or else to do so only at the same time as its competitor; that is, simultaneous disclosure.

In this chapter I consider two firms whose managers each have the opportunity to disclose to the market some private information about the profitability of a product, or technology, in which each firm has invested. Information signals indicating the strength of the product's profitability are obtained by the managers at random points in time. Hence, disclosing the signals will impact positively or negatively on the value of their respective firms. I assume that prior to disclosure, the market is unaware that the firm has invested in the product. Thus, signal disclosure is analogous to disclosing that they have made an investment in the product.

In Chapter 2, a threshold is derived on the *probability* of a positive shareholder response, above which the manager will opt to make an announcement and otherwise withhold the information from the market. The problem is solved as an optimal stopping problem by examining a number of scenarios whereby the manager has the option to disclose some set of signals to the market. In this chapter I use that threshold as a benchmark to examine how the influence of competition (in a duopoly framework) impacts on the disclosure timing decision of a firm. I find that a preemption, attrition, or synergy equilibrium arise, depending on the trade-off between first and second mover advantages and, also on the advantage from simultaneous disclosure.

This chapter is arranged as follows; I describe the set-up of the model in the next section, while in Section 3.3 I outline some of the equilibrium concepts for timing games that have been developed by Fudenberg and Tirole [15]. In Section 3.4 I solve for the equilibria of the game. I provide a numerical example in Section 3.5 to help better explain the theoretical results and Section 3.6 finally concludes.

3.2 Model

3.2.1 Background and Motivation

Consider two firms, both of which have invested in a new product or technology, and the problem for the manager of each firm is to determine at what point to disclose this information to the market, whilst taking into account the other firm's potential strategy. I assume that the product is still in the developmental stage and signals regarding the progress of the development, which are indicative of the potential profitability of the product for the firm, are obtained by both managers at random points in time. The uncertainty primarily arises from the managers being unsure how the market will respond to such an announcement. The more positive the signals they obtain, the more likely the market will interpret the information favourably. Hence, each time a signal is obtained, the managers update their beliefs as to the likely market response, in a Bayesian way. It is important to assume that each firm can choose to abandon their investment at any point, before they launch product. Thus, by choosing not to make an announcement, if the firm then abandons the investment, the market may never learn that such an investment took place. This implies another option for the managers; namely a disinvestment option. However, taking account of the value of such an option is beyond the scope of this chapter.

I assume that both firms compensate their managers via stock options, and hence, for each manager, the activities of their firm impacts upon their own utility from wealth. Their objectives are, then, to maximise the discounted expected current value of their respective firms. I show in Chapter 2 that once the manager is compensated via stock options, they act so as to maximise firm value, and this is irrespective of the amount of stock they hold.

In terms of the competitive aspect of the problem there are two possibilities; either a Stackelberg competition arises or both firms disclose simultaneously.

After disclosure has taken place by at least one firm, the other firm then knows how the market interprets the signals, or equivalently, they know the market's interpretation of such a firm's prospects given that they have invested in the product. Hence, in the case of Stackelberg competition, there is an information spillover from the leader to the follower, which creates a second mover advantage. The follower then decides immediately on whether to reveal his involvement in the product. I assume that this does not take any time.[1] If one firm discloses at a time $\tau \geq 0$, the follower will either disclose at τ as well, or not at all. This case is distinguished

[1]While the assumption that the follower reacts immediately may not seem realistic, it is not restrictive. If there is a time lag between disclosure of the leader and the follower, this only has an influence on the payoffs via extra discounting by the follower. The important point is that the game ends as soon as one firm has disclosed, because at that point the decision of the other firm is made as well. The fact that the actual disclosure may occur at a later date is irrelevant for the quantitative analysis.

from the case of simultaneous competition where both firms also disclose simultaneously at τ. However, at the time of disclosure both firms are uncertain as to how the market will respond to the announcement; that is, there is no second mover advantage.

As in Chapter 2, I further assume that all disclosures are (ex post) verifiable; that is, a manager will not issue mis-leading information in an attempt to alter the market's perception of his firm's prospects.

3.2.2 Model Set-Up

The managers both hold an option to voluntarily disclose their involvement in the product, via the signals they obtain, to the market and they are uncertain about how this information will be perceived. If the revelation is regarded positively by the market, this will result in a rise in the value of the firm by an amount V^P or, if regarded negatively, a fall in the value by an amount V^N, when the announcement is made, such that $V^N < 0 < V^P$. V^P and V^N are the infinitely discounted values resulting from making a disclosure, discounted at a constant rate $r \in (0, 1)$. In this model, disclosure is costly and the sunk cost involved from making a disclosure is denoted by $I > 0$, for each firm. It is important to note that these costs are direct and do not relate to the (indirect) proprietary costs that are typically referred to in the disclosure literature such as the cost of revealing firm sensitive information to competitors.

In the case that the market response is favourable, the leader's payoff equals $V_L^P > 0$, whereas if it is not favourable, the payoff is $V_L^N < 0$. If the response is favourable, the follower will immediately disclose and obtain $V_F^P > 0$, but will not disclose if the response is unfavourable, so $V_F^N = 0$. The sunk costs incurred by each firm on making a disclosure are denoted by $I > 0$. Without loss of generality, I is assume $V_L^P > V_F^P > I$. Hence there is a first mover advantage if the disclosure results in a positive market response, and disclosure is profitable for both firms. In other words, the positive payoff to the manager who is first to disclose is greater than the positive payoff to the manager who follows and discloses in response to the leader's action.

If the market response is not positive, the payoff is $V_L^N < 0$ (or a first mover disadvantage). If the response is unfavourable, the follower observes this and benefits because he can make his disclosure decision under complete information. This information spillover to the follower when the leader has disclosed earns him a second mover advantage. To ascertain whether the leader or the follower is in the better position the magnitudes of the first and second mover advantages have to be compared. If both firms disclose simultaneously, and the response is positive (negative), both receive $V_M^P > 0$ ($V_M^N < 0$), such that $V_F^P < V_M^P < V_L^P$ and $V_L^N < V_M^N < 0$.[2]

When a firm has the option to disclose their involvement in the product to the market, I assume that the manager has some *ex ante* belief about the market reaction to the announcement being either positive or negative. The prior probability of a positive reaction, and therefore, an increase in the firm's value is given by

$$\mathbb{P}(V^P) = p_0, \tag{3.2.1}$$

and this is identical for both firms.

I further assume that at some random points in time, both firms obtain imperfect signals, from various sources, indicating whether the profitability of their investment product is positive or negative. A high quality signal occurs with probability $\theta > \frac{1}{2}$. The signals are observed by both firms simultaneously as both have invested in the same product.

[2]Note that the payoffs are regarded as an infinite stream of earnings per share, π_j^i, discounted at rate $r > 0$; i.e. $V_j^i = \int_0^\infty e^{-rt}\pi_i^j dt = \frac{1}{r}\pi_j^i$, $i = P, N$ and $j = L, M, F$.

The signal arrivals are modelled via a Poisson process with parameter $\mu > 0$; that is, the probability that the manager obtains a signal is μdt and $1 - \mu dt$ if no new signal is obtained.

I assume that both firms have an identical belief $p_t \in (0, 1)$ that the market response will be positive at time t. Similar to Thijssen et al. [53], I denote by p_M the belief such that the *ex ante* expected payoff for the follower, denoted by $F(\cdot)$, equals the *ex ante* expected payoff of simultaneous disclosure, denoted by $M(\cdot)$; that is, p_M is such that $F(p_M) = M(p_M)$. When $p_t \geq p_M$, both firms will disclose simultaneously, before the market interpretation is known. On the other hand, if one firm discloses when $p_t < p_M$, it is not optimal for the other firm to do so also at time t.

If the leader discloses at a point where the belief in a positive response is p_t, the leader's *ex ante* expected payoff can be written as

$$L(p_t) = \begin{cases} p_t V_L^P + (1 - p_t) V_L^N - I & \text{if } p_t < p_M \\ p_t V_M^P + (1 - p_t) V_M^N - I & \text{if } p_t \geq p_M. \end{cases} \tag{3.2.2}$$

The follower only discloses in the case of a positive market response. Hence, the *ex ante* expected payoff for the follower, if the leader discloses when the belief in a positive response is p_t, is given by

$$F(p_t) = \begin{cases} p_t (V_F^P - I) & \text{if } p_t < p_M \\ p_t V_M^P + (1 - p_t) V_M^N - I & \text{if } p_t \geq p_M. \end{cases} \tag{3.2.3}$$

Finally, in the case of simultaneous disclosure at belief p_t, each firm has an *ex ante* expected payoff given by

$$M(p_t) = p_t V_M^P + (1 - p_t) V_M^N - I. \tag{3.2.4}$$

The preemption belief, denoted p_P, is defined as being the belief at which the managers are indifferent between being the leader or the follower; that is, $L(p_P) = F(p_P)$.

Equating equations (3.2.2) and (3.2.3) gives the preemption belief

$$p_P = \frac{I - V_L^N}{(V_L^P - V_F^P) - (V_L^N - I)} \tag{3.2.5}$$

which is well defined for $I > V_L^N$.

Equating equations (3.2.3) and (3.2.4) for $p_t = p_M$ gives

$$p_M = \frac{I - V_M^N}{(V_M^P - V_F^P) - (V_M^N - I)}, \tag{3.2.6}$$

which is the belief threshold above which both firms find it optimal to disclose simultaneously.

A graphical depiction of the situation is given by Figure 3.1 for a specific numerical parameterisation defined in Section 3.5.

It must be noted that a knife-edge result on whether the preemption belief threshold is below the threshold where both managers disclose simultaneously is not possible to obtain. However, $p_P < p_M$ for

$$V_L^P - V_F^P > \left(V_M^P - V_F^P\right) \frac{V_L^N - I}{V_M^N - I}. \tag{3.2.7}$$

Indeed, if $p_P > p_M$ preemption is nonsensical, since a point above which both firms try preempting each other cannot intuitively exist after both firms have disclosed simultaneously. This point is particularly important because it is the main contribution of this paper, and it is the point whereby this paper differs from Thijssen et al. [53]. They assume that $V_j^N = 0$ for $j = L, M, F$, and hence, they find that it is always the case that $p_P < p_M$. However, in this paper, V_L^N and V_M^N are assumed to be non-zero, and consequently the inequality $p_P < p_M$ does not always hold.

The intuition governing equation (3.2.7) is the following; the simultaneous disclosure effect outweighs the information spillover; i.e. $p_P < p_M$, when the magnitude of the first mover advantage, $V_L^P - V_F^P$, is greater than a multiple $\frac{V_L^N - I}{V_M^N - I}$ (> 1) of the cost to the follower from not making a simultaneous disclosure with the leader, $V_M^P - V_F^P$.

To compute the managers' belief that there will be a positive response to the announcement, $p_t := p(s_t)$, one must apply Bayes' rule because their beliefs as to the profitability of the product are updated each time a new signal arrives. From Chapter 2 this is given by

$$p(s_t) = \frac{\theta^{s_t}}{\theta^{s_t} + \zeta(1-\theta)^{s_t}}, \tag{3.2.8}$$

where $\zeta = \frac{1-p_0}{p_0}$ denotes the unconditional odds of a negative shareholder response and s_t the number of positive signals in excess of negative signals obtained by the managers at time t.

Furthermore, from equation (3.2.8), a solution for s_t can be obtained and is given by

$$s_t = \frac{\log\left(\frac{1-p_t}{p_t}\right) - \log\zeta}{\log\left(\frac{1-\theta}{\theta}\right)}. \tag{3.2.9}$$

3.3 Equilibrium Concepts for Timing Games

In this section I outline a formalisation of strategy spaces and payoffs for continuous-time games. This formalisation is developed in Fudenberg and Tirole [15] and Thijssen et al. [53].

Let $(\Omega, \mathcal{F}, (\mathcal{F}_t)_{0\le t\le\infty}, \mathbb{P})$ be a filtered probability space such that $\mathcal{F}_0$ contains all the $\mathbb{P}$-null sets of $\mathcal{F}$ and the filtration $(\mathcal{F}_t)_{0\le t\le\infty}$ is right-continuous. It is assumed that the stochastic process $(Y_t)_{t\ge 0}$ captures all of the uncertainty on the filtered probability space.

In the current chapter, a player's only decision is to choose a (single) time to disclose information signals to the market. The starting point of the game is $t = 0$.

A strategy consists of both a distribution function and an intensity function. All the definitions below are defined for each path $(Y_t(\omega))_{t\geq 0}$, resulting from $\omega \in \Omega$.

Definition 1. A simple strategy for player $n \in \{i, j\}$ in the subgame starting at $t_0 \in [0, \infty)$ is given by a tuple of real-valued functions $(G_n^{t_0}, \alpha_n^{t_0}) : [t_0, \infty) \times \Omega \to [0, 1] \times [0, 1]$, such that for all $\omega \in \Omega$

1. $G_n^{t_0}(\cdot, \omega)$ is non-decreasing and right continuous with left limits;
2. $\alpha_n^{t_0}(\cdot, \omega)$ is right continuous with left limits;
3. if $\alpha(\cdot, \omega) = 0$ and $t = \inf\{u \geq t_0 | \alpha_n^{t_0}(u, \omega) > 0\}$, then the right-derivative of $\alpha_n^{t_0}(u, \omega)$ exists and is positive.

Denote the strategy set of simple strategies of player n in the subgame starting at t_0 by $S_n^s(t_0, \omega)$. Furthermore, define the strategy space by $S^s(t_0, \omega) = \Pi_{n=i,j} S_n^s(t_0, \omega)$ and denote the strategy at $t \in [t_0, \infty)$ by $s^{t_0}(t, \omega) = (G_n^{t_0}(t, \omega), \alpha_n^{t_0}(t, \omega))_{n=i,j}$.

Simple strategies allow for several disclosure strategies. G_n^t is interpreted as the cumulative probability that one player has disclosed before, or at, time t. Additionally, it allows for continuous disclosure strategies (used in war of attrition models) and single jumps. α_n^t is a measure for the "intensity" of the atoms in the interval $[t, t + dt]$. This intensity function allows for coordination between firms in cases where disclosure by one firm is optimal, but simultaneous disclosure is not. The intensity function is included in the strategy space to replicate the discrete time results that are lost by modelling in continuous time (see Fudenberg and Tirole [15] for a more in-depth explanation). Briefly stated, as soon as the intensity function is non-zero, a game is played where both managers disclose with probabilities α_i and α_j, respectively. The game is repeated until at least one of the firms has disclosed.

Playing the game is assumed to cost no time, so that the stochastic process Y_t remains constant during this repetition process. The third condition is imposed for technical convenience.

The definition of simple strategies does not *a priori* exclude the possibility that both firms choose an intensity function that turns out to be inconsistent with G_n^t. In equilibrium it should naturally be the case that such inconsistencies do not occur. Therefore, the notion of α-consistency is introduced.

Definition 2. A tuple of simple strategies $((G_n^{t_0}, \alpha_n^{t_0}))_{n=i,j}$ for the subgame starting at $t_0 \geq 0$ is α-consistent if for all $\omega \in \Omega$ and $t \geq t_0$,

$$\begin{aligned}\alpha_i^{t_0}(t,\omega) - \alpha_i^{t_0}(t-,\omega) \neq 0 \Rightarrow G_i^{t_0}(t,\omega) - G_i^{t_0}(t-,\omega) = \\ \left(1 - G_i^{t_0}(t-,\omega)\right) \frac{\alpha_i^{t_0}(t,\omega)}{\alpha_i^{t_0}(t,\omega) + \alpha_j^{t_0}(t,\omega) - \alpha_i^{t_0}(t,\omega)\alpha_j^{t_0}(t,\omega)}.\end{aligned} \tag{3.3.1}$$

Definition 2 requires that if for either firm there is a jump in the intensity function, then the jump in the cumulative distribution function of both firms should equal the probability that the firm discloses by playing the game described above. Note that if $\alpha_i^{t_0}(t,\omega) - \alpha_i^{t_0}(t-,\omega) \neq 0$ and $\alpha_i^{t_0}(t,\omega) = 1$, then α-consistency implies that $G_i^{t_0}(t,\omega) = 1$.

Let the payoff function for firm $n \in \{i,j\}$ in the subgame starting at t_0 be given by $V_n : [0,\infty) \times S^s(t_0,\omega) \to \mathbb{R}$. An α-equilibrium for the subgame starting at $t_0 \geq 0$ is then defined as follows:

Definition 3. A tuple of simple strategies $s^* = (s^*(\omega))_{\omega\in\Omega}$, $s^*(\omega) \in S^s(t_0,\omega)$, for all $\omega \in \Omega$, is an α-equilibrium for the subgame starting at t_0 if for all $\omega \in \Omega$, $s^*(\omega)$ is α-consistent and

$$\forall_{n\in\{1,2\}} \forall_{s_n \in S_n^s(t_0,\omega)} : V_n(t_0, s^*(\omega)) \geq V_n(t_0, s_n, s_{-n}^*(\omega)). \tag{3.3.2}$$

A caveat with α-equilibrium is that it does not exclude time inconsistent strategies. Hence, we need a family of strategies $(G_n^t(\cdot,\omega))$, otherwise known as a closed loop. This closed loop is necessary, because to test for perfectness, strategies conditional on zero-probability events must be defined; in other words, it is needed to define a subgame perfect equilibrium. Furthermore, let for all $\omega \in \Omega$ and $t_0 \geq 0$, τ be defined as $\tau = \min_{n=i,j}\{\inf\{t \geq t_0 | \alpha_n^{t_0}(t,\omega) > 0\}\}$.

Definition 4. A closed loop strategy for player $n \in \{i,j\}$ is for all $\omega \in \Omega$ a collection of simple strategies $(G_n^t(\cdot,\omega), \alpha_n^t(\cdot,\omega))_{0\leq t<\infty}$, with $(G_n^t(\cdot,\omega), \alpha_n^t(\cdot,\omega)) \in S_n^s(t,\omega)$ for all $t \geq 0$ that satisfies the following intertemporal consistency condition for all $\omega \in \Omega$:

$$\forall_{0\leq t\leq u\leq v<\infty} : v = \inf\{\tau > t | Y_\tau = Y_v\} \Rightarrow G_n^t(v,\omega) = G_n^u(v,\omega)$$

and

$$\alpha_n^t(v,\omega) = \alpha_n^u(v,\omega). \tag{3.3.3}$$

The set of closed loop strategies for player $n \in \{i,j\}$ is denoted by $S_n^{cl}(\omega)$. As before, the strategy space is defined by $S^{cl}(\omega) = \Pi_{n=i,j} S_n^{cl}(\omega)$.

A consistent α-equilibrium is defined as follows:

Definition 5. A tuple of closed loop strategies $\bar{s} = (\bar{s}(\omega))_{\omega\in\Omega}$, $\bar{s}(\omega) \in S^{cl}(\omega)$ all $\omega \in \Omega$ is a consistent α-equilibrium if for all $t \in [0,\infty)$, the corresponding tuple of simple strategies $\big((G_i^t, \alpha_i^t), (G_j^t, \alpha_j^t)\big)$ is an α-equilibrium for the subgame starting at t.

For the remainder of the analysis, let $\omega \in \Omega$ be fixed. For notational convenience, ω will be dropped as an argument.

3.4 Equilibria of the Game

Suppose, for now, that one firm, say firm i, has been preassigned the leader's role and firm j can only disclose once the leader has done so. In this case, there exists a $p_t \in (0, p_M)$ such that the *ex ante* expected payoff for the leader is greater than the *ex ante* expected payoff from simultaneous disclosure; i.e. $L(p_t) > M(p_t)$. The intuition is that for such a belief, p_t, the leader's decision has no effect on the optimal response of the follower. Thus, the leader acts as if there is no follower and becomes a monopolist. From Chapter 2, it is optimal for the leader to disclose when p_t hits the threshold

$$p_L^* = \left[\frac{V^P - I}{I - V^N}\Pi + 1\right]^{-1}, \tag{3.4.1}$$

where

$$\Pi = \frac{\Big(\beta_1(r+\mu) - \mu\theta(1-\theta)\Big)\left(\frac{r}{\mu} + 1 - \theta\right) - \mu\theta(1-\theta)\beta_1}{\Big(\beta_1(r+\mu) - \mu\theta(1-\theta)\Big)\left(\frac{r}{\mu} + \theta\right) - \mu\theta(1-\theta)\beta_1} \tag{3.4.2}$$

and

$$\beta_1 = \frac{r+\mu}{2\mu} + \frac{1}{2}\sqrt{\left(\frac{r}{\mu} + 1\right)^2 - 4\theta\,(1-\theta)} > \theta. \tag{3.4.3}$$

From equation (3.2.9), it is easy to verify that s_t is increasing in p_t. Then $s_L := s(p_L) > s_P := s(p_P)$ when $p_L > p_P$. This is true for

$$\frac{V_L^P - V_F^P}{V_L^P - I} > \Pi. \tag{3.4.4}$$

The left-hand side (LHS) of equation (3.4.4) is the cost to the follower for waiting to obtain the information spillover relative to the leader's payoff. Comparative statics show that this relative cost is increasing in V_L^P and I. The greater the payoff to the leader, the more the follower "suffers" as a result of not having been the first to disclose. Similarly, the higher the costs of disclosure, the more severely his payoff after disclosing will be impacted, and thus, he pays a relatively higher price for his second mover advantage. Conversely, this price is decreasing in V_F^P, which intuitively makes sense.

Comparative statics show that the right-hand side (RHS) of equation (3.4.4) is decreasing in signal quality, θ, and in general signal quantity, μ. Intuitively, the value of the information spillover to the follower is greater when the quality and quantity of the information signals are low; that is for lower values of θ and (in general) μ. Hence, if a manager becomes the disclosure leader, he provides relatively more information to his competitor when the quality and quantity of signals are low, and thus, for the RHS of (3.4.4) relatively high, compared with when the RHS of (3.4.4) is low. This shows that (3.4.4) is essentially a relative comparison between the first and second mover advantages.

I further note that $p_P > p_{NPV}^L$. This implies that preemption, in a real options framework, still asserts later disclosure than the traditional net present value (NPV) rule would suggest. However, it is not possible to obtain an unambiguous relationship between p_{NPV}^L and p_M; that is, between the classical NPV rule and the point at which firms will disclose simultaneously. This is due to the fact that the condition $p_M > p_P$ only holds for certain values of V_j^i ($i \in \{P, N\}$ and $j \in \{L, M, F\}$) and I.

3.4.1 Preemption

If $p_L > p_P$, the leader advantage outweighs the information spillover. This implies that the firm who first discloses that it has invested in this new product will benefit, through an increase in outside investment, more than the firm who waits to ascertain how the market will react to the information. This is because the signals regarding the product's development are sufficiently good that each firm wants to be the first to disclose that it has undertaken this investment, and thereby, attain a greater positive impact on its value than the impact it would obtain from being the follower. The likely reaction to the firm that is the follower, while it will be positive, will be more muted than the reaction to the leader's disclosure, simply because the revelation is less novel from the follower. Additionally, in this instance, the signals are sufficiently strong that neither firm feels the need to wait for their competitor to disclose its decision to invest in the product so that they may observe the market's reaction to this information. This type of scenario will be covered in the following subsection.

For $p_P \leq p_t < p_M$, the optimal $\alpha_n^t(\cdot)$ function is obtained through maximising firm i's payoff in a competitive game such that if neither firm discloses, the game is repeated, and can be repeated infinitely many times.

I denote firm i's payoff by V_i. Then

$$\begin{aligned} V_i(t_0, s_i, s_j) =& \alpha_i\alpha_j M + \alpha_i(1-\alpha_j)L + (1-\alpha_i)\alpha_j F + \dots \\ &+ \alpha_i\alpha_j(1-\alpha_i)^{T-1}(1-\alpha_j)^{T-1}M \\ &+ \alpha_i(1-\alpha_i)^{T-1}(1-\alpha_j)^{T}L \\ &+ \alpha_j(1-\alpha_i)^{T}(1-\alpha_j)^{T-1}F \\ =& (\alpha_i\alpha_j M + \alpha_i(1-\alpha_j)L + \alpha_j(1-\alpha_i)F) \times \\ & \sum_{t=0}^{T-1} [(1-\alpha_i)(1-\alpha_j)]^t . \end{aligned} \tag{3.4.5}$$

If dt is the size of one time period and if $T_\Delta := Tdt$, then $T - 1 \equiv \frac{T_\Delta}{dt} - 1$. Hence, letting $dt \downarrow 0$, the summation over t is from 0 to ∞, implying (3.4.5) is the infinite sum of a geometric series with common ratio $(1-\alpha_i)(1-\alpha_j) < 1$. Therefore

$$V_i = \frac{\alpha_i\alpha_j M + \alpha_i(1-\alpha_j)L + \alpha_j(1-\alpha_i)F}{1-(1-\alpha_i)(1-\alpha_j)}. \tag{3.4.6}$$

Maximising this expression with respect to α_i (and noting that only symmetrical strategies are considered) gives

$$\begin{aligned}\alpha_j =& \frac{L(p_t) - F(p_t)}{L(p_t) - M(p_t)} \\ =& \frac{p_t\left(V_L^P - V_F^P\right) + (1-p_t)\left(V_L^N - I\right)}{p_t\left(V_L^P - V_M^P\right) + (1-p_t)\left(V_L^N - V_M^N\right)} \\ =& \alpha_i.\end{aligned} \tag{3.4.7}$$

Let $\mathbb{P}(i, \neg j|\tau)$ denote the probability that firm i is the only firm that discloses at time τ. By a similar limiting argument to that already outlined in equation (3.4.5),

$$\mathbb{P}(i, \neg j|\tau) = \frac{\alpha_i(1-\alpha_j)}{\alpha_i + \alpha_j - \alpha_i\alpha_j}. \tag{3.4.8}$$

If $\mathbb{P}(i, j|\tau)$ denotes the probability that both firms disclose simultaneously at τ,

$$\mathbb{P}(i, j|\tau) = \frac{\alpha_i\alpha_j}{\alpha_i + \alpha_j - \alpha_i\alpha_j}. \tag{3.4.9}$$

To analyse the equilibrium outcome in the preemption game, I consider three separate regions; (i) $p_t < p_P$, (ii) $p_P \leq p_t < p_M$, and (iii) $p_t \geq p_M$.

Region 1: If $p_t < p_P$, the payoff to the follower from disclosing at p_t is greater than the payoff to the leader; i.e. $F(p_t) > L(p_t)$. Therefore, neither firm wants to be the first to disclose and both will abstain from disclosing until the excess number of positive over negative signals, s_P, has been reached. Intuitively, the excess number of positive signals is insufficient for the manager to be confident of a positive market response to the revelation that they have invested in such a product. Therefore, each firm would prefer to wait until the other firm has disclosed so as to obtain the information spillover before deciding whether to make an announcement or not.

In equilibrium there are two possible outcomes. In the first outcome, firm i is the leader and discloses when the belief is p_P and firm j is the follower and discloses at p_M. The second outcome is the symmetric counterpart.

Region 2: If $p_P \leq p_t < p_M$ is the starting point of the game, both firms try to preempt each other to obtain a first mover advantage since $L(p_t) > M(p_t)$. However

$p_t < p_M$ implies that the belief in a positive response is not strong enough such that simultaneous disclosure is optimal.

If $p_t = p_P$, recall that $F(p_P) = L(p_P)$, and thus, from equation (3.4.7), $\alpha_i = 0$. The probability that i is the only firm that discloses is zero, from (3.4.8). Similarly, the probability that both firms disclose simultaneously is zero, from (3.4.9). However, firm j invests with probability one because $\mathbb{P}(\neg i, j|\tau) = \frac{(1-\alpha_i)\alpha_j}{\alpha_i+\alpha_j-\alpha_i\alpha_j} = 1$. Thus, the expected disclosure payoff for firm i is zero and for firm j is $\mathbb{P}(\neg i, j|\tau)F(p_P) = F(p_P)$.

However, if $p_t > p_P$, $L(p_t) > F(p_t)$ which implies $\alpha_i(p_t) > 0$. The probability that firm i discloses at p_t and firm j at p_M is given by (3.4.8). Both firms disclose simultaneously at p_t with probability given by (3.4.9), leaving both with a low payoff $M(p_t)(< F(p_t))$. The expected payoff to each firm is then

$$
\begin{aligned}
&\mathbb{P}(i, \neg j|\tau)L(p_t) + \mathbb{P}(\neg i, j|\tau)F(p_t) + \mathbb{P}(i, j|\tau)M(p_t) \\
=&\frac{\alpha_i L + \alpha_j F - \alpha_i\alpha_j(L + F - M)}{\alpha_i + \alpha_j - \alpha_i\alpha_j} \\
=&\frac{F(F - 2M + L)}{L - 2M + F} \equiv F(p_t),
\end{aligned}
\tag{3.4.10}
$$

by substituting for α_i and α_j using equation (3.4.7).

Region 3: If $p_t \geq p_M$, $M(p_t) = F(p_t)$. Therefore, both firms will disclose simultaneously, each getting $F(p_t)$.

Therefore, the overall equilibrium strategy of firm $n \in \{i, j\}$ for $p_L > p_P$ is as follows:

$$
G_n^t = \begin{cases} 0 & \text{if } p_t < p_P \\ \frac{p_t(V_L^P - V_M^P) + (1-p_t)(V_L^N - V_M^N)}{p_t(V_L^P - 2V_M^P + V_F^P) + (1-p_t)(V_L^N - 2V_M^N + I)} & \text{if } p_P \leq p_t < p_M \\ 1 & \text{if } p_t \geq p_M, \end{cases}
\tag{3.4.11}
$$

and

$$\alpha_n^t = \begin{cases} 0 & \text{if } p_t < p_P \\ \frac{p_t\left(V_L^P - V_F^P\right) + (1-p_t)\left(V_L^N - I\right)}{p_t\left(V_L^P - V_M^P\right) + (1-p_t)\left(V_L^N - V_M^N\right)} & \text{if } p_P \leq p_t < p_M \\ 1 & \text{if } p_t \geq p_M. \end{cases} \tag{3.4.12}$$

3.4.2 War of Attrition

On the other hand, if $p_P > p_L$ the information spillover outweighs the leader advantage. This implies that signals are less strong (in terms of content rather than quality) than in the preemption case, and that both firms are less convinced that the likely market reaction to the news that they have invested in this new product will be positive. For example, if the shareholders learn of the investment the manager has undertaken, they may regard such an investment as too risky a venture and that the sunk investment costs the firm may have incurred are not likely to be recouped. Therefore, it is optimal for the manager of each firm to wait until his competitor has disclosed so that they can make their own decision over whether to also disclose, or to wait for more signals to arrive, under complete information. That is, he will only disclose if he knows for sure that the market will respond positively to the information. Both firms wish to be the follower so as to obtain the information spillover and protect themselves against a negative response. Hence, a war of attrition arises between the two firms.

For $p_t > p_P$, the game is exactly the same as the preemption game already discussed. However, if the excess number of signals is such that $p_t \in [p_L, p_P)$, a war of attrition arises since both firms would prefer to be the follower. The game ends once p_P is reached. In a war of attrition, two asymmetric equilibria arise trivially; either firm i discloses with probability one and firm j with probability zero, or vice versa.

To find a symmetric equilibrium, I argue in line with Thijssen et al. [53] that for each point in time during a war of attrition the expected payoff from disclosing immediately exactly equals the payoff from waiting a small period of time dt and disclosing when a new signal arrives. The probability that the other firm discloses at belief p_t is denoted by $\gamma(s_t)$,[3] and following the analysis outlined in Thijssen et al. [53], $\gamma(\cdot)$ is given by:

$$\begin{aligned}\gamma(s_t) =& \frac{1-\gamma(s_t)}{F(s_t)-M(s_t)}\Big[L(s_t) - \frac{\mu}{r+\mu}\frac{\theta^{s_t+1}+\zeta(1-\theta)^{s_t+1}}{\theta^{s_t}+\zeta(1-\theta)^{s_t}}\times \\ &\Big(\gamma(s_t+1)\Big(M(s_t+1)-L(s_t+1)\Big)+L(s_t+1)\Big) \\ &+\frac{\mu}{r+\mu}\frac{\theta(1-\theta)\left(\theta^{s_t-1}+\zeta(1-\theta)^{s_t-1}\right)}{\theta^{s_t}+\zeta(1-\theta)^{s_t}}\times \\ &\Big(\gamma(s_t-1)\Big(M(s_t-1)-L(s_t-1)\Big)+L(s_t-1)\Big)\Big].\end{aligned} \tag{3.4.13}$$

To solve for $\gamma(\cdot)$, note that if $p_t < p_L$, neither firm will disclose, since the option value of waiting is higher than the expected payoff from disclosing. Therefore $\gamma(s_L) = 0$. On the other hand, if $p_t > p_P$, the firms enter a preemption game. It is also possible that $p_P = p_M$, and then the game proceeds directly from a war of attrition into a game where simultaneous disclosure is optimal. Thus, for other values of p_t; that is, for $p_t \in [p_L, p_P)$, it is necessary to solve a system of equations where the p_t-th entry is given by (3.4.13). A system such as this cannot be solved analytically but for any specific set of parameter values a numerical solution may be determined. Thijssen et al. [53] prove that a solution to a system of equations given by (3.4.13) always exists, and furthermore, $\gamma \in [0, 1]$.

Defining the time at which preemption occurs by $T_P^{t_0} := \inf\{t \geq t_0 | p_t \geq p_P\}$, and the number of signals that has arrived up until time t by $k_t := \sup\{k | T_k^{t_0} \leq t\}$,

[3] Of course, this is also the probability that the manager's own firm has disclosed since the equilibria are symmetric.

the symmetric (α-consistent) equilibrium is given by

$$G_n^t = \begin{cases} 0 & \text{if } p_t \leq p_L \\ \sum_k \frac{\gamma(s_k)}{1-\gamma(s_k)} \Pi_{k'=k_t}^{k} (1-\gamma(s_{k'})) & \text{if } p_L < p_t < p_P \\ \left(1 - G_n^t(T_P^{t_0}-)\right) \times & \\ \frac{p_t(V_L^P - V_M^P)+(1-p_t)(V_L^N - V_M^N)}{p_t(V_L^P - 2V_M^P + V_F^P)+(1-p_t)(V_L^N - 2V_M^N + I)} & \text{if } p_P \leq p_t < p_M \\ 1 & \text{if } p_t \geq p_M, \end{cases} \tag{3.4.14}$$

and

$$\alpha_n^t = \begin{cases} 0 & \text{if } p_t < p_P \\ \frac{p_t\left(V_L^P - V_F^P\right)+(1-p_t)\left(V_L^N - I\right)}{p_t\left(V_L^P - V_M^P\right)+(1-p_t)\left(V_L^N - V_M^N\right)} & \text{if } p_P \leq p_t < p_M \\ 1 & \text{if } p_t \geq p_M. \end{cases} \tag{3.4.15}$$

The technicalities of this result are not new to this paper, and thus, the reader is referred to Thijssen et al. [53] for further details.

3.4.3 Synergy

The condition given by equation (3.2.7) is necessary for $p_P < p_M$ to be true. However, if the values of I and V_j^i ($i = P, N$ and $j = L, M, F$) are such that this condition does not hold, then intuitively, there cannot be a preemption point. This produces a type of "synergistic effect" in that the simultaneous revelation that both firms have invested in the product is expected to generate a stronger positive market response (and thus a higher payoff from disclosure) than stand-alone disclosure by either firm would ever generate.

This scenario occurs if the managers both believe that by disclosing with its competitor that it has invested in this new product, the market will react more favourably (or less negatively) than if the firm was to disclose as the leader. In other words, if the market learns that two very similar firms have chosen to undertake an investment in the same product, investors are more reassured of the product's potential success than if they believed only one such firm had chosen to undertake the investment.

This new type of equilibrium that arises is driven by the assumption in my paper that $V_j^N \neq 0$ for $j = \{L, M\}$. If there was no direct negative impact on the firms' value through making a disclosure (i.e. in addition to the sunk costs incurred), then an attempt by the managers to temper the extent to which the investors will sell off their firm's stock would not be an issue. If this was simply an investment problem whereby the sunk costs incurred are the main loss to the firm, then it would be plausible to let $V_j^N = 0$, for all j. Indeed, this is the problem examined by Thijssen et al. [53]. However, with respect to disclosure, if the investors do not like what they learn, then they may sell their stock which lowers the firm's value. If such a negative response were to ensue under the condition that $p_P > p_M$, then revelation that a similar firm has also chosen to invest in this new product will serve to reassure the market of the product's potential success, and thereby temper the extent of the market sell-off. Conversely, if a positive response were to ensue, simultaneous disclosure would boost the extent of the market's investment in the firms through a firmer confidence in the product's success.

Technically, the inequality given by (3.2.7) is reversed when the first mover advantage is less than a multiple, $\frac{V_L^N - I}{V_M^N - I}$, of the difference between the positive payoff from simultaneous disclosure and the positive payoff obtained by a firm that is the follower. The situation occurs if the negative impact to the leader from disclosing, $V_L^N - I$, is very strong relative to the negative impact obtained from disclosing simultaneously with the other firm, $V_M^N - I$. To see this more clearly, if $V_L^N \to -\infty$, then the RHS of (3.2.7) becomes infinitely large, and the condition $p_P < p_M$ no longer holds. Similarly, if the negative payoff obtained from simultaneous disclosure is not particularly low, that is, if $V_M^N \uparrow 0$ and simultaneously, $I \downarrow 0$[4] then once again,

[4]One cannot say if $V_M^N - I \uparrow 0$, as this would imply that $V_M^N \uparrow I$, or vice versa, but $V_M^N < 0$

the RHS becomes infinitely large and the condition breaks down.

If the leader effect outweighs the synergy effect, $p_M < p_L$, neither firm will disclose until p_M is reached, and then both will disclose simultaneously each getting the payoff $F(p_M)$. It is never optimal for one firm to disclose on its own and information spillover has no value. This contrasts with the case when $p_P < p_M < p_L$. In this case, the market will learn sooner about the investment since one of the firms will disclose once p_P is reached. The other firm then decides whether to reveal its involvement in the investment or not, and hence, the ensuing market reaction to the two firms' actions is likely to have different impacts than if they were to only ever disclose together or not at all.

Hence the synergistic equilibrium strategy is given by

$$G_n^t = \begin{cases} 0 & \text{if } p_t < p_M \\ 1 & \text{if } p_t \geq p_M, \end{cases} \tag{3.4.16}$$

and

$$\alpha_n^t = \begin{cases} 0 & \text{if } p_t < p_M \\ 1 & \text{if } p_t \geq p_M. \end{cases} \tag{3.4.17}$$

If the synergy effect outweighs the leader effect; i.e. $p_L < p_M$, a war of attrition arises in the region $[p_L, p_M)$ because both firms would prefer to wait and disclose together with its competitor rather than be the leader. The analysis is similar to that which yields the equilibrium strategy given by equations (3.4.14) and (3.4.15), so it suffices to state that the equilibrium strategy for this scenario is given by

$$G_n^t = \begin{cases} 0 & \text{if } p_t \leq p_L \\ \left(1 - G_n^t(T_L^{t_0}-)\right) \times & \\ \frac{p_t(V_L^P - V_M^P) + (1-p_t)(V_L^N - V_M^N)}{p_t(V_L^P - 2V_M^P + V_F^P) + (1-p_t)(V_L^N - 2V_M^N + I)} & \text{if } p_L < p_t < p_M \\ 1 & \text{if } p_t \geq p_M, \end{cases} \tag{3.4.18}$$

---

and $I > 0$, by assumption. Thus, it is necessary to specify that if V_M^N is sufficiently small and I sufficiently low such that the difference between these values is negligible.

and

$$\alpha_n^t = \begin{cases} 0 & \text{if } p_t \leq p_L \\ \frac{p_t(V_L^P - V_F^P) + (1-p_t)(V_L^N - I)}{p_t(V_L^P - V_M^P) + (1-p_t)(V_L^N - V_M^N)} & \text{if } p_L < p_t < p_M \\ 1 & \text{if } p_t \geq p_M, \end{cases} \tag{3.4.19}$$

where $T_L^{t_0} := \inf\{t \geq t_0 | p_t \geq p_L\}$.

A graphical depiction of this synergy equilibrium, for a specific parameterisation defined in Section 3.5, is given in Figure 3.2.

3.5 Numerical Example

My aim in this section is to provide an insight into the magnitude of some of the effects which I discuss in previous sections. For the parameterisation given in Table

Table 3.1: Parameter Values

Parameter	Value	Parameter	Value
V_L^P	20	I	5
V_L^N	-10	p_0	0.5
V_F^P	10	μ	4
V_M^P	12	θ	0.6
V_M^N	-5	r	0.04

3.1; $s_L = 6$, $s_M = 4$ and $s_P = 1$. The corresponding belief probabilities are $p_L \approx 93\%$, $p_M \approx 83\%$ and $p_P \approx 60\%$. Since $s_P < s_M < s_L$ the leader advantage outweighs the information spillover. Both firms will try to preempt each other when they have one extra positive signal regarding the product's profitability, and if the excess of positive over negative signals is four or more, it is optimal for both firms to disclose simultaneously, before the market response is known. The probability of simultaneous disclosure can be found using equations (3.4.12) and (3.4.9).

Figure 3.1 depicts this situation graphically. The leader's payoff, $L(p_t)$, intersects with the follower's payoff, $F(p_t)$, at $p_P = 0.6$. As shown, for all $p_t < 0.6$, the leader curve lies below the follower's curve; i.e. $L(p_t) < F(p_t)$ and neither firm wants to be the first to disclose. $F(p_t)$ intersects with the payoff curve from simultaneous disclosure, $M(p_t)$, at $p_M \approx 0.83$, and for $p_t \geq 0.83$ it is clear that $F(p_t) = M(p_t)$. However, for $p_t < p_M$, $M(p_t)$ lies below $F(p_t)$ implying that the manager would prefer to wait and obtain the information spillover from the leader rather than disclosing simultaneously before the market response is known. The final intersection point is for $L(p_t) = M(p_t)$ at $p_t \approx 0.38$. However, since this plot depicts the situation whereby the leader advantage outweighs the information spillover; i.e. $p_L > p_P$ (recall $p_L \approx 0.93$), no action will be taken by either firm for $p_t < 0.6$. Hence, $p_t = 0.38$ is not a point that needs to be discussed.

Consider, however, if the parameterisation is such that $V_L^P = 15$ and $V_L^N = -25$.

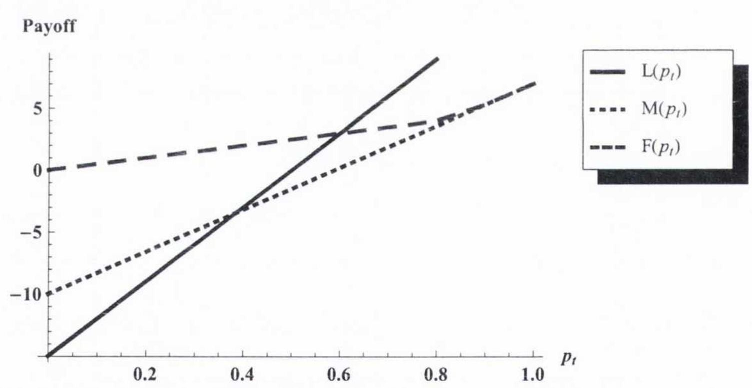

Figure 3.1: Payoff functions.

The condition (3.2.7) no longer holds; that is $p_M > p_P$, and a synergy equilibrium emerges. The situation is depicted graphically in Figure 3.2. The payoff functions $M(p_t)$ and $F(p_t)$ intersect at $p_M \approx 0.83$. It appears from the figure that $L(p_t)$ also intersects them at $p_M \approx 0.83$, but it actually lies slightly below the intersection point at p_M since $F(p_M) = M(p_M) \approx 4.17$ and $L(p_M) \approx 3.33$. For all values of $p_t \leq p_M$, the leader's payoff function lies below the follower's implying that the information spillover outweighs the leader advantage, and thus, neither manager wants to be the first to disclose. Thus, for all $p_t \leq p_M$, there is no point, p_P, such that the leader and follower payoffs are equal. Similarly, for all $p_t < p_M$, $F(p_t) > M(p_t)$ implying that the information spillover also outweighs the synergy effect, and thus, it is not optimal for either manager to disclose simultaneously with his competitor. Hence, no disclosure will be taken by either firm until p_M is reached. Once $p_t \geq p_M$, it is optimal for both firms to disclose simultaneously, and the game ends.

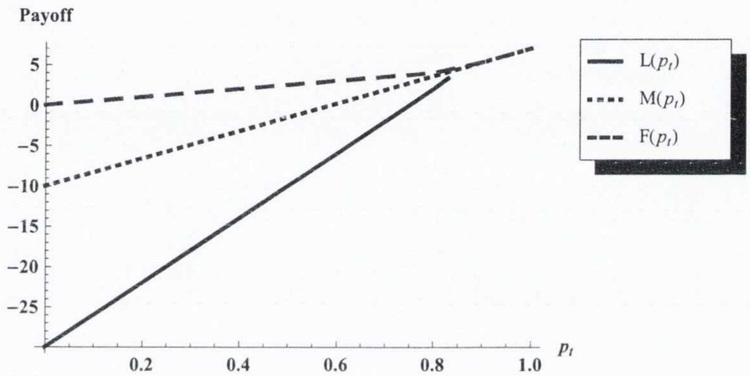

Figure 3.2: Synergistic equilibrium.

3.6 Conclusion

In this chapter I examine the impact of competition, in a duopoly framework, on the voluntary disclosure policy of firms. I assume that each firm has invested in a specific product and the manager of each firm must then decide when to optimally disclose its involvement in the product to the market, while taking into consideration the disclosure strategy of the other firm. A preemption, attrition, or synergy equilibrium arises, depending on the trade-off between first and second mover advantages and, also on the advantage from disclosing simultaneously with the competing firm.

I do not make the assumption that the negative impact of disclosure on firm value is zero, and therefore, a new equilibrium emerges whereby preemption is nonsensical. This so-called "synergistic" equilibrium implies that the optimal strategy of a firm is to never announce, or else to do so only at the same time as its competitor. The intuition behind this equilibrium result is that the investors' conviction that their firm has invested in a profitable venture is strengthened by the fact that another similar firm has also chosen to undertake the same investment. This will then temper any sell-off in shares, if the market were to respond in a negative way to the information, than if only one firm were to disclose, or conversely, amplify the effect of a positive market response.

Chapter 4

An Application of the Real Options Model: Disclosure and Corporate Control

4.1 Introduction

In this chapter, I show how the benchmark (real options) model of voluntary disclosure which I describe in Chapter 2 can be extended to show that when a manager is threatened with a corporate control challenge, with the ensuing possibility of dismissal, he always adopts a more transparent disclosure policy. "Corporate control is the right to determine the management of corporate resources; to hire, fire and set compensation", (see Henderson [23], Jensen and Ruback [24], Fama and Jensen [13]).

For ease of exposition, I assume the situation for the manager in Chapter 2 remains the same; that is, he has invested in some new product or technology and he must decide on the optimal time to reveal his involvement in the investment to the market so as to maximise firm value. Recall that the manager wishes to maximise firm value because he is compensated via stock options. For the managerial belief threshold, p^*, derived in Section 2.2.3 of Chapter 2, there is no possibility that he will face a corporate control challenge from the shareholder. In such instances, the manager never has an incentive to adopt a highly transparent disclosure policy. This is consistent with survey evidence by Graham et al. [17] who find strong support for delaying bad news to allow for further analysis and interpretation of the information they possess.

Typically, a shareholder also wishes for firm value to be maximised, and therefore, the incentives of both agents are perfectly aligned. However, there may be instances whereby the shareholder does not wish for firm value to be maximised, and demands a more transparent disclosure policy instead. In order to keep with the idea of the manager having invested in a new potentially profitable product, I assume that the shareholder wishes to learn of all such investment opportunities the manager has attained so that he, too, may invest in such a new venture with his own private wealth. For the investment to be worthwhile, he must learn of the opportunity early enough so as to acquire an acceptable equity stake for the amount of capital he is willing to invest. If the manager waits until the product is very well developed to reveal any information about the investment to the market; that is, after a large net of positive over negative signals have been obtained, the shareholder may have missed his opportunity to invest; that is, he can no longer hope to acquire an acceptable equity stake for his investment, and the investment opportunity becomes worthless to him. Under such a scenario, the shareholder would prefer the manager to adopt a more transparent disclosure policy. In order to incentivise the manager to be more forthcoming with disclosure, I assume that the shareholder can impose a corporate control challenge on the manager, with some positive probability. If the manager is found to be withholding too much information for the shareholder's liking, he is dismissed. This assumption is consistent with Henderson [23].

This chapter is most closely related to Henderson [23]. She analyses the effect of corporate control challenges on corporate investment in incomplete markets. I adapt that approach to provide an instrument to align the interests of the manager and the shareholder. However, she uses standard stochastic calculus tools to develop her result, which is not possible under my set-up (since information is not constant over time). Furthermore, I do not assume the market for voluntary disclosure is incomplete. The reason I neglect to make this assumption at this stage is for analytical convenience. Such an analysis will be left for further research.

Before analysing the effectiveness of a shareholder's strategy to better incentivise the manager to be more forthcoming with disclosure, I analyse the problem from the shareholder's perspective as if there was *no information asymmetry* between the two parties; that is, if the shareholder were to know all the information the manager has obtained, then at what point would he wish for the manager to disclose so that he may acquire the investment opportunity at the best possible level.

I derive, in Section 4.2.1, a threshold for the shareholder wishing to invest in the product such that his (discounted) expected utility from wealth is maximised. Note that this assumption differs slightly from that of the typical principal-agent model, described by Mas-Colell et al. [32], in which the shareholder wishes to maximise firm value. However, the assumption that the shareholder wishes to maximise his utility is consistent with Suijs [50]. He assumes that the potential shareholder's objective is to maximise his expected utility from his investment payoff, whereby the shareholder has a limited amount of capital available which he can invest in three different projects, namely the firm, the risk-free asset, and some alternative risky investment project. It is further supported by Dye [11] who also assumes that shareholders wish to maximise their (current) utility from wealth.

In Section 4.2.2 I derive the manager's disclosure threshold, but in this case, when he is faced with the threat of a corporate control challenge from the shareholder. An equilibrium is attained when the probability of a control challenge is such that the manager always adopts a disclosure policy that is sufficiently transparent for the shareholder.

I find that the manager's threshold under corporate control is always lower than the threshold when no such corporate control challenge is imposed. The result is intuitive, and it corroborates broadly with anecdotal evidence from Healy and Palepu [21] who hypothesise that managers use corporate disclosures to hedge against the risk of job loss. Furthermore, the greater the probability the manager is faced with a control challenge, the more transparent is the disclosure policy he chooses to adopt.

In Section 4.3, I examine the agency costs that the shareholder may incur through delegating the disclosure decisions to the manager. With respect to my setting, any agency costs that arise are owing to the information asymmetry that exists between the manager and the shareholder. Henderson [23] studies agency conflicts that arise from managerial risk-aversion and incompleteness. There are numerous other forms of agency conflicts between managers and shareholders some of which include empire building, short-termism, and overconfidence (see Stein [46] for a review). However, such studies usually concentrate on the impact of these agency costs on capital budgeting decisions as distinct from disclosure timing. I find that the greater the probability that the manager is faced with a control challenge, the lower the agency costs the shareholder potentially incurs. This is because the greater the probability of control, the more transparent the manager's disclosure policy, and the earlier the shareholder learns of the investment opportunity.

4.2 The Model

4.2.1 Shareholder's Problem

Assume that if the shareholder was to make his own investment in the product, this would impact positively on his discounted, expected utility from wealth by an amount $\bar{U}^P$ or negatively by an amount $\widetilde{I}$.[1] Since this is an investment opportunity for the shareholder, the only negative impact comes from the (sunk) costs of investment, $\widetilde{I}$. The *ex ante* belief that investing in the product will have a positive impact on his utility is denoted by p_0.

I assume that the shareholder knows all of the information the manager has obtained, and thus, he obtains signals regarding the potential profitability of the product at random points in time, and the signal arrivals are modelled via the Poisson process with parameter μ. The signals are accurate with probability $\theta > \frac{1}{2}$.

The solution method for the optimal stopping problem is identical to that for the manager's problem that I derived in Chapter 2. Note, however, that s_t is replaced with $-s_t$ in the analysis. The intuition for this is that as the signals regarding the project's profitability get more and more positive, the value of the investment opportunity for the shareholder declines. While this may appear an unrealistic assumption to make, my reasoning is that the greater potential the product is expected to have, the more capital the shareholder must invest for an acceptable equity stake. Hence, as $s_t \to \infty$, the value of the option to invest tends to zero, because the number of positive signals overwhelming outweigh the number of negatives and it becomes increasingly too expensive for the shareholder to invest, for the amount of equity he will receive in return.

[1] $\bar{U}^P$ is discounted at a constant rate $r > 0$.

Furthermore,

$$s_t := s(p_t) = \frac{\log\left(\frac{p_t}{1-p_t}\right) - \log\zeta}{\log\left(\frac{\theta}{1-\theta}\right)}, \tag{4.2.1}$$

is the inverse function to the shareholder's posterior probability that investing at p_t will have a positive impact on his utility. $\zeta = (1-p_0)/p_0$, and represents the unconditional odds ratio. s_t is an increasing function of p_t, implying one can work with either the critical net number of signals or the shareholder's critical belief.

Solving, then, for the optimal stopping problem yields the shareholder's threshold belief:

$$\underline{p}_* = \frac{(\bar{U}^P - \widetilde{I})\Pi}{(\bar{U}^P - \widetilde{I})\Pi + \widetilde{I}}, \tag{4.2.2}$$

where Π is given by

$$\Pi = \frac{\Big(\beta_1(r+\mu) - \mu\theta(1-\theta)\Big)\left(\frac{r}{\mu} + 1 - \theta\right) - \mu\theta(1-\theta)\beta_1}{\Big(\beta_1(r+\mu) - \mu\theta(1-\theta)\Big)\left(\frac{r}{\mu} + \theta\right) - \mu\theta(1-\theta)\beta_1}. \tag{4.2.3}$$

Above the threshold $\underline{s}_* := s(\underline{p}_*)$, it is optimal for the shareholder to do nothing and below it to invest. This is because for any $s_t > \underline{s}_*$, the shareholder must impart with too much capital to be satisfied of an acceptable return on his investment. Conversely, for $s_t \leq \underline{s}_*$, the shareholder can invest less capital for a higher equity stake, which is a much more acceptable investment for him in the long-term. Of course, implicit in this set-up is that the shareholder believes that in time, the product will turn out to be very profitable, but is only a worthwhile investment at this stage if he can attain a sufficient equity stake for the capital he is willing to invest.

Theorem 2. *The optimal stopping problem for the shareholder,* $\widetilde{U}^*(s_t) = \sup_{t\geq\tau}\mathbb{E}_t[e^{-r\tau}\widetilde{U}(s_\tau)]$, *is solved by*

$$
\widetilde{U}^*(s_t) = \begin{cases} \widetilde{U}(s_t) & \textit{if } s_t \le \underline{s}_* \\ \frac{\mu}{r+\mu}\Big(\frac{\theta(1-\underline{p}(s_t))}{1-\underline{p}(s_t-1)}\widetilde{U}(s_t-1) + \Big[\frac{r}{\mu(1-\theta)}\frac{\widetilde{U}(\underline{s}_*)}{1-\underline{p}(\underline{s}_*)} + \frac{\widetilde{U}(\underline{s}_*+1)}{1-\underline{p}(\underline{s}_*+1)}\Big]\times \\ (1-\theta)(\frac{\beta_1}{\theta})^{\underline{s}_*-s_t}\left(1-\underline{p}(s_t)\right)\Big) & \textit{if } \underline{s}_* < s_t \le \underline{s}_*+1 \\ (\frac{\beta_1}{\theta})^{\underline{s}_*-s_t+1}\left(1-\underline{p}(s_t)\right)\Big[\frac{r}{\mu(1-\theta)}\frac{\widetilde{U}(\underline{s}_*)}{1-\underline{p}(\underline{s}_*)} + \frac{\widetilde{U}(\underline{s}_*+1)}{1-\underline{p}(\underline{s}_*+1)}\Big] & \textit{if } s_t > \underline{s}_*+1. \end{cases} \tag{4.2.4}
$$

where $\widetilde{U}(s_t)$ *is given by*

$$\widetilde{U}(s_t) = (1-\underline{p}(s_t))V^P - I,$$

$\underline{p}(s_t) = \frac{\zeta(1-\theta)^{-s_t}}{\theta^{-s_t}+\zeta(1-\theta)^{-s_t}}$, *and* $\underline{s}_*$ *is given by (4.2.1).*

Additionally, the optimal stopping time, τ^*, *is given by*

$$\tau^* = \inf\{t \ge 0 | s_t \le \underline{s}_*\}.$$

Proof. The proof is similar to that outlined for Theorem 1 in Chapter 2. □

The probability that the shareholder imposes a corporate control challenge on the manager will be dependent on the value of his option to invest. Additionally, this probability must, intuitively, increase the further the manager's disclosure level deviates from $\underline{s}_*$. The formulation I adopt for this probability ensures these considerations are adhered to.

I let the probability of a corporate control challenge be given by

$$\mathbb{P}(s_t) = 1 - \left(\frac{\widetilde{U}(s_t)}{\widetilde{U}^*(s_t)}\right), \tag{4.2.5}$$

where $\widetilde{U}^*(s_t)$, the value of the shareholder's investment option, has been defined in Theorem 2. Note that s_t in equation (4.2.5) represents the level at which the manager makes a disclosure.

Equation (4.2.5) is well-defined if, and only if, $\widetilde{U}^*(s_t) \ge \widetilde{U}(s_t) > 0$. The probability is zero for all $\underline{s}_* \ge s_t$. This implies that there is no chance of a control challenge if the manager discloses at, or below, the shareholder's preferred threshold $\underline{s}_*$. This is because if $s_t \leq \underline{s}_*$, the manager's disclosure policy is sufficiently transparent for the shareholder. This implies that if the manager has invested in a product that is of interest to the shareholder, the shareholder learns of the opportunity early enough; that is, when the capital required for an acceptable amount of equity is small enough to make the investment worthwhile.

Furthermore, $\widetilde{U}^*(s_t)$ dominates $\widetilde{U}(s_t)$ for (4.2.5) to be well-defined, then this implies that $\mathbb{P}(s_t)$ is increasing in s_t. Therefore, the less transparent the manager's disclosure policy, that is, the higher s_t, the higher the probability that he will face a corporate control challenge.

I note that the model of corporate control which I describe here relates to large firms whose shareholders are not active in management decisions. However, many firms have controlling shareholders who are often active in management. LaPorta et al. [28] find "family control of firms appears to be common, significant, and typically unchallenged by other equity holders". In such firms, monitoring and disciplining the manager becomes very difficult. However, this proxied for in my model because if the shareholder is active in management, he always learns of the investment opportunity in a timely manner; that is, he always learns about it when $s_t \leq \underline{s}_*$, and thus, $\mathbb{P}(s_t) = 0$.

4.2.2 Manager's Problem

I assume a quasi-linear utility function for the manager, such that if he is dismissed, he obtains no compensation from disclosure. Then the manager's objective function becomes

$$U^*(s_t) = \sup_{\tau \geq t} \mathbb{E}_t[e^{-r\tau} U(s_\tau)], \tag{4.2.6}$$

with

$$U(s_t) := \left(p(s_t)V^P + (1-p(s_t))V^N - I\right)\mathbb{I} \tag{4.2.7}$$

and

$$\mathbb{I} = \begin{cases} 1 & \text{if no dismissal} \\ 0 & \text{if manager dismissed.} \end{cases}$$

Once again, I solve the manager's problem, which incorporates the probability of a corporate control challenge being imposed, as an optimal stopping problem (as in Chapter 2). The threshold I obtain is given by

$$p_c^* = \left[\frac{V^P - I}{I - V^N}\Pi_c + 1\right]^{-1}, \tag{4.2.8}$$

where

$$\Pi_c = \frac{\varsigma(\mu,\theta,r)\left[\left(\frac{r}{\mu}+1\right)\widetilde{U}(s^*) - \theta\nu(s^*)\right] - \upsilon(\mu,\theta,s^*)}{\varsigma(\mu,\theta,r)\left[\left(\frac{r}{\mu}+1\right)\widetilde{U}(s^*) - (1-\theta)\nu(s^*)\right] - \upsilon(\mu,\theta,s^*)}, \tag{4.2.9}$$

and

$$\varsigma(\mu,\theta,r) = \beta_1(r+\mu) - \mu\theta(1-\theta),$$

$$\upsilon(\mu,\theta,s^*) = \mu\theta(1-\theta)\beta_1\widetilde{U}(s^*),$$

$$\nu(s^*) = \frac{\widetilde{U}(s^*+1)}{\widetilde{U}^*(s^*+1)}\widetilde{U}^*(s^*).$$

It is easy to verify, from equation (4.2.7), that the net present value belief level under the threat of a control challenge is the same p_{NPV} than when no such threat exists; that is

$$p_{NPV}^c = \frac{I - V^N}{V^P - V^N} \tag{4.2.10}$$

for all $\mathbb{P}(s_t) \geq 0$.

The following propositions state some of the important properties associated with p_c^*, the proofs of which are found in Appendices A, B, and C, respectively.

Proposition 6. *If the probability of a control challenge is zero, then* $\Pi_c = \Pi$ *and* $p_c^* = p^*$, *as given by equation (2.11). Moreover,* $p_c^* > p_{NPV}$ *irrespective of the probability of a corporate control threat.*

Proposition 7. p_c^*, *given by equation (4.2.8), is a well defined probability.*

Proposition 8. *An increase in the probability of a control challenge leads to a more transparent disclosure policy being adopted by the manager.*

Figure 4.1 depicts graphically the results stated in Proposition 6 and Proposition 8. The thick solid line shows how p_c^* decreases in the probability of a control challenge, and $p_c^* = p^*$ at the intersection with the vertical axis. The threshold lies above the NPV threshold for all values $\mathbb{P}(s_t)$, and hence, the real options approach always demands a more stringent criteria on the optimal level of disclosure than the traditional NPV approach demands.

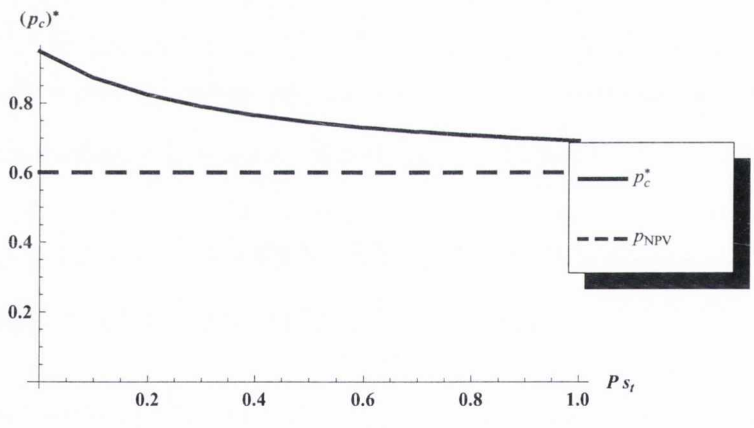

Figure 4.1: The effect of a control challenge threat on p_c^*.

4.2.3 Model Implications

In order to ascertain the implications of this model, I first recall the manager's optimal disclosure threshold when he faces no risk of incurring a corporate control challenge. From Chapter 2, this is given by

$$p^* = \left[\frac{V^P - I}{I - V^N}\Pi + 1\right]^{-1}, \tag{4.2.11}$$

where Π is defined by equation (2.12).

As I discussed in Chapter 2, p^* is typically an equilibrium threshold owing to the assumption that the manager is compensated via stock options. I compare this threshold level, when the manager is not faced with a corporate control challenge, with the shareholder's investment threshold given by (4.2.2) by making the assumption that $\overline{U}^P = V^P$ and $\widetilde{I} = I$. I make this assumption for analytical convenience, and it is without loss of generality. The threshold given by (4.2.2) represents the shareholder's optimal investment level, given that he desires a highly transparent disclosure policy.

In particular, I find that p^* is no longer an equilibrium threshold because it is always the case that $p^* > 1 - \underline{p}_*$ because $V^N < 0$. Note that I compare p^* with $1 - \underline{p}_*$ because $1 - \underline{p}_*$ is the level *above* which the shareholder will invest and p^* is the level *above* which the manager will disclose. What this result implies is that the manager will always disclose at a higher threshold, when he is not faced with a corporate control challenge, than the shareholder would prefer. Specifically, in the absence of control, the manager's disclosure policy is not sufficiently transparent for the shareholder.

This is driven by the fact that making a disclosure may have a negative impact, in addition to the costs of disclosure, on the value of the firm, i.e. $V^N < 0$. However, for the shareholder, any loss from investment will be limited to the investment cost incurred. Thus, the manager always opts to disclose his information about the product's potential profitability later than would be optimal for the shareholder.

In order to incentivise the manager to act in the shareholder's interest through adopting a more transparent approach to disclosure, the manager is faced with the probability of a corporate control challenge if his value-maximising disclosure policy is too far mis-aligned from such a shareholder's utility maximising policy.

Under this scenario, an equilibrium is obtained, and the incentives of the two parties are aligned when the probability of a corporate control challenge is such that

$$p_c^* \leq 1 - \underline{p}_*,$$

where p_c^* is given by (4.2.8). Hence an equilibrium is attained when

$$\Pi_c \geq \left(1 - \frac{V^N}{I}\right)\Pi, \tag{4.2.12}$$

such that Π_c is given by (4.2.9). To extract a specific equilibrium level for $\mathbb{P}(s_t)$ is too cumbersome, but the condition given by (4.2.12) gives an adequate insight into the mechanisms at play.

If the condition given by (4.2.12) fails to hold, then the manager's disclosure policy is too intransparent for the shareholder's satisfaction. This situation will ensue if the possible negative impact on the firm value through making a disclosure, V^N, is too large relative to the cost of disclosure. Technically, this result arises from the fact that the right hand side of (4.2.9) decreases in V^N. This conclusion is intuitive, since the greater the possible negative impact from disclosure, the longer the manager will wait before announcing his information (recall Section 2.3 in Chapter 2). Hence, the less transparent the disclosure policy will be.

4.3 Agency Costs

In this section I examine the agency costs that may be incurred by the shareholder, considering when to invest capital in the new product, as a result of acting in line with the manager's voluntary disclosure policy. My aim is to ascertain whether the threat of a corporate control challenge helps to reduce any agency costs that he may incur as a result of delegating the disclosure decision to the manager.

I define these agency costs by the difference in the value of the investment option for the shareholder at his own optimal threshold, $\underline{s}_*$, and the value of the option if he were to act at the point where the manager discloses, s_t. Since the manager discloses at s_t, then of course, it is always the case that $s_t \geq s_c^*$.

$$\underline{C} := \widetilde{U}^*(\underline{s}_*) - \widetilde{U}^*(s_t), \tag{4.3.1}$$

where $\widetilde{U}^*(\cdot)$ is defined in Theorem 2.

If $s_t \leq \underline{s}_*$, then (by Theorem 2)

$$\begin{aligned} \underline{C} &= \widetilde{U}(\underline{s}_*) - \widetilde{U}(s_t) \\ &= \overline{U}^P \left(\underline{p}(s_t) - \underline{p}(\underline{s}_*)\right) \leq 0, \end{aligned} \tag{4.3.2}$$

since $\underline{p}(s_t)$ increases in s_t. The negative identity implies that the shareholder incurs no agency costs. This ensues because the value of the option to invest for the shareholder is at least as great if he were to invest at the manager's point of disclosure than if he were to invest at $\underline{s}_*$. In other words, if the shareholder were to invest in the product at the same level the manager discloses, that is, if he were to invest at s_t, the value of his investment opportunity would be greater at that point than if he were to invest at $\underline{s}_*$. This is because he will, for example, learn about the product's existence at an earlier stage in the development process and may therefore attain a high level of equity for a relatively small amount of capital.

If, however, $s_t > \underline{s}_*$,

$$\begin{aligned} \underline{C} &= \widetilde{U}(\underline{s}_*) - \widetilde{U}^*(s_t) \\ &\leq 0 \\ &\iff s_t \leq \underline{s}_*. \end{aligned} \tag{4.3.3}$$

However, $s_t > \underline{s}_*$, by assumption, and thus, $\widetilde{U}(\underline{s}_*) > \widetilde{U}^*(s_t)$. This implies that if the manager discloses above the shareholder's threshold, $\underline{s}_*$, the value of the option to the shareholder of investing is lower if he were to act at the manager's disclosure level, than at his own. Hence agency costs will be incurred by the shareholder through delegating the disclosure decision to the manager. For example, the shareholder will only learn about the investment opportunity too far on in the (product's) development process for him to attain an acceptable equity stake for the amount of capital he can afford to put up.

The following proposition shows how an increase in the probability that the manager faces a control challenge results in lower agency costs being incurred by the shareholder who desires a transparent disclosure policy. The proof is outlined in Appendix D.

Proposition 9. *An increased threat imposed on the manager of a corporate control challenge reduces the agency costs that may be incurred by the shareholder.*

This result is clearly depicted in Figure 4.2, which shows the agency cost, as a proportion of the shareholder's utility-maximising threshold, for each level of $\mathbb{P}(s_t)$.

4.4 Conclusion

In this chapter, I show how the benchmark (real options) model of voluntary disclosure I describe in Chapter 2 can be extended to show that when a manager is threatened with a corporate control challenge, with the ensuing possibility of dismissal, he always adopts a more transparent disclosure policy.

I derive the manager's disclosure threshold, adjusted for the fact that he is faced with the threat of a corporate control challenge. An equilibrium is attained between

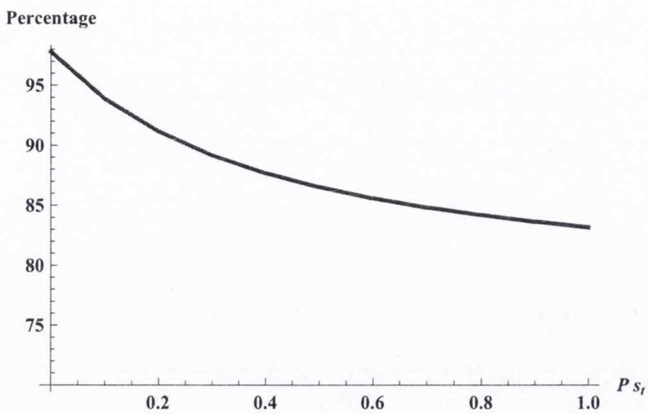

Figure 4.2: The effect of a control challenge threat on the agency costs incurred by the shareholder.

the manager and the shareholder when the probability of such a challenge is such that manager always adopts a disclosure policy that is sufficiently transparent for the shareholder.

I find that the manager's threshold under corporate control is always lower than the threshold when no such corporate control challenge is imposed. Furthermore, the greater the probability the manager is faced with a control challenge, the more transparent is the disclosure policy he chooses to adopt. Additionally, if there is a high probability of a control challenge being imposed, the current approach still asserts that disclosure should occur later, but not much later, than the NPV approach suggests. An implication of this result is that the NPV approach, when combined with a high probability of a corporate control challenge being imposed, may not be a such a poor representation of voluntary disclosure behaviour.

Finally, I examine the agency costs that the shareholder may incur through delegating the disclosure decisions to the manager. I find that the greater the probability the manager is faced with a control challenge, the lower the agency costs the shareholder potentially incurs. This is because the greater the probability of control, the more transparent the manager's disclosure policy, and the earlier the shareholder learns of the investment opportunity.

Appendix

A Proof of Proposition 6

$\mathbb{P}(s_t) = 0$ if, and only if, $s_t \leq \underline{s}_*$, if, and only if, $s^* \leq \underline{s}_*$.

So if $\mathbb{P}(s_t) = 0$, $\widetilde{U}^*(s^*) = \widetilde{U}(s^*)$ and equation (4.2.9) reduces to

$$\Pi_c = \frac{\varsigma(\mu, \theta, r)\left[\left(\frac{r}{\mu}+1\right) - \theta\frac{\widetilde{U}(s^*+1)}{\widetilde{U}^*(s^*+1)}\right] - \mu\theta(1-\theta)\beta_1}{\varsigma(\mu, \theta, r)\left[\left(\frac{r}{\mu}+1\right) - (1-\theta)\frac{\widetilde{U}(s^*+1)}{\widetilde{U}^*(s^*+1)}\right] - \mu\theta(1-\theta)\beta_1}.$$

If $s^* + 1 \leq \underline{s}_*$, then $\widetilde{U}^*(s^*+1) = \widetilde{U}(s^*+1)$, and $\Pi_c = \Pi$, trivially.

However, if $s^* + 1 > \underline{s}_*$, then $\widetilde{U}^*(s^*+1)$ is given by

$$\widetilde{U}^*(s^*+1) = \frac{\mu}{r+\mu}\Big(\frac{\theta(1-\underline{p}(s^*+1))}{1-\underline{p}(s^*)}\widetilde{U}(s^*) + \Big[\frac{r}{\mu(1-\theta)}\frac{\widetilde{U}(\underline{s}_*)}{1-\underline{p}(\underline{s}_*)} + \frac{\widetilde{U}(\underline{s}_*+1)}{1-\underline{p}(\underline{s}_*+1)}\Big] \times (1-\theta)(\frac{\beta_1}{\theta})^{\underline{s}_*-s^*+1}\left(1-\underline{p}(s^*)\right)\Big)$$

By the continuity condition utilised in the derivation of $\underline{p}_*$, this expression is exactly equal to $\widetilde{U}(s^*+1)$ for $\underline{s}_* < s^* + 1 \leq \underline{s}_* + 1$. Hence, whenever $\mathbb{P}(s_t) = 0$, $\Pi_c = \Pi$.

It is easy to verify from equation (4.2.8), given $p^c_{NPV} = \frac{I-V^N}{V^P-V^N}$, that $p^*_c > p^c_{NPV}$ if, and only if, $\Pi_c < 1$. It is easily established that $\Pi_c < 1$ if, and only if, $1-\theta < \theta$, which is satisfied.

This proves that $p^*_c > p^c_{NPV}$. ∎

B Proof of Proposition 7

Firstly, $p_c^* = p^*$ when $\underline{s}_* \geq s^*$ (see Proposition 6 above). It has been proven in Proposition 1 of Chapter 2 that p^* is well-defined, and therefore p_c^* is well-defined for $\underline{s}_* \geq s^*$. It is necessary to show that p_c^* is also well-defined for $\underline{s}_* < s^*$.

It is easily proven that for $0 < p_c^* \leq 1$ to hold, it must be that $\Pi_c \geq 0$.

As shown in Proposition 6, if $\mathbb{P}(s^*) = 0$, $\Pi_c = \Pi > 0$.

If $\mathbb{P}(s^*) = 1$, this implies, from (4.2.5) that $\widetilde{U}(s^*) = 0$. Then, from (4.2.9), $\Pi_c = \frac{\theta}{1-\theta}$.

But $\frac{\theta}{1-\theta} > \Pi$, where Π is given by (2.12), if

$$\beta_1(r+\mu)\left(\frac{r}{\mu}+1\right) - \mu\theta(1-\theta)(\frac{r}{\mu}+1+\beta_1) > 0,$$

which is trivially satisfied since $\beta_1 > \theta$. Hence, for $\mathbb{P}(s^*) = 1$, $\Pi_c > \Pi$.

Therefore, $\Pi_c \geq \Pi$ for all s^*. From Proposition 1, $\Pi \geq 0$, and therefore, $\Pi_c \geq 0$, as required. ∎

C Proof of Proposition 8

$$\frac{\partial p_c^*}{\partial \mathbb{P}(s_t)} = -\left(\frac{V^P - I}{I - V^N}\Pi_c + 1\right)^{-2} \frac{V^P - I}{I - V^N}\frac{\partial \Pi_c}{\partial \mathbb{P}(s_t)}.$$

From Proposition 7, $\frac{\partial \Pi_c}{\partial \mathbb{P}(s_t)} > 0$, implying $\frac{\partial p_c^*}{\partial \mathbb{P}(s_t)} < 0$. Thus, the greater the probability of a corporate control challenge, the lower the threshold above which the manager will disclose. ∎

D Proof of Proposition 9

It is clear from equation (4.3.1) that

$$\frac{\partial \underline{C}}{\partial \mathbb{P}(s_t)} \leq 0 \Longleftrightarrow \frac{\partial \widetilde{U}^*(s_t)}{\partial \mathbb{P}(s_t)} \geq 0 \tag{D.1}$$

However, since s_t increases in p_t, and from Proposition 8, the level at which the manager discloses decreases in the probability of a control challenge, s_t decreases in $\mathbb{P}(s_t)$.

Furthermore,

$$\frac{\partial \widetilde{U}^*(s_t)}{\partial s_t} < 0 \tag{D.2}$$

since the value of the shareholder's investment decreases in s_t. Therefore,

$$\frac{\partial \widetilde{U}^*(s_t)}{\partial \mathbb{P}(s_t)} \geq 0 \tag{D.3}$$

implying that the agency costs are decreasing in the threat of a corporate control challenge. ■

Chapter 5

Jump Diffusion Models: Estimation of Fit and Predictive Power

5.1 Introduction

Most of the models and option pricing techniques employed in applied areas of finance are rooted in the well known Black-Scholes model. The classical model used for stock prices or indices, and which became the basis for the Black-Scholes option pricing theory is the geometric Brownian motion (GBM hereafter). However, almost as universally accepted as the Black-Scholes model itself, are its weaknesses. For instance, GBM is based on the predominant assumption that observations follow a Gaussian (Normal) distribution. This is largely due to the fact that the normal distribution, as well as the continuous-time process it generates, has nice analytic properties. However, a look at data from various areas of finance such as equity, fixed income, foreign exchange or credit, clearly reveals that by assuming normality, one gets a model which is only a poor approximation of reality.

The central assumptions underlying a sequence of events that lead to a Gaussian distribution are;

1. The events are independent of one another; that is, they have no memory. In terms of stock prices, this would imply that this period's return is totally independent of any previous period's return. In reality this is not the case because a type of "herding" activity is prevalent in equity trading. For example, if a stock price drops by a significant amount in one period, it may continue to drop by a significant amount in subsequent periods, in response to the initial decline, as traders attempt to protect their portfolios. This is precisely what happened on October 19th, 1987, when the Dow Jones Industrial Average dropped almost 300 points in one day.[1]

2. There are no "wild" jumps or uncertainty as to step size. However, recent events have shown that stock prices have been subject to abrupt and unanticipated large changes or "jumps", and have become highly unstable and volatile in nature. Black-Scholes based models, such as GBM, fall apart in environments with rapid movements in the underlying assets. This is because the key distributional assumption is that the price of an asset follows a diffusion; that is, a stochastic process that generates a continuous sample path. In fact, this assumption implies normality, so that over a short interval of time, the stock price cannot change by much. The recent stock market volatility, during the 2007/08 Credit-Liquidity Crisis, and the example cited above of October 1987, provide evidence that diffusions inadequately characterise asset price movements and that processes allowing for jumps would be more appropriate.

From a practical viewpoint, financial decision making using models which are

[1]This is according to the Brady Commission Report, published by Lewis [29], page 29.

based in a continuous-time setting will be satisfactory only if reasonable specifications of the stock price process are built upon. As well as this, the extent of skewness and the presence of outliers in an actual return distribution are important inputs to hedging and risk management decisions, as well as for option pricing. However, in a Black-Scholes based framework, such inputs are unaccounted for. Indeed, much of the catastrophic occurrences in the global financial sector of late have been attributable, in effect, to the Black-Scholes theory.

Despite these shortcomings of classical financial theory, the market has still not abandoned the Black-Scholes framework. In fact, its influence has become more pronounced than ever. At the end of 2006, according to the Bank for International Settlements, there was $415 trillion in derivatives for which there is no completely satisfactory pricing model (see Lewis [29]). As well as this there are the trillions more of other such derivatives, for example, mortgage bonds and exchange traded options, most of which are still priced using some version of Black-Scholes, and thus, without regard to the possibility of crashes and panics.

Although the GBM had served as a convenient and tractable framework, as the empirical evidence against GBM accumulated (see Sundaresan [51]), Merton's jump diffusion (LJD) representation gained wide acceptance, primarily because it was shown to be more consistent with the empirical returns distributions; that is, it produced a higher peak and accounted for excess kurtosis and skewness.

Recent work has stressed the importance of continuing to search for models based on processes that admit jumps and thereby providing a more accurate fit to the observed data. Concerted efforts are also being made to ensure such models are meaningful and mathematically plausible. In extant literature, a wide range of continuous-time models have been constructed by choosing different theoretical structures for the drift, the diffusion, and the jump component of the process (for example, stochastic volatility and mean reversion). Also many variations have been proposed to enhance the jump specification by, for example, including different distributional assumptions for the jump magnitudes. Andersen and Andreasen [2] proposed a model in which a non-random volatility structure is combined with log-normally distributed Poisson jumps. Kou [27] proposes the Double Exponential Jump Diffusion (DEJD) model whereby a single Poisson process with fixed intensity generates the jumps in prices, but the jump amplitudes are drawn from two independent exponential distributions. The point of such models is to improve derivative pricing and portfolio optimisation. These extensions are intended to reduce the deviation between model and reality. Adding a jump component should improve the fit to the observed time series of returns, since the jumps may accommodate outliers as well as asymmetry in the return distribution. The presence of outliers depends upon the magnitude and variability of the jump component, while the asymmetry is controlled for by the average magnitude of the jump.

While much of the literature has focussed primarily on improving the fit of these specifications with the data, to my knowledge, there has been very little effort, if indeed any, to assess their predictive power. The aim of this research is to go beyond the process introduced by Merton [35] and, through a selection analysis, by assuming a different distributional choice to model the jump component, in particular a Gamma Distribution for the "good" news component and a Beta Distribution for the "bad" news component, assess whether the fit of the model will be enhanced, and/or more importantly, whether its forecasting accuracy will be improved.

I use daily returns data for the ISEQ, FTSE100 and S&P500 indices and also from a number of stocks included in one or other of these indices, in conjunction with cumulant moment matching to fit the models. The data source is Bloomberg. I will utilise the Schwartz Bayesian Information Criterion (BIC) to assess the relative performance of the models as outlined in Ramezani and Zeng [40].[2] In order to

[2]The more commonly used Akaike criterion (AIC) for model selection tends to over-

assess the predictive performance, I calculate the Root Mean Square Error (RMSE) and the Janus Coefficient (J).

In the next section I discuss the standard GBM model and Merton's LJD model. In Section 5.3 I explain the motivation behind the so called Gamma-Beta specification (GBJD). In sections 5.4 through to 5.6 I describe the model estimation, the selection process, and the assessment of its predictive power in some detail. In sections 5.7 and 5.8 the data is examined and the results are obtained, while in Section 5.9 I discuss the results in context with the Black-Scholes option pricing model. Section 5.10 finally concludes.

5.2 Log-Normal Jump Diffusion Model

In order to establish a benchmark, I initially estimate a representation that is compatible with the Black-Scholes model. The classical model of GBM is given by the Stochastic Differential Equation (SDE):

$$\frac{dS_t}{S_{t-}} = \mu dt + \sigma dW_t \tag{5.2.1}$$

which represents the price process of the stock with price S_t, at time t, and $S_{t-} := \lim_{dt \downarrow 0} S_t dt$. All processes are defined on a probability space $(\Omega, \mathscr{F}, \mathbb{P})$ with filtration $(\mathscr{F}_t)_{t \geq 0}$.

The two terms are familiar from the Black-Scholes model where the drift rate (or instantaneous expected return on the stock) is denoted by μ, volatility σ, conditional on no arrivals of important new information (both μ and σ are assumed to be constant), and the random walk (Wiener process) by W_t.

As a first extension of the GBM representation, I estimate Merton's model (Merton [35]). His papers suggest that asset price dynamics may be modelled as jump-

parameterise the models (see Schwartz [42]), hence I opt to utilise BIC.

diffusion processes and they provide the foundations to value contingent claims under this specification. In particular, he asserted that the true process of the underlying asset is a combination of a log-normal process and a jump process. These jump diffusion class of representations of an asset's return process may be decomposed into three building blocks; a linear drift, a Brownian motion (diffusion component) representing "normal" price variations due to, for example, changes in the economic outlook or other new information that causes marginal changes in the asset's value, and a compound Poisson process (jump component) that generates "news" arrivals leading to "abnormal" (or more than marginal) changes in prices. I assume that this important new information arrives only at discrete points in time, and it is reasonable to expect that the volatile and more "abnormal" periods are random.

Upon arrival of news, jump magnitudes are determined by sampling from an independent and identically distributed (IID) random variable. Merton's special case has become the most important representation of the jump diffusion process. In the jump diffusion model posited by Merton [35], the GBM model (or Black-Scholes specification) is extended to accommodate a jump component, thus representing the process like so:

$$\frac{dS_t}{S_{t-}} = \mu dt + \sigma dW_t + \sum_{j=1}^{J} Y_{j,t} dN_{j,t}. \tag{5.2.2}$$

The last term represents the jumps, with J being the number of Poisson processes denoted by $N_{j,t}$, and the number of stochastic or deterministic jump amplitudes are denoted by $Y_{j,t}$. Hence, there is an instantaneous jump in the relative stock price of size $Y_{j,t}$ conditional on an increment in $N_{j,t}$. $N_{j,t}$ has constant jump intensity λ_j for $j = 1 \ldots J$; that is, λ_j is the mean number of arrivals of important new information per unit time and $\mathbb{P}(dN_{j,t} = 1) = \lambda_j dt$. The jump amplitude, $Y_{j,t}$, may follow any distribution, but Merton [35] assumes an IID log-normal (α, δ^2) distribution (that is, $\log(1 + Y_t) \backsim N(\alpha, \delta^2)$) and Poisson (λ) arrival process. Hence, the model is more commonly referred to as the Log-Normal jump diffusion (LJD) model.[3] He further assumes that all processes are independent and that $Y_{j,t} > -1$ for all j, which ensures that stock prices are non-negative.

The presence of a jump component provides additional flexibility in capturing the salient features of equity returns, including skewness and leptokurtosis.

By applying Ito's formula (for semi-martingales) to $\partial \ln S_t$ and, through integration and the Fundamental Theorem of Calculus, a solution for (5.2.2) is obtained and given by[4]:

$$S_t = S_0 \exp\{(\mu - \frac{1}{2}\sigma^2)t + \sigma W_t\} \prod_{0<s<t} \prod_{j=1}^{J} (1 + Y_{j,s} dN_{j,s}). \tag{5.2.3}$$

The density function for the log-return, $r_{i+1} = \log(S_{i+1}) - \log(S_i)$, is:

$$p(x;\Theta) = \sum_{j=0}^{\infty} \frac{e^{-\lambda t}(\lambda t)^j}{j!} \varphi(x; (\mu - \frac{1}{2}\sigma^2)t + j\alpha, \sigma^2 t + j\delta^2), \tag{5.2.4}$$

where $\varphi(x; \mu, \sigma^2)$ is the density for a normally distributed random variable with mean μ and variance σ^2 and t is the sampling frequency. The log-likelihood function can be written as:

$$l(x_1 \dots x_T; \Theta) = \sum_{i=1}^{T} \log p(x_i; \Theta). \tag{5.2.5}$$

As a second extension to the GBM, I assume a different modelling structure for the jump components and refer to this new formation as the Gamma-Beta jump diffusion (GBJD) model.

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[3]Another strong assumption of the model is that the jump component of the underlying stock's return represents non-systematic or diversifiable risk, and therefore, all of the stock's systematic or non-diversifiable risk is contained within the continuous component.

[4]Alternatively, an explicit solution is provided by the Doleans-Dade formula outlined in Protter [39].

5.3 Gamma-Beta Jump Diffusion Model

While Merton's LJD model is an improvement on the Black-Scholes based GBM specification, it too is based on underlying assumptions which are clear deviations from reality. For example, the model makes no distinction between the intensity or distributional characteristics of news that cause an upward jump in prices, that is, "good news", and news that cause downward jumps, or "bad news". It simply has a single jump component that captures the impact of news on security prices.

This limitation of Merton's LJD model has led me to propose another specification of the jump diffusion model in which the upward and downward jumps are distinguished in terms of their distributional characteristics. I model the upward jump amplitudes via the Gamma distribution and the downward jumps via a Beta distribution and investigate if this choice of distributions will improve the fit or, more importantly, the forecasting accuracy over the other models.

There are several economic justifications for distinguishing between so called "good" and "bad" news. One such justification is provided by Milgrom [36], who has formalised the notion of good and bad news and shown that such a distinction plays an important role for models used in information economics. Because information economics is the study of situations in which different economic agents have access to different information, signalling models, such as that of Spence [44], are typically applied to deal with such information asymmetries. In such signalling models, the analysis is driven by a monotonicity property; for example, more talented workers buy more education. In order to incorporate the important role of monotonicity in models of rational expectations, which form the basis of information economics, a model which makes the distinction between good and bad news is necessary to obtain reliable results; specifically, in a rational expectations model, the rise in a firm's stock price should be attributable to the arrival of good news about the firm's prospects, and vice versa.

The separation of good from bad news implies that some constraints must be imposed upon the range of values for the random return series. Firstly, the returns due to bad news must be bounded on the downside by -100% because stocks represent limited liability. Secondly, the returns due to good news must be positive. These constraints imply that one cannot model either the up or down jump amplitudes by assuming a log-normal distribution. They also indicate which distributions may be plausibly utilised when modelling upward and downward movements. The Gamma distribution requires that the underlying random variables are necessarily positive, and thus, I model the jump amplitudes for good news by a Gamma(1, α_u^{-1}) distribution, and assume a Beta(1, α_d) distribution to model those amplitudes that are due to bad news. As with many other statistical distributions, the Beta distribution does not require the underlying random variables to be necessarily positive or negative. However, I opt to use this distribution to model the downward jump amplitudes because of its compatibility with the Gamma distribution for modelling purposes.

Equation (5.2.2) then becomes:

$$\frac{dS_t}{S_{t-}} = \mu dt + \sigma dW_t + \sum_{j=1}^{J_u} Y_{j_u,t} dN_{j_u,t} + \sum_{j=1}^{J_d} Y_{j_d,t} dN_{j_d,t} \tag{5.3.1}$$

where the third term is a summation over the upward jumps (see subscripts u) and the fourth over the downward movements (see subscripts d). The solution is given by:

$$S_t = S_0 \exp\{(\mu - \frac{1}{2}\sigma^2)t + \sigma W_t\} \prod_{0<s<t} \prod_{j=u,d}^{G,B} (1 + Y_{j,s} dN_{j,s}) \tag{5.3.2}$$

such that G and B relate to the number of observations with upward movements and downward movements respectively.

From this model, the parameters $\Theta = (\mu, \sigma, \lambda_u, \lambda_d, \alpha_u, \alpha_d)$ must be estimated.

In essence, the Gamma-Beta model reduces to a single jump diffusion model, such as Merton's LJD, when $\lambda = \lambda_u + \lambda_d$ and has a jump amplitude which takes the form of a mixed distribution of Gamma(1, α_u^{-1}), with probability $\frac{\lambda_u}{\lambda}$, and Beta(1, α_d) with probability $\frac{\lambda_d}{\lambda}$.

5.4 Estimation

One method of obtaining parameter estimates for the model is to match cumulants; that is, to equate the first six population cumulants with the first six sample cumulants, since the model has six unknown parameters that need to be estimated $(\mu, \sigma, \lambda_u, \lambda_d, \alpha_u, \alpha_d)$. Then the resulting equation for the parameters must be solved. I follow the procedures outlined in Kendall and Stuart [25].

I used STATA10 to calculate the first six sample cumulants, $\bar{M}_s, s = 1 \ldots 6$ from the sample moments, $\bar{m}_s = \mathbb{E}[X^s]$, in each of the data sets via the equation $\bar{M}_s = \mathbb{E}[(X - \mathbb{E}[X])^s] = \mathbb{E}[(X - m_1)^s]$, $s = 1, \ldots 6$.

I define $U := \sum_{i=1}^{G_s} \ln(Y_i^u)$ and $D := \sum_{i=1}^{B_s} \ln(Y_i^d)$ for the up and down jumps respectively. These summations are compound Poisson processes, where G_s and B_s have intensities λ_u and λ_d respectively. The Moment Generating Function (MGF) of these processes is given by $\phi_{\ln(Y_i^j)}(s) = \exp \lambda(\phi_{\ln(Y_i^j)}(s) - 1)$, $j = u, d$. Thus, the Cumulant Generating Function (CGF), given by the logarithm of the MGF, is $\kappa_J(s) = \lambda_j(\phi_{\ln(Y_i^j)}(s) - 1) = \lambda_j \sum_{i=1}^{\infty} \frac{\mathbb{E}[(\ln(Y_i^j))^i]}{i!}$, $J = U, D; j = u, d$.

From this information, equations for the first six population moments, M_p, $p = 1 \ldots 6$ can be derived:

$$M_1 = s(\mu - \frac{1}{2}\sigma^2 + \frac{\lambda_u}{\alpha_u} - \frac{\lambda_d}{\alpha_d}). \tag{5.4.1}$$

$$M_2 = s(\sigma^2 + 2\frac{\lambda_u}{\alpha_u^2} + 2\frac{\lambda_d}{\alpha_d^2}). \tag{5.4.2}$$

$$M_3 = s(6\frac{\lambda_u}{\alpha_u^3} - 6\frac{\lambda_d}{\alpha_d^3}). \tag{5.4.3}$$

$$M_4 = s(24\frac{\lambda_u}{\alpha_u^4} + 24\frac{\lambda_d}{\alpha_d^4}). \tag{5.4.4}$$

$$M_5 = s(120\frac{\lambda_u}{\alpha_u^5} - 120\frac{\lambda_d}{\alpha_d^5}). \tag{5.4.5}$$

$$M_6 = s(720\frac{\lambda_u}{\alpha_u^6} + 720\frac{\lambda_d}{\alpha_d^6}). \tag{5.4.6}$$

Then by setting $M_p = \bar{M}_s$, I obtain the six estimates, which can be easily solved using simultaneous equations and a program such as Mathematica. Some simple algebraic manipulation produces equations which are easier to handle numerically. One such equation being:

$$\left(\frac{\bar{M}_5^2}{100} - \frac{\bar{M}_4\bar{M}_6}{120}\right)\hat{\alpha}_u^2 + \left(\frac{\bar{M}_4\bar{M}_5}{20} + \frac{\bar{M}_3\bar{M}_6}{30}\right)\hat{\alpha}_u + \left(\frac{\bar{M}_4^2}{4} - \frac{\bar{M}_3\bar{M}_5}{5}\right) = 0. \tag{5.4.7}$$

Solving for the positive root of this equation yields an estimate of α_u, denoted $\hat{\alpha}_u$, and then by substitution into the remaining equations, the following expressions are obtained:

$$\frac{5\bar{M}_4\hat{\alpha}_u - 20\bar{M}_3}{-5\bar{M}_5\hat{\alpha}_d + 5\bar{M}_4} = \hat{\alpha}_d \tag{5.4.8}$$

$$\frac{\hat{\alpha}_d{}^4(\frac{\bar{M}_4}{24s}\hat{\alpha}_u - \frac{\bar{M}_3}{6s})}{\hat{\alpha}_u + \hat{\alpha}_d} = \hat{\lambda}_d \tag{5.4.9}$$

$$\hat{\alpha}_u^3\left(\frac{\bar{M}_3}{6} + \frac{\hat{\alpha}_d(\frac{\bar{M}_4}{24s}\hat{\alpha}_u - \frac{\bar{M}_3}{6s})}{\hat{\alpha}_u + \hat{\alpha}_d}\right) = \hat{\lambda}_u \tag{5.4.10}$$

$$\frac{\bar{M}_2}{s} - 2\frac{\hat{\lambda}_u}{\hat{\alpha}_u{}^2} - 2\frac{\hat{\lambda}_d}{\hat{\alpha}_d{}^2} = \hat{\sigma}^2 \tag{5.4.11}$$

$$\frac{\bar{M}_1}{s} + \frac{1}{2}\hat{\sigma}^2 - \frac{\hat{\lambda}_u}{\hat{\alpha}_u} + \frac{\hat{\lambda}_d}{\hat{\alpha}_d} = \hat{\mu} \tag{5.4.12}$$

This method was used by Beckers [4] to obtain parameter estimates for the LJD model. The parameters for the Gamma-Beta model are presented in Table 5.5 in Appendix B of this chapter.

However, while the estimates that cumulant matching yields are consistent, they are inefficient. As well as this, as Press [38] discusses, the cumulants are functions of the sample moments and therefore, the distributions of the cumulant estimators in large samples will be Normal. For this reason, it may be advisable to only use cumulant matching to obtain initial values for Maximum Likelihood Estimation (MLE). The MLE method can, theoretically, be used since the proposed Gamma-Beta model is a first order stochastic differential equation of generalised Ito type. With equally-spaced sample data, the log-likelihood function given N returns observations is:

$$L(r; \mu, \sigma, \lambda_u, \lambda_d, \alpha_u, \alpha_d) = \sum_{i=1}^{N} \ln(f(r_i)) \tag{5.4.13}$$

where the derivation of $f(r_i)$ is given in Appendix A.

However, the unconditional distribution of returns is a mixture density; that is, the sum of four conditional densities, each of which are assigned Poisson weights, but for such densities, a global maximum of the likelihood function does not exist (see Kiefer [26]). This is due to the fact that the log-likelihood function tends towards infinity at a point where for the ith observation, $r_i = \mu$ and $\sigma_i \to 0$. However, Hamilton [20] (page 689) shows that such problems are not a major obstacle once the choice of numerical optimisation procedure converges to a local maxima.

The Newton-Raphson procedure is the most widely used optimisation method for jump-diffusion models. However, this method requires the calculation of first and second order derivatives of the log-likelihood function, which are difficult to obtain for the GBJD specification. While there are numerical optimisation procedures which do not necessitate the use of derivatives, such as Powell's method, these too are not without their caveats.

The estimation of the GBJD, as well as the calculation of the standard errors via Powell's method, would be computationally extremely time consuming because the likelihood function involves double infinite summations and double improper integrals. A high-performance computer would also be needed to carry out the calculations.

Another challenge that is likely to arise during the estimation process is that the likelihood function may not converge, and hence a type of switching algorithm may need to be used; that is, to combine Powell's method with another algorithm, such as method of Steepest Descent, so that explosion of the likelihood function may be avoided.

Hence, I have chosen to stick with the estimates obtained via the cumulant matching method, and despite its shortcomings, the estimates still yield informative results.

5.5 Model Selection

For model selection I have applied the Bayesian Information Criterion (BIC) proposed by Schwartz [42]. The advantage of this method over likelihood tests is that the BIC allows the comparison of more than two model specifications simultaneously and it does not require that the alternatives be nested.

Suppose that the ith model M_i has a vector of parameters θ_i, where θ_i has n_i independent parameters to be estimated. $\hat{\theta}_i$ denotes the estimator of θ_i. Then the BIC for model M_i is defined by:

$$BIC_i = -2 \log f(D|\hat{\theta}_i; M_i) + n_i \log(T) \tag{5.5.1}$$

where T is the number of observations in the data set, D, and $f(D|\hat{\theta}_i; M_i)$ the estimated function. The best "fit" model is the one with the smallest BIC. However, while fit is important in terms of model selection, the critical test of any economic or financial model is its ability to forecast future returns.

5.6 Predictive Power

The ultimate test of the quality of a fitted model is the accuracy of the forecasts of the conditional distribution of future observations given past observations on a variable. While stock returns are affected by the usual fluctuations in economic variables, a significant driver of returns is the innate human propensity to swing between euphoria and fear. While this behaviour of market participants is heavily influenced by economic events, often extreme actions are not underpinned by any fundamental factor. Owing to this extent of unpredictable human behavior on determining stock returns, no such model is ever going to be able to accurately predict future observations. That is, a fitted model is at best only an estimate or approximation of the process that generates the underlying data set, and thus, the model and the forecasts that it produces are subject to identification and estimation errors. It is also crucial to be aware that forecasting assumes that the data generating process remains stable into the future.

The forecast of returns that will have the minimum mean square forecast error; that is, the optimal predictor of returns, is the expected value of r_{T+l}, $l = 1, 2, \ldots$ conditional on the information available at time T i.e. $\hat{r}_{T+l} = \mathbb{E}(r_{T+l}|\mathcal{F}_T)$.

5.6.1 GBM Forecast Estimates

From equation (5.2.3) above, the log-return $r_{T+l} = \log S_{T+l} - \log S_{T+l-1}$ is given by:

$$r_{T+l} = \left(\mu - \frac{1}{2}\sigma^2\right) + \sigma\left[W_{T+l} - W_{T+l-1}\right], \tag{5.6.1}$$

and thus

$$\hat{r}_{T+l} = \mathbb{E}\left(r_{T+l}|\mathcal{F}_T\right) = \hat{\mu} - \frac{1}{2}\hat{\sigma}^2 \tag{5.6.2}$$

since $W_i, i = 1, 2, \ldots$ is a Brownian motion and therefore has expected value zero.

5.6.2 LJD Forecast Estimates

For the LJD specification, the log-return for the l-period ahead forecast is given by:

$$r_{T+l} = \left(\mu - \frac{1}{2}\sigma^2\right) + \sigma\left[W_{T+l} - W_{T+l-1}\right] + \sum_{j=1}^{J} \log\left(1 + Y_{j,T+l} dN_{j,T+l}\right) \tag{5.6.3}$$

and

$$\hat{r}_{T+l} = \mathbb{E}(r_{T+l}|\mathcal{F}_T) = \hat{\mu} - \frac{1}{2}\hat{\sigma}^2 + \hat{\lambda}\hat{\alpha}. \tag{5.6.4}$$

5.6.3 GBJD Forecast Estimates

Through similar reasoning,

$$\begin{aligned} r_{T+l} = &\left(\mu - \frac{1}{2}\sigma^2\right) + \sigma\left[W_{T+l} - W_{T+l-1}\right] \\ &+ \sum_{j=u}^{J_u} \log\left(1 + Y_{j,T+l} dN_{j,T+l}\right) + \sum_{j=d}^{J_d} \log\left(1 + Y_{j,T+l} dN_{j,T+l}\right) \end{aligned} \tag{5.6.5}$$

and

$$\hat{r}_{T+l} = \mathbb{E}(r_{T+l}|\mathcal{F}_T) = \hat{\mu} - \frac{1}{2}\hat{\sigma}^2 + \frac{\hat{\lambda}_u}{\hat{\alpha_u}} - \frac{\hat{\lambda}_d}{\hat{\alpha_d}}. \tag{5.6.6}$$

5.6.4 Assessing Forecasting Accuracy

In order to assess the accuracy of the forecasts, two popular measures are employed; the Root Mean Square Error (RMSE) and the Janus Coefficient (J).[5] The Mean Absolute Error (MAE) is another popular measure of forecasting adequacy, but it does not penalise large forecasting errors as much as the RMSE measure does. Hence, I calculate only the RMSE measure and J. Small values of the RMSE and J indicate good forecasting performance. The values of r_i, $i = 1, 2, \ldots T$ are the

[5] $RMSE = \sqrt{\frac{1}{l}\sum_{i=T+1}^{T+l}(\hat{r}_i - r_i)^2}$ and $J = \frac{\frac{1}{l}\sum_{i=T+1}^{T+l}(\hat{r}_i - r_i)^2}{\frac{1}{T}\sum_{i=1}^{T}(\hat{r}_i - r_i)^2}$.

returns in the original sample and for r_i, $i = T+1, \dots T+l$, I used the return values starting from the day immediately following the last observation in the sample for each stock until July 6th, 2009.

5.7 Sample Statistics

Tables 5.1 and 5.2 below give some summary statistics for the sample taken of daily returns from the ISEQ, FTSE100 and S&P500 composite indices and a list of nine individual stocks which trade on one or other of the three indices. The stocks that I selected are very liquid, an important characteristic given the event driven nature of the jump diffusion models. The indices are broad indicators of the equity market, and the daily sampling frequency captures high-frequency fluctuations in the returns process that are critical for identification of jump components.[6] However, since none of the indices reported are adjusted for dividends, it is more correct to note that I model the observed series of log-price differences and refer to it hereafter as the "return process".

The ISEQ index spans the period 01/2000 through 12/2008 ($N = 2319$), the FTSE100 spans the period 10/1985 through 10/2008 ($N = 5849$) and the S&P500 series spans the period 12/1988 through 12/2008 ($N = 5042$). The number of days in the sample with positive returns (Up Freq.), no change in returns and negative returns (Down Freq.) appear in the last three columns of the table. For the indices there are a comparable number of days with positive and negative returns. However, there are significantly fewer days with no change in the returns in each instance. The range of returns (($-.3850$, $.3755$) for the ISEQ, ($-.1303$, $.8469$) for the FTSE100 and ($-.0947$, $.1096$) for S&P500) is large for all indices. This is indicative of the

[6]The daily sampling frequency avoids modelling intra-day return dynamics which are confounded by market microstructure effects and trading frictions.

occurrence of significant booms and busts during the sample periods. The excess kurtosis is induced by stochastic volatility in the returns process and exceeds what can be rationalised by the GBM model.

Indeed, the summary statistics for the stocks produce a very similar picture to those of the indices, and hence, do not require a separate discussion in this section.

Table 5.1: Summary Statistics

	Mean	SD	Min	Max
FTSE100	.0002	.0111	−.1303	.0847
S&P500	.0002	.0112	−.0947	.1096
ISEQ	−.0002	.0174	−.3850	.3755
Intel	.0006	.0270	−.2489	.1833
Vodafone	.0004	.0232	−.1590	.1371
HSBC	.0004	.0185	−.1455	.1442
British American Tobacco	.0006	.0218	−.2202	.1872
General Electric	.0003	.0175	−.1368	.1276
Johnsons&Johnsons	.0005	.0151	−.1725	.1154
Bank of Ireland	−.0016	.0326	−.2725	.3443
Fyffes	−.0012	.0295	−.5766	.1335
Elan Corp.	.0005	.0600	−1.140	.2377

5.8 Results

Tables 5.3, 5.4 and 5.5, reported in Appendix B, are estimates of the parameters for the GBM, LJD, and GBJD models respectively. All of the estimated parameters are of daily sizes.

Table 5.2: Summary Statistics cont.

	Skewness	Kurtosis	Up Freq.	No Change	Down Freq.
FTSE100	.6918	13.82	3054	13	2782
S&P500	.2664	13.38	2675	3	2364
ISEQ	−.0877	19.74	1179	65	1073
Intel	−.3944	8.17	2512	120	2409
Vodafone	.0205	6.13	2443	231	2379
HSBC	−.1643	8.81	2080	118	1982
British American Tobacco	.3535	15.15	1295	69	1265
General Electric	−.1443	9.69	2426	195	2420
Johnsons&Johnsons	−.1856	9.66	2471	164	2406
Bank of Ireland	.6082	28.52	703	100	756
Fyffes	−.6489	11.27	584	359	616
Elan Corp.	−.6971	11.63	741	99	719

The second last column in each table reports the BIC values for the three specifications. As mentioned previously, the model with the smallest BIC value provides the best fit to the data. The values in boldface are the smallest values. As expected, the GBM specification does not provide a better fit over the jump diffusion specifications for any of the return series examined. This is consistent with intuition and expectations. The GBJD is superior to the LJD for eight of the returns series, with the LJD beating the GBJD for only four cases. This provides strong support for the GBJD specification in terms of model fit.

The last column in these tables reports the Janus Coefficient value, J. Similarly, the smallest values are in bold. For brevity I do not to report the RMSE value, since these results yielded the same conclusions to those produced by J. From a forecasting adequacy perspective, the GBJD specification also appears to perform better than the other two specifications. For the three indices, the GBJD provides both a better fit and appears to have greater predictive power than the GBM and LJD models. For the individual stocks, the link between forecasting adequacy and fit is more opaque. For HSBC and Bank of Ireland, the LJD is strongest in terms of fit and predictive power and for General Electric, the GBJD seems to be the preferred model for both. For the rest of the stocks, the model which gives the best fit for a particular stock is not the same model that has the strongest predictive power for that stock. Indeed, the GBM appears to have the greatest forecasting ability for Intel, Vodafone, and Elan Corp. Overall, the results for forecasting adequacy of the models are not very informative. However, the GBJD has a greater predictive power for five of the twelve returns series studied, whereas the GBM and LJD have greater predictive power for only three and four of the twelve series respectively.

In discussing the estimate results, I focus on the daily returns for the FTSE100 (first row in the tables). This is largely because the series spans the period which includes the market crisis of October 1987, the years 1997 and 1998 (Russian default and Long-Term Capital Management collapse), September 11th 2001, and some of the 2007/08 credit and liquidity crisis. Hence, it incorporates the rare events that had a significant impact on stock prices and causes dramatic consequences on the market volatility; see Figure 1 in Appendix B. As well as this, the sample is large enough to encompass the periods where the market stabilised after these rare events (excepting the most recent crisis, however).

Considering firstly, the LJD parameters, it appears that a jump in the return process occurs approximately once every 3,300 days (λ^{-1}). As expected, the estimated volatility associated with the continuous component of the jump diffusion specifications is smaller than the corresponding estimate under GBM. However, turning to the GBJD specification of the FTSE100, it appears that "good" and "bad" news arrive once every 625 (λ_u^{-1}) and 87 (λ_d^{-1}) days respectively, which is considerably more realistic than a jump occurring approximately once every 10 years, as the LJD specification suggests.

Overall, the parameter estimates obtained for the GBJD, the model of most interest, have reasonable values which are informative. One of the most notable things is that the volatility parameter for all of the returns series is significantly reduced by separating the jump components into up jumps and down jumps, as expected.

5.9 Application to Black-Scholes

The standard Black Scholes formula for the price of a European call option is given by

$$C(S,t) = SN(d_1) - Ke^{-r(T-t)}N(d_2), \tag{5.9.1}$$

where

$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma^2}{2}\right)(T-t)}{\sigma\sqrt{T-t}} \tag{5.9.2}$$

and

$$d_2 = d_1 - \sigma\sqrt{T-t}. \tag{5.9.3}$$

The price of a European put option may be computed from this by put-call parity and is given by

$$P(S,t) = Ke^{-r(T-t)}N(-d_2) - SN(-d_1). \tag{5.9.4}$$

$N(\cdot)$ is the cumulative distribution function of the standard normal distribution, $T-t$ the time to maturity, S the spot price of the underlying asset, K the strike price, r is the risk free (annual) rate and, σ the volatility of the underlying stock.

Comparative statics of $C(S,t)$ and $P(S,t)$ with respect to σ indicate that the price of a call option is increasing in volatility and the price of a put option is decreasing (while all other parameters remain constant).

An empirical investigation by Macbeth and Merville [31] shows that if one assumes that the Black–Scholes model correctly prices at the money options with at least ninety days to expiration, then the Black–Scholes model predicted prices are on average less than market prices for in the money options. The current chapter shows that the volatility parameter for all of the return series, over the period examined, is significantly reduced by separating the jump components into up and down jumps. This would imply that by applying the volatility parameter obtained from the GBJD specification to calculate a call and a put price, for a specific strike, time to maturity and risk-free interest rate, the price of the call option would be less and the price of the put would be greater than if the GBM volatility parameter was applied. If the results of Macbeth and Merville are true, then it would appear that the GBJM specification would be better at predicting market prices for out of the money calls and in the money puts than the GBM specification.

However, these results contrast with Black [6] who reports that deep in the money options generally have Black–Scholes model prices which are greater than market prices. Thus, there is apparently conflicting empirical observations on option pricing which appear in the literature, the explanation for which can be difficult to ascertain. A possible explanation is the following; if Black–Scholes model prices are calculated using a constant volatility parameter, $\hat{\sigma}$, obtained from a time series of past returns to the underlying common stock, then on days when the true volatility, σ_t, exceeds $\hat{\sigma}$, the Black–Scholes model price based upon $\hat{\sigma}$ will be less than the market price; but on other days when σ_t is less than $\hat{\sigma}$, the reverse will be true. Therefore, it is easy to see how one researcher may find in the money options overpriced by the Black–Scholes model while the other finds in the money options underpriced if they use different data to estimate the variance rate $\hat{\sigma}$ and/or compute Black–Scholes model prices over different time periods. Hence, a watertight conclusion on whether the GBJD specification is preferred to the GBM specification in predicting the market prices of European options is not possible to obtain.

5.10 Concluding Remarks

In this chapter I extend the standard geometric Brownian motion (GBM) and log-normal jump diffusion (LJD) models of option pricing and derive a new specification which distinguishes between upward and downward jumps in returns. I compare this new specification, namely the Gamma-Beta jump diffusion (GBJD) model, with the other two specifications in terms of model fit and forecasting power. I find that the separation of the jump component to distinguish between upward and downward movements clearly improves the characterisation of the empirical distribution of returns. In terms of both fit and predictive performance, the GBJD specification is the preferred model over the GBM and the LJD for the series of returns that I examine.

Theoretically, the GBJD specification can be applied to assess the dynamics of a wide number of other economic variables, not simply stock returns. Such variables include inflation, short-term interest rates and foreign exchange.

Jumps arise for many reasons, such as sudden financial turmoil, as witnessed globally in August 2007, litigation issues or incomplete accounting information. Hence, searching for models that account for such jumps, or "abnormal" movements in the underlying assets, are becoming increasingly important in terms of financial modelling.

Appendix

A Derivation of the Unconditional Density Function

Let $G_s = m$ be the number of upward jumps and $B_s = n$ the number of downward jumps over the time span $t = 0, \dots, s$. By letting $U := \sum_{i=1}^{G_s} \ln(Y_i^u) > 0$, $D := \sum_{i=1}^{B_s} \ln(Y_i^d) < 0$ and $T := U + D$, the s period return can be written as:

$$r(s) = (\mu - \frac{1}{2}\sigma^2)s + Z(s) + U + D. \qquad \text{(A.1)}$$

As shown in Walck [55], $\exp(\alpha) = \Gamma(1, \alpha^{-1})$. Thus, $\ln(Y^u) \sim \Gamma(1, \alpha_u^{-1}) = \exp(\alpha_u)$. Thus, for $G_s = m \geq 1$ the conditional distribution of U is given by $f_{U|m} \sim \Gamma(m, \alpha_u^{-1})$. Also, if $Y^d \sim Beta(1, \alpha_d)$, then $\ln(Y^d) \sim \exp(-\alpha_d) = \Gamma(1, -\alpha_d)$. Then for $B_s = n \geq 1$, the conditional distribution of $D < 0$ is denoted by $f_{-D|n} \sim \Gamma(n, -\alpha_d)$.

Therefore, if $m, n \geq 1$, the conditional density for $r(s)$ is an independent sum of

$\Gamma(m, \alpha_u)$, $\Gamma(n, -\alpha_d)$ and $N((\mu - \frac{1}{2}\sigma^2)s, \sigma^2 s)$:

$$f_{r(s)|m,n}(r) = \int_{-\infty}^{\infty} f(r-t)\Big(\int_{-\infty}^{0} f_{-D}(x) f_U(t-x) dx\Big) dt, \tag{A.2}$$

where $f(r-t) \sim N((\mu - \frac{1}{2}\sigma^2)s, \sigma^2 s)$.

It is also necessary to derive the unconditional density of $s = 1$ period returns as it plays a crucial role in estimation and hypothesis testing. The function can be written as a Poisson weighted sum of the four conditional densities; i.e. $f(r)$ for $m = n = 0$, $f(r)$ for $m \geq 1, n = 0$, $f(r)$ for $m = 0, n \geq 1$ and $f(r)$ for $m, n \geq 1$. where $P(n, \lambda) = \frac{e^{-\lambda}\lambda^n}{n!}$.

$$f(r) = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} P(m, \lambda_u) P(n, \lambda_d) f_{m,n}(r) \tag{A.3}$$

where $P(n, \lambda) := \frac{e^{-\lambda}\lambda^n}{n!}$.

B Tables and Figures

Table 5.3: GBM

	$\hat{\mu}$	$\hat{\sigma}$	BIC	J
FTSE100	.0003	.0111	−30219	0.62259
S&P500	.0003	.0112	−30946	0.69740
ISEQ	−.00001	.0174	−12177	0.15453
Intel	.0010	.0265	−21723	**0.32605**
Vodafone	.0007	.0228	−23216	**0.33777**
HSBC	.0005	.0185	−21492	1.30006
British American Tobacco	.0008	.0218	−12650	0.18880
General Electric	.0005	.0161	−26599	1.53640
Johnsons&Johnsons	.0006	.0147	−27493	0.36612
Bank of Ireland	−.0010	.0326	−6235	1.64332
Fyffes	−.0006	.0295	−6553	0.40311
Elan Corp.	.0023	.0600	−4335	**0.85912**

Table 5.4: LJD

	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\lambda}$	$\hat{\alpha}$	$\hat{\delta}$	BIC	J
FTSE100	.0003	.0109	.0003	$-.1362$	.0456	-36395	0.62247
S&P500	.0003	.0119	.0000	$-.2818$	.1435	-31206	0.69738
ISEQ	.0001	.0046	.0172	$-.0047$	.1375	-12991	0.15444
Intel	.0011	.0260	.0004	$-.2460$	.1016	-21911	0.32606
Vodafone	.0007	.0228	.0000	1.386	.6112	-23351	0.33778
HSBC	.0005	.0184	.0001	$-.3918$	.2246	**-21564**	**1.30005**
British American Tobacco	.0000	.0217	.0000	1.3849	.4679	**-12759**	0.18881
General Electric	.0005	.0161	.0000	$-.6793$	.4911	-26636	1.53639
Johnsons&Johnsons	.0006	.0146	.0051	$-.2309$	.0913	-27629	**0.36602**
Bank of Ireland	.0002	.0281	.0062	.0261	.2071	**-8574**	**1.63810**
Fyffes	.0012	.0210	.0055	$-.1814$	.2111	-7583	**0.40203**
Elan Corp.	.0032	.0400	.0069	$-.3456$	.4123	**-6575**	0.85957

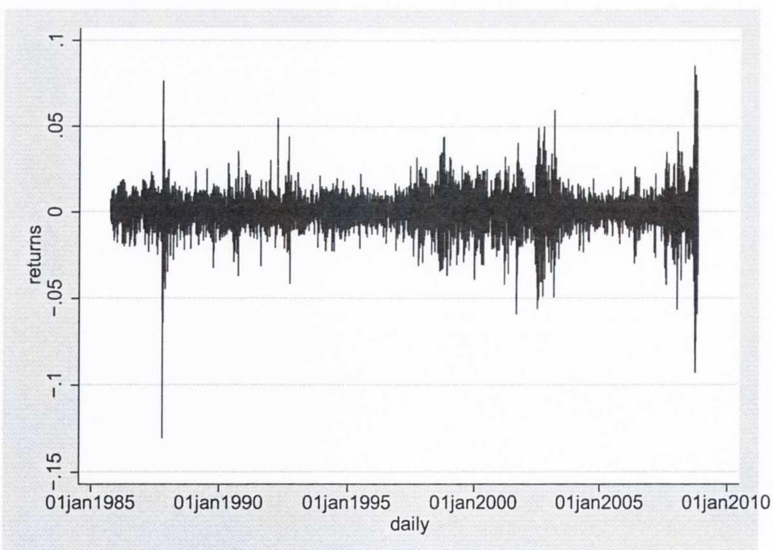

Figure 5.1: FTSE100 Returns

Table 5.5: GBJD

	$\hat{\mu}$	$\hat{\sigma}$	$\hat{\lambda}_u$	$\hat{\alpha}_u$	$\hat{\lambda}_d$	$\hat{\alpha}_d$	BIC	J
FTSE100	.0005	.0103	.0016	32.24	.0115	38.08	**-36452**	**0.62244**
S&P500	.0006	.0078	.0646	68.01	.0903	69.57	**-35784**	**0.69737**
ISEQ	−0.0001	.0083	.0109	13.57	.0077	11.45	**-13551**	**0.15443**
Intel	.0016	.0247	.0032	18.64	.0164	20.84	**-21945**	0.36797
Vodafone	−.0012	.0162	.3316	67.08	.1785	56.91	**-23513**	0.33789
HSBC	.0008	.0144	.0732	49.76	.0834	47.64	−21511	1.30027
British American Tobacco	−.0008	.0142	.1150	37.11	.0517	31.43	−12741	**0.18879**
General Electric	.00003	.0146	.0443	55.91	.0093	31.55	**-26676**	**1.52794**
Johnsons&Johnsons	.0007	.0143	.0008	22.64	.0028	23.22	**-27800**	0.36629
Bank of Ireland	−.0047	.0170	.2412	32.49	.0424	16.37	−8295	1.63811
Fyffes	.0106	.0177	.00001	1.16	.2040	15.62	**-7835**	0.40328
Elan Corp.	.0172	.0305	.00003	.6232	.1432	8.10	−6142	0.86977

Chapter 6

Conclusion

6.1 Concluding Remarks

In Chapters 2, 3, and 4 I apply a real options framework to value those announcements willingly made by firms outside of their legal and regulatory requirements.

Real options theory has been fruitfully applied in other areas of strategic decision making where investment decisions are affected by particularly high levels of underlying uncertainty. This includes, for example, valuing the contribution of research and development programs (see McGrath and Nerkar [34]). My research in Chapter 2 adds to this literature and the application of real options methods by conceptualising voluntary information release as a valuable real option which can impact positively or negatively on firm value.

By introducing the announcement option in this thesis, I aim to contribute to the ongoing exploration of corporate real options as well as to extend our understanding of what a strategic option can be. As such, my research answers the early call of Bowman and Hurry [7] that "more valuation studies and more studies that identify different options and their related strategies are needed", by providing a new application of real options theory.

Relations between announcement timing and earnings news are relevant for two main communities. Policy makers are concerned with promoting timely disclosure by firms in order to promote market efficiency. They should be interested in whether there exist incentives and/or frictions in the reporting process that lead to significant systematic delays in earnings announcements. Financial market participants are also likely to be interested in this area of research since their information gathering and trading activities are likely to be affected by evidence concerning a significant relation between the timing of an announcement and the direction and magnitude of the news in the announcement.

The research I conduct in Chapter 3 primarily touches on two streams of literature; the literature that deals with voluntary disclosure and the literature that addresses the non-exclusivity feature inherent in a real option, in particular, the issue of imperfect competition. While corporate voluntary disclosure has become an important and topical area of research in recent years, particularly in the accounting literature, there have been very few real option applications concerned with voluntary disclosure and none, as far as I am aware, concerning competitive interactions between firms in determining equilibrium exercise policies from a real options perspective. Therefore, such an analysis should provide an interesting and useful contribution to the literature.

With respect to my (benchmark) model set-up, there is an asymmetry of information between the manager, who holds all of the information about the firm, and the shareholder who gains no information until disclosure has taken place at the manager's discretion. I address this aspect of the problem in Chapter 4. In particular, I extend the benchmark model described in Chapter 2 to account for the possibility that the manager is faced with a corporate control challenge, with the ensuing possibility of dismissal, if his disclosure policy is too far mis-aligned with the shareholder's utility maximising policy. I find that the manager's threshold under corporate control is always lower than the threshold when no such corporate control challenge is imposed. Furthermore, the greater the probability the manager is faced with a control challenge, the more transparent is the disclosure policy he chooses to adopt.

I conclude with some empirical research on option pricing. In Chapter 5 I extend the standard geometric Brownian motion (GBM) and log-normal jump diffusion (LJD) models of option pricing and derive a new specification in which I distinguish between upward and downward jumps in stock price returns. I compare this new specification, namely the Gamma-Beta jump diffusion (GBJD) model, with the other two specifications in terms of model fit and forecasting power. In terms of both, I find that the GBJD specification is the preferred model over the GBM and the LJD for the series of returns that are examined.

As I discussed in Chapter 5, jumps, or "abnormal" movements in the underlying assets, arise for many reasons and searching for models that accounts for such jumps are becoming increasingly important in terms of financial modelling. In theory, the GBJD specification can be applied to assess the dynamics of a wide number of other economic variables, not simply stock returns. Examples of such variables include inflation, short-term interest rates, and foreign exchange. Hence, a specification such as the GBJD model may provide financial economists and technicians with a very useful form of option pricing model. In particular, the possibility of obtaining a closed-form solution lends the specification a certain degree of technical tractability, and the intuitive reasoning which underlines it deepens the realism of the other widely used specifications such as the GBM and Merton's LJD.

Bibliography

[1] Ahmed, K. and J. Courtis (1999). Associations between corporate characteristic and disclosure levels in annual reports: A meta-analysis. *British Accounting Review 31*, 35–61.

[2] Andersen, L. and J. Andreasen (2000). Jump-diffusion processes: Volatility smile fitting and numerical methods for pricing. *Review of Derivatives Research 4*, 231–262.

[3] Bayus, B., S. Jain, and A. Rao (2001). Truth or consequences: An analysis of Vaporware and new product announcements. *Journal of Marketing Research 38(1)*, 3–14.

[4] Beckers, S. (1981). A note on estimating the parameters of the jump diffusion model of stock returns. *Journal of Financial and Quantitative Analysis 16(1)*, 127–140.

[5] Bettis, R. (1983). Modern financial theory, corporate strategy and public policy. *Academy of Management Review 8(3)*, 406–415.

[6] Black, F. (1975). Fact and fantasy in the use of options. *Financial Analysts Journal 31(4)*, 36–72.

[7] Bowman, E. and D. Hurry (1993). Strategy through the options lens: An inte-

grated view of resource investments and the incremental-choice process. *Academy Management Review 18*, 760–782.

[8] Dempster, A. (2006). Valuing announcement options. *European Management Journal*, 117–127.

[9] Dixit, A. and R. Pindyck (1994). *Investment under uncertainty.* Princeton, NJ: Princeton University Press.

[10] Dutta, S. and B. Trueman (2002). The interpretation of information and corporate disclosure strategies. *Review of Accounting Studies 7*, 75–96.

[11] Dye, R. (1985). Disclosure of non-proprietary information. *Journal of Accounting Research 23*, 123–145.

[12] Einhorn, E. and A. Ziv (2008). Inter-temporal dynamics of voluntary corporate disclosures. *Journal of Accounting Research 46(3)*, 567–589.

[13] Fama, E. and M. Jensen (1983a). Separation of ownership and control. *Journal of Law and Economics 26*, 301–325.

[14] Feller, W. (1971). *An introduction to probability theory and its applications.* New York: John Wiley and Sons.

[15] Fudenberg, D. and J. Tirole (1985). Preemption and rent equalisation in the adoption of new technology. *The Review of Economic Studies 52*, 383–401.

[16] Gal-Or, E. (1986). Information transmission - cournot and bertrand equilibria. *The Review of Economic Studies 53*, 85–92.

[17] Graham, J., C. Harvey, and S. Rajgopal (2005). The economic implications of corporate financial reporting. *Journal of Accounting and Economics 40*, 3–73.

[18] Grossman, S. (1981). The informational law of warranties and private disclosure about product quality. *Journal of Law and Economics 24*, 461–483.

[19] Grossman, S. and O. Hart (1980). Disclosure laws and take-over bids. *Journal of Accounting Research 23*, 123–145.

[20] Hamilton, J. (1994). *Time Series Analysis.* Princeton, NJ: Princeton University Press.

[21] Healy, P. and K. Palepu (2001). Information asymmetry, corporate disclosure, and the capital markets: A review of the empirical disclosure literature. *Journal of Accounting and Economics 31*, 405–440.

[22] Heil, O. and T. Robertson (1991). Towards a theory of competitive market signalling: A research agenda. *Strategic Management Journal 12*, 403–418.

[23] Henderson, V. (2010). Is corporate control effective when managers face investment timing decisions in incomplete markets? *Journal of Economic Dynamics and Control 34*, 1062–1076.

[24] Jensen, M. and R. Ruback (1983). The market for corporate control: the scientific evidence. *Journal of Financial Economics 11*, 5–50.

[25] Kendall, M. and A. Stuart (1977). *The Advance Theory of Statistics.* London: Griffen and Co.

[26] Kiefer, N. (1978). Discrete parameter variation: Efficient estimation of a switching regression model. *Econometrica 46(2)*, 427–434.

[27] Kou, S. (2002). A jump-diffusion model for option pricing. *Management Science 48(8)*, 1086–1101.

[28] LaPorta, R., F. L. de Silanes, and A. Shleifer (1999). Corporate ownership around the world. *Journal of Finance 54*, 471–517.

[29] Lewis, M. (2008). *The Story of Modern Financial Insanity.* London: Penguin.

[30] Li, L. (1985). Cournot oligopoly with information sharing. *RAND Journal of Economics 16(4)*, 521–536.

[31] Macbeth, J. and L. Merville (1979). An empirical examination of the black-scholes call option pricing model. *Journal of Finance 34(5)*, 1173–1186.

[32] Mas-Colell, A., M. Whinston, and J. Green (1995). *Microeconomic theory.* New York: Oxford University Press.

[33] McDonald, R. and D. Siegel (1986). The value of waiting to invest. *Quarterly Journal of Economics 101*, 707–728.

[34] McGrath, R. and A. Nerkar (2004). Real options reasoning and a new look at the R&D investment strategies of pharmaceutical firms. *Strategic Management Journal 25(1)*, 1–22.

[35] Merton, R. (1976). The impact on option pricing of specification error in the underlying stock price returns. *Journal of Finance 31(2)*, 333–350.

[36] Milgrom, P. (1981). Good news and bad news: Representation theorems and applications. *Bell Journal of Economics 12*, 380–391.

[37] Peskir, G. and A. Shiryaev (2006). *Optimal stopping and free-boundary problems.* Berlin: Birkhäuser Verlag.

[38] Press, S. A modified compound poisson process with normal compounding. *Journal of American Statistical Association.*

[39] Protter, P. (1991). *Stochastic Integration and Differential Equations.* Berlin: Springer.

[40] Ramezani, C. and Y. Zeng (2007). Maximum likelihood estimation of the double exponential jump diffusion process. *Annals of Finance 3*, 487–507.

[41] Sarkar, S. (2000). On the investment-uncertainty relationship in a real options model. *Journal of Economic Dynamics and Control 24(2)*, 219–225.

[42] Schwartz, G. (1978). Estimating the dimension of a model. *Annals of Statistics 6(2)*, 461–464.

[43] Smets, F. (1991). Exporting versus FDI: The effect of uncertainty, irreversibilities, and strategic interactions. Working Paper, Yale University.

[44] Spence, M. (1973). Job market signalling. *The Quarterly Journal of Economics 87(3)*, 355–374.

[45] Spulber, D. (1995). Bertrand competition when rivals' costs are unknown. *Journal of Industrial Economics 43*, 1–11.

[46] Stein, J. (2003). *Agency, information, and corporate investment. In Handbook of Economics and Finance.* Amsterdam: North-Holland.

[47] Stocken, P. (2000). The credibility of voluntary disclosure. *RAND Journal of Economics 31(2)*, 359–374.

[48] Subarwal, T. (2005). The non-neutrality of debt in investment timing: a new NPV rule. *Annals of Finance 1*, 433–445.

[49] Subramani, M. and E. Walden (2001). The impact of e-commerce announcements on the market value of firms. *Information Systems Research 12(2)*, 135–154.

[50] Suijs, J. (2007). Voluntary disclosure of information when firms are uncertain of investor response. *Journal of Accounting and Economics 43*, 391–410.

[51] Sundaresan, S. (2000). Continuous-time methods in finance: A review and an assessment. *Journal of Finance 55(4)*, 1569–1622.

[52] Thijssen, J., K. Huisman, and P. Kort (2004). The effect of information streams on capital budgeting decisions. *European Journal of Operational Research 157*, 759–774.

[53] Thijssen, J., K. Huisman, and P. Kort (2006). The effects of information on strategic investment and welfare. *Economic Theory 28*, 399–424.

[54] Verrecchia, R. (2001). Essays on disclosure. *Journal of Accounting and Economics 32*, 97–180.

[55] Walck, C. (1996). Handbook on statistical distributions for experimentalists. Particle Physics Group, University of Stockholm.

[56] Wen, X. (2008). Voluntary disclosure and investment. preprint (2008), available at `http://ssrn.com/abstract=1262382`.