HOW THE CHARACTERISTICS OF RESEARCH, DEVELOPMENT AND INNOVATION PARTNERSHIPS MEDIATE THEIR DEVELOPMENT

An empirical study in the emerging area of nanotechnology

VICTOR ACINAS GARZON

Thesis submitted for the degree of Doctor of Philosophy

Trinity Business School

Trinity College Dublin

2022

Declaration

I declare that this thesis has not been submitted as an exercise for a degree at this or any other university and it is entirely my own work.

I agree to deposit this thesis in the University's open access institutional repository or allow the Library to do so on my behalf, subject to Irish Copyright Legislation and Trinity College Library conditions of use and acknowledgement.

I consent to the examiner retaining a copy of the thesis beyond the examining period, should they so wish (EU GDPR May 2018).

Date: 27 / 08 / 2021

Signature: 

Victor Acinas Garzon

Abstract

Whereas much has been written on the inter-organisational relations phenomenon from different bodies of literature such as strategy, innovation and management, it is typically done through variance studies built on major blind spots – single-party, single-level and single time conceptualization approaches – and rarely on the dynamics of inter-organisational relations. Hence, the motivation of this study is to enhance our understanding of inter-organisational relations development by overcoming these major blind spots in the literature and shedding light on the mechanisms which mediate their development.

This study examines Research, Development and Innovation (RDI) partnerships focused on nanotechnology activities as they unfold over time by formulating the following research question: *how can the characteristics of nanotechnology RDI partnerships mediate their development?* In answering the research question, this study undertakes a longitudinal critical realism case study research method based on four cases consisting of two sets of polar cases within the emerging nanotechnology context.

The main finding of this study is a co-evolutionary, multi-level mechanism-based explanation of how the characteristics in nanotechnology RDI partnerships can mediate their development. This finding contributes not only to inter-organisational relations theory in the area of RDI partnerships but also the innovation and strategy literature. Its significance is also underpinned by the novelty of the nanotechnology research context which is characterised by rapid technological change and the integration of knowledge from across different disciplines. In reaching this theoretical contribution, the study developed a structured and comprehensive research framework which integrates and extends previous research. This framework advances the application of critical realism by providing methodological guidance and illustrating in a contextualised step by step basis how to carry abductive and retroductive analysis through coding and analysis techniques which overcome criticisms to the commonly used grounded theory techniques.

In memory of my mother María Del Carmen Garzón González

Acknowledgements

This thesis would not have been possible without the support and encouragement from my supervisor, colleagues, friends and family whose contributions I deeply appreciate. I would like to thank my supervisor Professor Louis Brennan whose mentorship and dedication supported me throughout the PhD journey.

A special word of thanks to Helen Marks for her attention to detail in reading my thesis and providing invaluable feedback. To Paul Ryan for his time to discuss and constructively challenge my research. To staff and colleagues at the School of Business who provided guidance, especially to Deepak Saxena for his feedback on my work from time to time.

My appreciation also goes to the organisations and professionals for giving their time and energy to participate in this study. As well as to my employers and work supervisors, particularly M.H. and J. R., for their continuous support and understanding.

I also wish to thank my family and, especially my dad, for their continuous support, encouragement and inspiration to start and finalise my PhD journey. Finally, my deepest gratitude goes to my love, Silvia, and daughters, Erica and Lina.

Table of Contents

List of Tables

List of Figures

List of abbreviations

CR	Critical Realism
DCV	Dynamic Capabilities View
EDM	Electronics Device Manufacturer
EDP	Electronics Development Producer
KBV	Knowledge Based View
M	Milestone
MDM	Medical Device Manufacturer
MDS	Medical Devices Supplier
MPS	Medical Polymer Supplier
nm	nanometer
NMS	NanoMaterial Suppliers
R	Report
R&D	Research and Development
RBV	Resource Based View
RDI	Research, Development and Innovation
RDT	Resource Dependence Theory
RIA	Research Institute A
RIB	Research Institute B
RIC	Research Institute C
RID	Research Institute D
RIS	Research Institute Subcontract
SCP	Specialty Chemical Provider
SMS	Semiconductor Material Supplier
SNT	Social Network Theory
TCE	Transaction Cost Economics
WP	Work Package

1 Introduction

Inter-organisational relations are regarded as a valuable source of competitive advantage for organisations and industries (Bogers, Chesbrough, Heaton, & Teece, 2019; Coghlan & Coughlan, 2011; Dyer & Singh, 1998; Martínez-Noya & Narula, 2018; Nippa & Reuer, 2019; Sakakibara, 1997; Todeva & Knoke, 2005). This has resulted in a continuous increase in networks, joint ventures, alliances, R&D partnerships and other inter-organisational relations in practice which has been followed by a myriad of studies across different bodies of literature such as economics, management, organisation, sociology and strategy (Gomes, Barnes, & Mahmood, 2016; Gulati, 1995, 1998; Hagedoorn, 2002; Kogut, 1988; Milagres & Burcharth, 2019; Ring & Van de Ven, 1994). However, over the last three decades the literature has shown scant attention to the developmental processes of inter-organisational relations (Das & Teng, 2002; Hagedoorn, Link, & Vonortas, 2000; He, Meadows, Angwin, Gomes, & Child, 2020; Majchrzak, Jarvenpaa, & Bagherzadeh, 2015; Ring & Van de Ven, 1994). At the same time, inter-organisational relations exhibit high failure rates which have been reported to be of up to 70% (Campart & Pfister, 2007; Duysters & Kok, 1999; Gomes et al., 2016; Lahiri, Kundu, & Munjal, 2021; Oliveira & Lumineau, 2019; Park & Ungson, 2001; M. E. Porter, 1987).

To shed light into how this phenomenon develops, grows and terminates, this study examines the conditions, processes and outcomes of Research, Development and Innovation (RDI) partnerships as they unfold over time. For this, an empirical research study is conducted within the emerging context of nanotechnology which is characterised by high technological and market opportunities and uncertainty as well as the combination of diverse sets of competencies which are typically distributed among several entities (Islam & Miyazaki, 2009; Petricevic & Verbeke, 2019; A. L. Porter et al., 2019; Roco, Mirkin, & Hersam, 2011; Werker, Korzinov, & Cunningham, 2019). Figure 1 provides an overview of where the research topic of this study and the inter-organisational relations field are positioned.

In what follows, Section 1.1 describes the research background for this study. Then, Section 1.2 details the motivations of the researcher to conduct this study and Section 1.3 introduces the research context and Section 1.4 the research question. Finally, Section 1.5 offers a summary of the study and the key results achieved in each chapter.

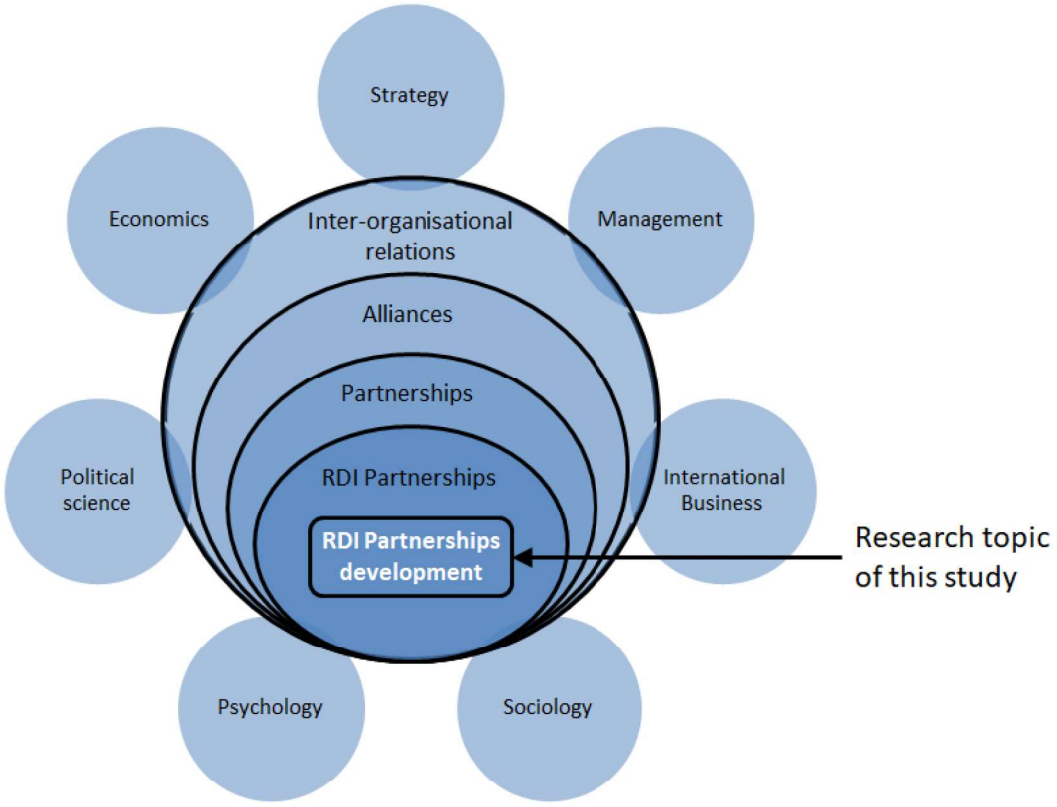


Figure 1 Overview of the research topic of this study and the inter-organisational relations field

1.1 Research rationale

As in the inter-organisational relations literature, partnership studies highlight and recognize the importance of their development to better understand this phenomenon. However, the extant literature is overwhelmingly focused on the areas of partnership formation and assessing partnership performance by analysing the formation conditions and the outcomes derived from a partnership (Ariño, 2003; Bidault, 2020; Cui, Calantone, & Griffith, 2011; Doz, Olk, & Ring, 2000; Dyer, Powell, Sakakibara, & Wang, 2007; Gulati, 1998). This imbalance may be attributed to the common use of quantitative research methods which in turn may also indicate a lack of focus on

explaining partnership development and the underlying processes (Gulati, 1995; Lumineau & Oliveira, 2018; Majchrzak et al., 2015; Stuart, 1998). Going beyond the formation conditions and outcomes of partnerships and understanding how these and other characteristics are interlinked over time is critical for the management of partnerships and explaining this phenomenon. Doing so responds to long standing and continuous calls across different areas in the literature of inter-organisational relations. Some illustrative examples of these calls spanning the past three decades are as follows.

> *"Relatively little scholarly attention has been devoted to studying developmental processes of IORs [Inter-Organisational Relations]. Instead, most of the research to date has been focused either on the antecedent conditions or the structural properties of interorganizational relationships in comparison with other governance forms."* (Ring & Van de Ven, 1994, p. 91)

> *"...most [inter-organizational and network theoretical contribution] have explained outcomes by referring to the structural antecedents that condition the different contexts which actors behave within."* (Vincent, 2008, p. 875)

> *"The relationship of dynamics to IOC [Inter-organizational Collaboration] outcomes suggests the need for rigorous research specifically focused on identifying key descriptive elements of the dynamics and the different conditions under which these dynamic descriptive elements are likely to occur"* (Majchrzak et al., 2015, p. 1357)

> *"future research may examine how sub-processes [such as management] evolve and how individual evolution relates to the evolution of entire IFC [inter-firm collaboration]... , it is possible that the evolution sub-process may not progress as planned with the collaborating partners."* (Lahiri et al., 2021, p. 9)

Moreover, the formation of RDI partnerships in high technology environments has experienced a remarkable growth and outweighed other types of inter-organisational relations (Choi &

Contractor, 2019; Duysters & Kok, 1999; Eisner, Rahman, & Korn, 2009). According to Hagedoorn (2002, p. 490), *"If joint ventures once dominated inter-firm R&D partnering, this activity is now almost completely dominated by contractual agreements as about 90% of the recently established partnerships are of a contractual nature"*. Yet, as in the general area of partnerships, the interactions and developmental processes of RDI partnerships during the execution stage remain widely unexplored as highlighted by different scholars (see e.g. Doz et al., 2000; García-Terán & Skoglund, 2019; Martínez-Noya & Narula, 2018) and the literature review carried in Chapter 3.

1.2 Personal Research Motivation

This study originates from the professional experience in academia and industry of the researcher of this study. As an electronics researcher, project manager and senior manager contributing and managing hundreds of RDI partnerships, it became apparent that while the prospects of RDI partnerships are typically viewed positively, often the derived outcomes are viewed differently. Yet this does not deter organisations in high technology environments from joining RDI partnerships. In fact, the researcher of this study observed that the need to execute RDI partnerships is typically heightened when general purpose technologies emerge.

Hence, after completing a BSc. and MSc. in Telecommunications in Spain and participating in several failed RDI partnerships, the researcher of this study enrolled in a MSc. in Business and Technology in Finland to better understand the management and business aspects at play in RDI partnerships. However, the acquired knowledge and available literature was still not sufficient to explain in detail RDI partnership development and the underlying developmental processes. Consequently, the researcher of this study decided to enrol in the Ph.D. program provided by the School of Business at Trinity College Dublin and conduct a study which focuses on and links the conditions, processes and outcomes of RDI partnerships as they unfold over time. With this in mind, the study is conducted within the nanotechnology context because its multidisciplinary nature tends to require the formation of inter-organisational relations and the large potential

economic and societal benefits (Guzmán, Brown, & Acatitla, 2020; Youtie, Iacopetta, & Graham, 2008).

1.3 Research context

One of the areas which has recently caught the attention of diverse stakeholders such as social scientists and garnered large industrial and governmental RDI investments is nanotechnology (Funk, 2014; Guzmán et al., 2020; OECD, 2009; A. L. Porter & Youtie, 2009; Shapira, Youtie, & Porter, 2010; Youtie et al., 2008). Although there is still no commonly accepted definition, nanotechnology is typically used as an umbrella term to describe a wide range of technologies leveraging the manipulation of materials at the scale of atoms and molecules or the nanometre scale. To put this in perspective, you can consider that a human hair is about 60,000 nanometres in diameter, a nanometre is one billionth of a meter and most atoms are 0.1 to 0.2 nanometres. This study, adopts the following definition of nanotechnology based on Forfas (2010, p. 19):

> *"The purposeful engineering of matter at scales of around or less than 100 nanometres (nms) to achieve size-dependent properties and functions"*

Nanotechnology allows the introduction of hitherto impossible property changes and functions which arise from the modification, handling and processing of materials at the nanoscale. Consequently, changes in the properties and functions of materials arise from different factors such as their increased ratio between surface area and volume which makes smaller particles more chemically reactive than larger particles.

During the last years the development of nanotechnology is transitioning from academic and discipline-based contexts triggered in the second half of the 20th century to application driven and multidisciplinary contexts (Gibbons et al., 1994; LuxResearch, 2014; Werker et al., 2019). This transition and the resulting need to draw knowledge from different sources has resulted in a growing number of nanotechnology inter-organisational relations focused on RDI activities which

put together expertise from different disciplines (Islam & Miyazaki, 2009; Petricevic & Verbeke, 2019).

1.4 Research question

The research rationale together with the personal research motivation and the novel research context, provide the basis to search for a research question which can lead the researcher of this study to contribute to inter-organisational relations in the area of RDI partnerships within the emerging context of nanotechnology. With this in mind and the literature reviews in chapters 2 and 3, the research question is defined as follows.

> ***How can the characteristics of nanotechnology RDI partnerships mediate their development?***

In formulating a "how" question the research of this study strives to search for explanations which are not accounted for in the literature on inter-organisational relations given they are by enlarge focused on variance approaches (Doz et al., 2000; Gomes et al., 2016; Salk, 2005). Taking into account the research question and the literature contributions (Edmondson & McManus, 2007), this study carries an explanatory methodological approach based on longitudinal qualitative and quantitative data. This methodological approach allows to address the research question by enhancing our understanding of RDI partnerships as they unfold over time in a nanotechnology context.

1.5 Outline of the thesis structure, methodological approach and results

This thesis is composed of seven chapters. Chapter 1 provides an introduction to this study by highlighting the research justification and research question as well as an outline of the thesis structure, methodological approach and research results. Then Chapter 2 and 3 review the fragmented and heterogenous literature on partnerships and RDI partnerships (Gulati, 1998;

Martínez-Noya & Narula, 2018; A. L. Oliver & Ebers, 1998; Parmigiani & Rivera-Santos, 2011) and identify the key findings and research gaps.

Taking stock of the outcomes presented in previous chapters, Chapter 4 describes and justifies the methodological approach of this study by defining the underpinning research philosophy and research method. For this, Chapter 4 describes the selection and justification of a critical realism comparative case study design which builds on the work by Fletcher (2017) and follows the critical realism principles presented in D. Wynn and Williams (2012) and methodological recommendations of Wynn and Williams (2020). This design is based on four cases consisting of two sets of polar cases studies and longitudinal data from four sources of evidence to increase comparison and contrasts across the cases and, thus, maximize the prospects of answering the research question (Pettigrew, 1990). As a result, Chapter 4 provides a detailed and structured research framework to undertake critical realism based case studies.

Chapter 5, identifies and details the events within the data collected from four sources of evidence – documentation, archival records, interviews and direct observation – and develops the case narratives of the four case studies focused on RDI partnership development during their execution. The case narratives present the empirical evidence chronologically and detail not only the execution of the RDI partnership development in each of the cases, but also relevant contextual details of the partners involved, previous inter-organisational relations, the formation and the outcomes derived from the RDI partnerships even if they took place beyond the execution.

Chapter 6 starts by describing how the conceptual structure and the demi-regularities of each case study are identified through deductive and pattern coding. Then it presents how the collected data is theoretically redescribed to analyse, from a different frame of reference, the identified conceptual structure and demi-regularities. Subsequently, the chapter details how the causal mechanisms are retroduced and their originating conditions and outcomes identified. This is followed by the validation of the identified conditions, mechanisms and outcomes across the different cases and data collection sources causal mechanisms through their corroboration across the four case studies

and data collection sources. Finally, the chapter ends with a discussion of the findings and their comparison with the extant literature.

Chapter 7 describes the theoretical, empirical, methodological, policy and practice contributions as well as the implications for future research. Finally, the thesis concludes with a number of appendices which extend the information provided in the chapters of this thesis. As a summary, Figure 2 outlines the highlighted thesis structure, methodological approach and key results.

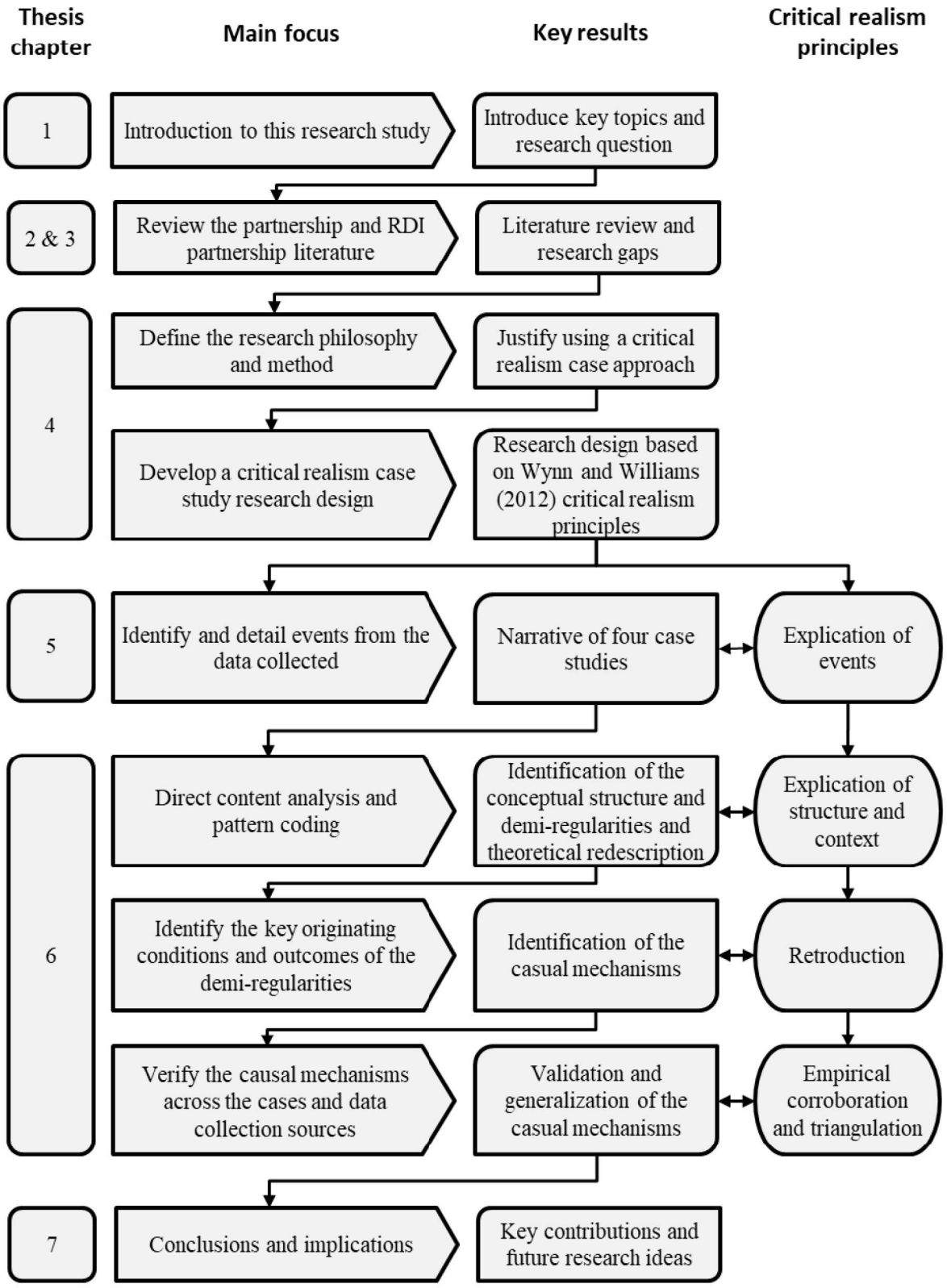


Figure 2 Outline of the thesis structure, methodological approach and key results

2 Literature review on partnerships

Together with Chapter 3, this Chapter presents the consulted and reviewed literature of this study. As shown in Figure 2, this Chapter presents the consulted and reviewed literature on partnerships in the field of inter-organisational relations. Section 2.1 positions the literature on partnerships within the extensive and diverse research on inter-organisational relations and introduces key terms and types of inter-organisational relations. Since the literature of partnerships is included within the study of alliances, a type of inter-organisational relation, Section 2.2 also positions the literature on partnerships within the area of alliances. This is followed by Section 2.3 which introduces the area of partnerships and Section 2.4 which provides a summary of the main theoretical perspectives found in the literature on partnerships. Then Section 2.5 describes the characteristics of partnerships as well as their common features and Section 2.6 describes the dynamics of partnerships. This chapter ends with the conclusions which are presented in Section 2.7.

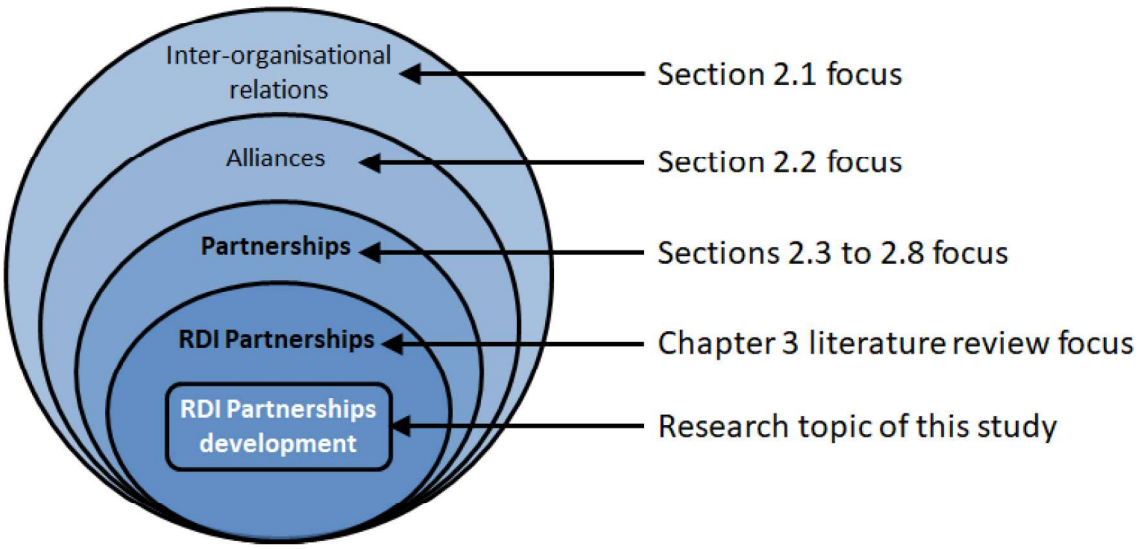


Figure 3 Overview and structure of the literature review

2.1 Inter-organisational relations

Organisational relations can either be intra-organisational or inter-organisational (Mena, Humphries, & Wilding, 2009). In this study the term inter-organisational relations consists of all

the types of relations between two or more organisations such as alliances, partnerships and cooperatives. The increasing interest and number of inter-organisational relations over the last decades is reflected in the growing number of different types of inter-organisational relations such as joint ventures, partnerships, buyer-supplier agreements and R&D consortia (F. J. Contractor & Lorange, 2002; Gulati, 1995, 1998; Hagedoorn, 2002; Kogut, 1988; Milagres & Burcharth, 2019; Ring & Van de Ven, 1994).

Kogut (1988) and Dyer and Singh (1998) argue that the growing interest of organisations in pursuing inter-organisational relations arises from one or more of the following three complementary motivations: cost efficiencies, improving the organisation's competitive position and to increase the organisational knowledge and learning. Some of the underlying benefits that can ensue from inter-organisational relations are an increase in competitive advantage and access to new competencies while reducing risks and costs (Dyer & Singh, 1998; Mowery, Oxley, & Silverman, 1996; Narula, 2001; Peeters, Callaert, & Van Looy, 2020; Singh, 1997; Todeva & Knoke, 2005).

The continuous increase in inter-organisational relations in practice has been followed by a myriad of studies across different bodies of literature such as economics, psychology and strategy. As a result of this growing interest from different bodies of literature and perspectives, the field suffers from several limitations. First, the field is marked by a lack of coherence and fragmentation which hinders theoretical construction and its translation to practitioners (Gulati, 1998; A. L. Oliver & Ebers, 1998; Parmigiani & Rivera-Santos, 2011). At the same time this creates an accumulation of studies using theories and concepts from other research areas which have not been confirmed or substantially adopted in the inter-organisational literature (e.g. C. S. Lee & Vonortas, 2002; A. L. Oliver & Ebers, 1998). Furthermore, the previous limitations are exacerbated by the interchangeable use of different terms such as inter-organisational relations, networks, and alliances in many studies. (Bergenholtz & Waldstrøm, 2011; Gulati, 1998; A. L. Oliver & Ebers, 1998; Osborn & Hagedoorn, 1997; Parmigiani & Rivera-Santos, 2011).

To clarify and set the boundaries within the encompassing literature of inter-organisational relations, the main different research areas are classified in Table 1. This classification structures the literature by arranging the different types of inter-organisational relations according to whether the ties among organisations are informal, contractual, or equity based. The development of this classification is informed by publications which defined and categorized the available types of tie and inter-organisational relations in practice (see e.g., Ariño & de la Torre, 1998; F. J. Contractor & Lorange, 2002; Jenssen & Nybakk, 2013; Martínez-Noya & Narula, 2018; Narula & Hagedoorn, 1999; Nooteboom, 2002; Peeters et al., 2020; Todeva & Knoke, 2005).

Table 1 Types of inter-organisational relations and their relationship with alliances

<table>
<tr><th colspan="3">INTER-ORGANISATIONAL RELATIONS</th><th rowspan="2"></th></tr>
<tr><th>Informal</th><th>Contractual</th><th>Equity-based</th></tr>
<tr><td>Clusters (M. E. Porter, 1998; Speldekamp, Saka-Helmhout, & Knoben, 2020)</td><td>Partnerships (Hagedoorn, 2002; Milagres & Burcharth, 2019; Peeters et al., 2020)</td><td>Joint Ventures (Barmeyer & Davoine, 2019; Kogut, 1988; Lane, Salk, & Lyles, 2001)</td><td rowspan="3">ALLIANCES</td></tr>
<tr><td>Networks (Gulati & Gargiulo, 1999)</td><td colspan="2">Triple and Quadruple Helix (Carayannis & Campbell, 2012; Etzkowitz & Leydesdorff, 2000; García-Terán & Skoglund, 2019)</td></tr>
<tr><td>Other (e.g. arm's-length relations (Uzzi, 1997))</td><td>Other (e.g. unilateral contractual agreements (J. E. Oxley, 1997))</td><td>Other (e.g. cooperatives (Shantz, Kistruck, Pacheco, & Webb, 2020))</td></tr>
</table>

Within this table, the different types of inter-organisational relations that fall within the term alliance are also highlighted since it is the focus of the next Section. This clearly marked delimitation is often overlooked by most of the publications on alliances and contributes to the fragmentation and lack of coherence among the numerous accumulated studies (Casson & Mol, 2006)[1].

[1] Casson and Mol's (2006) literature review found that 117 articles out of 172 do not define the term alliances.

2.2 Alliances

Alliances are a sub-set of inter-organisational relations which, depending on the scholar, encompass different types of inter-organisational relations (see e.g. Caloghirou, Vonortas, & Ioannides, 2004; Hagedoorn et al., 2000; Mohr & Spekman, 1994; Todeva & Knoke, 2005). As indicated in Table 1, in this study alliances are defined as the collaboration that takes places between two or more organisations that establish contractual or equity-based relations (see e.g., Choi & Contractor, 2019; Mowery et al., 1996; Powell, Koput, & Smith-Doerr, 1996; Sampson, 2007; Schultz, 2011).

For many decades there has been an on-going increase in the formation of alliances such as joint ventures, partnerships, buyer-supplier agreements and R&D consortia (F. J. Contractor & Lorange, 2002; Gulati, 1995, 1998; Gupta & Rosenkopf, 2019; Hagedoorn, 2002; Kogut, 1988; Ring & Van de Ven, 1994). However this growth in alliances has been accompanied by failure rates of up to 70% in different empirical settings such as the biotechnology, pharmaceutical and electronics industries (Campart & Pfister, 2007; Duysters & Kok, 1999; Gomes et al., 2016; Lahiri et al., 2021; Oliveira & Lumineau, 2019; Park & Ungson, 2001; M. E. Porter, 1987). These outcomes have garnered the attention of a myriad of scholars from different bodies of knowledge such as economics, sociology and strategy towards the study of alliances (Prange, Eng, & Li, 2015). Interestingly, this attention has mainly focused on the study of dyads despite the abundant calls for research on triads and larger groups to confirm and extend results from the study of dyads (see e.g. Eisner et al., 2009; Gulati, 1998; Vonortas & Okamura, 2009; S. Xu, Fenik, & Shaner, 2014).

Overall, the literature on alliances is marked by a lack of coherence and fragmentation as well as the inter-organisational relations literature (Bergenholtz & Waldstrøm, 2011; Martínez-Noya & Narula, 2018; A. L. Oliver & Ebers, 1998; Osborn & Hagedoorn, 1997). This is reflected in the absence of an overarching theoretical framework (F. J. Contractor & Lorange, 1988; Koza & Lewin, 1998; Prange et al., 2015) and an overwhelming number of purpose and context specific frameworks (see amongst others, Das & Kumar, 2011; Harrigan & Newman, 1990; Johanne

Rønnow, Harmsen, & Friis, 2008; Kusari, Hoeffler, & Iacobucci, 2013; C. S. Lee & Vonortas, 2002; Leydesdorff & Meyer, 2006; Park & Ungson, 2001; Wittmann, 2007).

This lack of coherence is also reflected in how some studies view alliances as a collaborative effort and in others as a cooperative effort between the organisations involved (see e.g., Castañer & Oliveira, 2020; Hagedoorn, 2002; Jenssen & Nybakk, 2013; Osborn & Hagedoorn, 1997). Although this may be due to the use of cooperation and collaboration as synonyms, it is important to highlight the differences between these terms and the adopted view of this study. In inter-organisational relations, the use of the term collaboration implies that the organisations involved share activities and responsibilities which are interconnected and allow them to pursue common and interrelated objectives more efficiently than individually (McNamara, 2012). While the use of the term cooperation relates to organisations interacting with a view to achieve individual interests (McNamara, 2012). Hence, in this study cooperation is considered to mainly take place under inter-organisational relations with informal ties and collaboration mainly among the different types of alliances which either have contractual or equity-based ties as shown in Table 1.

2.3 Partnerships

In the same way as alliances share many traits with the encompassing field of inter-organisational relations, partnerships, as a subset of the alliances literature, also shares many traits with alliances. For example over the last decades partnerships have also experienced strong formation growth, high failure rates, and similar benefits to those found in the formation of alliances and inter-organisational relations (Duysters & Kok, 1999).

Again the literature lacks coherence and it is not unusual to find that the term partnership is used as a synonym for alliance or used to cover both informal and contractual inter-organisational relations (see e.g. Caloghirou et al., 2004; Gupta & Rosenkopf, 2019; Hagedoorn et al., 2000; Mohr & Spekman, 1994; Prange et al., 2015; Todeva & Knoke, 2005). To avoid this lack of clarity, in this study the term partnership is defined as…

> *...non-equity contractual based inter-organisational relations established by two or more organisations to collaborate and achieve common and interrelated objectives by sharing resources.*

This definition is derived from the work of Hagedoorn (2002), Mohr and Spekman (1994) and the developed categorization of inter-organisational relation types shown in Table 1.

Despite this lack of coherence, the literatures on partnerships and alliances are typically focused on exploring partnerships with specific types of relations among the partners, either vertical or horizontal (F. J. Contractor & Lorange, 2002; Milagres & Burcharth, 2019; Narula & Hagedoorn, 1999; Sydow, Windeler, Schubert, & Mollering, 2012). Vertical partnerships are a type of partnership between an organisation and its supply chain partners whether upstream or downstream (Cannavale, Esempio, & Ferretti, 2021; O'Dwyer & Gilmore, 2018). In contrast, horizontal partnerships are a type of partnership between organisations operating in the same business area (Cannavale et al., 2021; O'Dwyer & Gilmore, 2018).

More recently, the literature has also focused on exploring partnerships that not only involve industrial partners. Hence, there has been an increase in studies around partnerships consisting of industrial, academic and public organisations (Caloghirou et al., 2004; Eichler, Kong, & Grégoire, 2006; Peeters et al., 2020; Turpin, Garrett-Jones, & Woolley, 2011; Van de Ven & Poole, 1990). These arrangements are typically referred to as public-private partnerships. Finally, another type of partnership found in the literature consists of partnerships between different public organisations (Dill, 2010; Greasley, Watson, & Patel, 2008).

To illustrate and provide examples of the identified types of partnerships found in practice, Table 2 outlines all these partnership types according to the nature of the partners involved and the types of relations established between the partners. Some partnership examples such as joint research labs and standardization consortia are repeated in several categories within Table 2 because they can include organisations that are private, public or both and at the same time can be related to each other vertically or horizontally.

Table 2 Types of partnerships

	Vertical partnerships	Horizontal partnerships
Private organisations involved	**Private-Private Partnerships**	
	e.g. Buyer-supplier agreements like those between automotive OEMs and tier 1 suppliers.	e.g. industry shaping partnerships and cooperatives like those established between farmers.
Public and private organisations	**Public-Private Partnerships**	
	e.g. industry-academia joint R&D programs and research labs like SEMATECH.	e.g. standardization consortia like GSM.
Public organisations involved	**Public-Public Partnerships**	
	e.g. government-community and inter-government partnerships like living labs.	e.g. infrastructure projects across regions, joint research labs like CERN and oil or gas pipelines.

In addition, the field suffers from a clear imbalance since most studies are focused on the formation or the assessment of performance by linking conditions at formation and partnership outcomes (Ariño, 2003; Bidault, 2020; Cui et al., 2011; Doz et al., 2000; Dyer et al., 2007; Gulati, 1998; Majchrzak et al., 2015). This imbalance may be attributed to the common use of quantitative methods which in turn may also explain a lack of focus on the dynamics of partnerships (Gomes et al., 2016; Gulati, 1995; He et al., 2020; Majchrzak et al., 2015; Stuart, 1998).

2.4 Theoretical perspectives on partnerships

Even though a number of theoretical frameworks have emerged, none has been confirmed or substantially adopted in the partnerships or inter-organisational literature (F. J. Contractor & Lorange, 1988; Das & Teng, 2002; Doz, 1996; Koza & Lewin, 1998; Prange et al., 2015; Ring & Van de Ven, 1994). Typically, the literature on partnerships, as well as the alliances and overarching inter-organisational relations fields, adopts theories coming from other research areas (see e.g. C. S. Lee & Vonortas, 2002; A. L. Oliver & Ebers, 1998). As a result, the main and complementary theoretical approaches identified in the review of partnerships are the transaction cost economics, resource-based view, resource dependence theory and social network theory

(Delbufalo, 2012; Eva Niesten & Jolink, 2020; A. L. Oliver & Ebers, 1998; Vincent, 2008). From the application and combination of these theories emanates different implications and approaches to the formation and management of partnerships.

Transaction Cost Economics (TCE) is an economic theory for organisations focused on minimizing the cost of the transactions that take place when products and services are exchanged (Williamson, 1989). Hence, the transactions can take place either within an organisation or with other organisations. Williamson (1979) claims that the intra-and inter-organisational relations ensue from the nature of the transactions. Accordingly, inter-organisational relations such as partnerships would typically arise from transactions that are frequent, relatively uncertain and require a high degree of commitment from the partnering organisations. Interestingly, the applicability of TCE to partnerships and inter-organisational relations in general is questionable due to the complex and evolutionary dynamics involved in these relations (Olk, 1998). As Kay (1992, p. 330) noted *"Williamson's theory rests on comparative statics and cannot be used to describe dynamic evolutionary phenomena, despite his claims to the contrary"*.

In contrast, the Resource Based View (RBV) theory provides a perspective on organisational performance by explaining why and how organisations are competitive (Barney, 1991, 1995). The RBV states that an organisation is a collection of both tangible and intangible resources and its performance lies in the organisation's ability to use and combine these resources (Hall, 1992; Peteraf, 1993). Some examples of organisational resources are financial, human, knowledge-based, technological and relational. In this way, the performance of organisations lies on the value, rarity, inimitability and the organisation of the accumulated resources as well as the combination of these resources (Barney, 1995). This is why Dyer and Singh (1998, p. 660) argue that this emphasis on the firm overlooks *"the important fact that the (dis)advantages of an individual firm are often linked to the (dis)advantages of the network of relationships in which the firm is embedded"* and can be considered against the rationale of partnerships and inter-organisational relations in general. Ultimately this focus on the individual organisation led Dovev Lavie (2006) to extend the resource-

based view by including the network of resources of interconnected organisations in assessing the performance of organisations.

In a similar vein, resource dependence theory acknowledges that organisations do not control all the resources they require. In fact, resource dependence theory is based on the power and dependence relationships that arise from the exchange of resources between organisations (Pfeffer & Salancik, 1978). Accordingly, organisations establish power and dependence relationships when an organisation's dependence on the resource(s) of another enable the organisation providing the resource(s) to have power over the other. In other words, *"power resides implicitly in the other's dependence"* (Emerson, 1962, p. 32). Furthermore, organisations which are mutually dependent on the resources of each other are considered to be interdependent. This typically leads to the formation of partnerships and inter-organisational relations in general as a means of effectively managing their power and dependence relationships (Gulati & Gargiulo, 1999; Pfeffer & Nowak, 1976). However, this emphasis on establishing power and dependency relations brings a prescriptive and deterministic view opposed to the evolutionary and dynamic processes of partnerships discussed in Sections 2.5.3 and 2.6.

Finally, social network theory brings a completely different perspective to the previous theories. Instead of focusing on the resources of individual organisations or why particular organisations exchange resources, social network theory takes a broader view to the environment surrounding organisations (Wasserman & Faust, 1994). This theory is based on viewing organisations as part of a network where they relate to other organisations. There are diverse definitions of network but one of the most cited according to Bergenholtz and Waldstrøm (2011, p. 541) is *"a set of nodes (e.g. persons, organisations) linked by a set of social relationships (e.g. friendship, transfer of funds, overlapping membership) of a specified type"* (Laumann, V. Marsden, & Prensky, 1983, p. 458). This implies that the ties and position of an organisation in a network influence their ability to partner and control the interactions in the network (Granovetter, 1985; Gulati, 1998; Vincent, 2008).

A further implication, is that a network perspective is useful to explain and investigate the behaviour and performance of partnering organisations on the basis of antecedents such as social, trust and prior experiences (Gulati, 1998; Gulati & Gargiulo, 1999). However, this emphasis in social connections can overlook other relevant aspects that influence partnerships. For example, König, Battiston, Napoletano, and Schweitzer (2011, p. 146) observe that all the empirical studies across different industries show that *"from all possible connections between firms, only a small subset is realized"*.

2.5 Partnership characteristics

Prior research has uncovered different characteristics of partnerships that can be categorised in three types. First, the partnership conditions under which partnerships operate. Second, the outcomes delivered by a partnership and third the processes that take place as partnerships unfold over time. In what follows in this Section, the partnership characteristics are described following the logic of a partnership unfolding over time and in ascending order of complexity. This allows each of the introduced partnership characteristics to build on the previous ones.

Thus, Section 2.5.1 starts by detailing the partnership conditions and how they trigger different outcomes, follows with the description of partnership outcomes in Section 2.5.2 and ends with Section 2.5.3 which deals the processes that intertwine conditions and outcomes throughout a partnership. After the definition of these characteristics, this Section concludes with an analysis of the multi-level and evolving nature of the partnership characteristics in Sections 2.5.4 and 2.5.5 respectively. Details on the review approach of this Section can be found in Appendix A.

2.5.1 Partnership characteristics: conditions

Following Das and Teng (2002), in this study conditions are defined as the key factors of a partnership at any point of time during the partnership development which starts at the formation and finalises with the dissolution of the partnership. Conditions are of great importance in the partnership literature due to their influence on how a partnership evolves over time (Doz, 1996;

Kohtamäki, Rabetino, & Möller, 2018; Prange et al., 2015). Interestingly, conditions are not static and a condition or set of conditions that once motivated establishing a relation between several organisations can also lead to its dissolution (Kogut, 1988; Milagres & Burcharth, 2019). This evolving nature also implies that different conditions can co-evolve during the development of a partnership and have diverse impacts in how a partnership develops (Das & Teng, 2002).

It is this influence on partnerships that has attracted an impressive number of scholars towards the study of conditions, especially in relation to those that motivate the formation of partnerships (Cannavale et al., 2021; Doz, 1996). These studies have identified a large number of partnership conditions and categorized them into different groupings such as success and failure factors, barriers, inducements and many others (see e.g., Ahuja, 2000; Gulati, 1998; Johanne Rønnow et al., 2008; McNamara, 2012; Oliveira & Lumineau, 2019; A. L. Oliver & Ebers, 1998; Stuart, 1998).

Although the partnership conditions have been thoroughly reviewed by many authors this review did not find any classification that stands out in the literature (see Buckley and Park (2013); Todeva and Knoke (2005); Nooteboom (2002); Sakakibara (2002) ; Knoben and Oerlemans (2006); C. S. Lee and Vonortas (2002); Eisner et al. (2009); and F. J. Contractor and Lorange (2002) for some reviews on general and specific alliance conditions). However, partnership conditions typically fall within the following five categories:

1. Environmental (e.g. industry convergence and regional policies and regulations).
2. Strategic (e.g. those related with organisational learning and product development).
3. Operational (e.g. geographical proximity between partners and the partnership governance and financing).
4. Cultural (e.g. organisational culture and risk aversion).
5. Social (e.g. trust and individual relations)

The literature also indicates that conditions influence partnerships at different levels (see e.g.Cohen & Levinthal, 1990; Gupta & Rosenkopf, 2019; Olk, 1998; Parmigiani & Rivera-Santos, 2011). For example some key conditions at the organisational level are cost pressures, limited market access

and lack of resources (Agarwal & Ramaswami, 1992; Gulati, 1998; Narula & Hagedoorn, 1999; O'Dwyer & Gilmore, 2018), and at the inter-organisational level prior history of relations, agreed conflict resolution techniques, governance flexibility and sense of interdependency (Duysters & Kok, 1999; Gupta & Rosenkopf, 2019; Hagedoorn & Duysters, 2002; Jenssen & Nybakk, 2013; J. E. Oxley, 1997; Yang, Zhu, & Santoro, 2021; Zaheer, Gözübüyük, & Milanov, 2010).

The highlighted multi-level and evolving nature of conditions and partnership characteristics in general is discussed in detail within the Section 2.5.4 and 2.5.5 following the discussion of all the partnership characteristics.

2.5.2 Partnership characteristics: outcomes

The literature acknowledges that organisations expect to benefit from partnerships through the achievement of one or several outcomes. However, the consideration and measurement of outcomes is challenging and numerous approaches and peculiarities have been highlighted. As in the case of partnership conditions, the fact that outcomes can take place at different levels in a partnership hinders their identification (Kohtamäki et al., 2018; Oliveira & Lumineau, 2019; Todeva & Knoke, 2005; Zajac & Olsen, 1993). Typically, the outcomes that are tracked on partnership studies take place at the organisational and inter-organisational level and are related to new products, the partnership duration and the number of subsequent partnerships (Davis & Eisenhardt, 2011; Milagres & Burcharth, 2019). However, partnerships can also trigger relational outcomes between individuals at different organisations even if the partnership did not deliver any organisational or inter-organisational outcomes (Olk, 1998).

Beyond the level at which an outcome operates, there are also different approaches in the literature when measuring the outcomes of a partnership. Studies typically track objective quantitative based outcomes such as the number of patents and joint publications but subjective qualitative based outcomes such as the perception of partnership success, tacit knowledge or acquired learning can also be taken into account (Kohtamäki et al., 2018; Milagres & Burcharth, 2019; Todeva & Knoke, 2005). Scholars adopting the latter approach often argue that only looking at objective quantitative

outcomes can neglect many others such as knowledge, learning and reciprocity (Cannavale et al., 2021; Martinkenaite, 2011; Parker, 2012). Because of this, some studies also include the perception of success that partnership participants have when identifying and assessing the outcomes in a partnership (Davis & Eisenhardt, 2011; Reuer & Zollo, 2005; Sambasivan, Siew-Phaik, Mohamed, & Leong, 2013).

The idea that outcomes, at least partially, depend on the partners' perceptions and aspirations for a partnership have major implications in the measurement and assessment of partnership outcomes (Milagres & Burcharth, 2019). For instance, while specific knowledge and learnings developed in a partnership may be considered an outcome by a specific partner, others who are already in possession of that knowledge and learnings or simply not interested, may not consider it an outcome (Ariño, 2003; Lumineau & Oliveira, 2018).

Introducing subjective qualitative outcomes reinforces the strand of research where outcomes are not to be viewed as static indicators and emphasizes the importance of acknowledging their dynamic dimension (Ariño, 2003; Lumineau & Oliveira, 2018). For example, Ariño (2003) explains how the inherently dynamic indicator of organisations adhering to partnership routines and processes is viewed by partnership participants as an outcome. This dynamic nature is in line with the highlighted evolving nature of partnerships conditions and a processual perspective of inter-organisational relations which underlines that *"there is no final outcome that can be pinned down once and for all... but the action of performing or instantiating network relations"* (Bizzi & Langley, 2012, p. 231).

Another complexity related to partnership outcomes is their randomness. Although many outcomes are clearly sought by the partners, others emerge from the collaboration in the partnership, such as acquisition of unexpected knowledge acquisition and IP leakages (Oliveira & Lumineau, 2019; Parker, 2012). Emergent outcomes can arise from diverse partnership conditions such as pressures to acquire new knowledge or lack of resources to maintain an ongoing partnership (Mowery et al., 1996; Reuer & Zollo, 2005; Todeva & Knoke, 2005). Whether sought or emergent, it is worth

noting that outcomes have major implications not only for the partnership literature in general but, in particular, for that focused on the assessment of partnership performance (Ariño, 2003; van Fenema & Keers, 2018).

2.5.3 Partnership characteristics: processes

It is widely recognised in the field that partnerships *"are usually not one-off transactions but, rather, entail continuing exchange and adjustments, as a result of which process issues become salient"* (Gulati, 1998, p. 304). In spite of this, process research on partnerships is scarce and most of the research on partnerships has even disregarded processes (Davis & Eisenhardt, 2011; Salk, 2005; Van de Ven & Poole, 1990). Nonetheless, given the strategic nature of partnerships, seminal articles typically call for more process research (Salk, 2005) following Van De Ven (1992, p. 70) *"definition of process [that] takes an historical developmental perspective, and focuses on the sequences of incidents, activities, and stages that unfold over the duration of a central subject's existence"*. This study subscribes to this definition of process.

Although partnership research on processes is scarce, studies have approached this topic when researching how partnerships unfold over time. To summarize and compare the key processes identified, Table 3 contains different exemplar studies on how partnership develop and the key underlying processes identified. The processes these studies introduce typically revolve around the planning and negotiation of a partnership as well as the execution, continuous evaluation and, if needed, redefinition and termination of the partnership. These processes and others have also been integrated under the construct of alliance capability or adjacent constructs such as alliance relational capability and management capability which has been the primary focus of the relatively recent literature on alliance capabilities (Kohtamäki et al., 2018).

Table 3 Summary of key processes identified as partnerships unfold over time

Ariño and de la Torre (1998)	**Das and Teng (2002)**	**Doz (1996)**	**Gulati (1998)**	**Ring and Van de Ven (1994)**	**Zajac and Olsen (1993)**	**Wittmann (2007)**	**(Prange et al., 2015)**
Negotiation	Evaluation of internal conditions	Evaluation of initial conditions	Formation	Negotiation	Strategy definition	Strategic planning	Partner selection
Commitment	Evaluation of partnership conditions	Learning	Governance	Commitment	Assessing and defining interactions	Partner identification and selection	Negotiation
Execution	Formation	Re-evaluation of initial conditions	External change	Execution	Developing trust	Implementation and management	Capability sharing
External change	Operation	Re-definition of conditions		Re-evaluation	Conflict management	Alliance termination	Knowledge exchange
Re-evaluation	Stabilization				Creating relational norms		Learning
Re-adjustment	Reformation				Redefining strategy		Governance changes
Dissolution	Termination				Redefining interactions		Contractual monitoring
							Dissolution

Das and Teng (2002) is the only study found to clearly point out that like partnership conditions and outcomes, processes are dynamic. In this way, processes evolve independently and, as needed, interactively with each other and the other partnership characteristics. Because of these interactions, studies in Table 3 typically highlight the importance and interdependency of the partnership conditions and outcomes with the processes. This is for example illustrated in Das and Teng (2002) and Ariño and de la Torre (1998) discussions on how the internal conditions of each partner and the partnership as well as the external conditions can influence and trigger different processes such as the partnership re-adjustment and termination processes.

Hence, the processes shown in Table 3 and others that may arise in a partnership are of utmost importance because they weave all of the previously described partnership characteristics, that is conditions and outcomes, over the course of a partnership. As observed from the analysis of conditions and outcomes, processes can take place at different levels and, therefore, the weaving of conditions and outcomes can take place at different levels. This is exemplified during the partner selection process. During this process commercial, social, and regulatory conditions at the individual, organisational, inter-organisational and environmental levels are intertwined as the partnership unfolds until the partners are selected (Ahuja, 2000; F. J. Contractor & Lorange, 2002; Yang et al., 2021).

2.5.4 Multi-level nature of partnership characteristics

As highlighted in the review and analysis of the partnership conditions, outcomes and processes, partnership characteristics influence and/or stem from one or several levels within and beyond a partnership as it unfolds over time. The levels at which the partnership characteristics operate can classified as four. The first level is the intra-organisational level which consists of characteristics that are specific to individuals, groups and units within an organisation in a partnership (Gupta & Rosenkopf, 2019; Lane & Lubatkin, 1998; Mindruta, 2013; Olk, 1998; Yang et al., 2021). For example, Yang et al. (2021), Olk (1998) and Gupta and Rosenkopf (2019) illustrate the importance

of individual-level conditions by analysing how the previous relation of two researchers in two separate organisations led to the first partnership between the two researchers' organisations.

Secondly, the organisational level in a partnership compromises those characteristics of an organisation in a partnership that relate to the overall organisation. Some examples are the geographical location, network position and institutional culture of the organisation (Funk, 2014; Knoben & Oerlemans, 2006; Yang et al., 2021). Next, the inter-organisational level consists of characteristics that rely on the interactions of the partnering organisations. For example, joint value maximization and trust among partners (Kwon, Rondi, Levin, De Massis, & Brass, 2020; Zajac & Olsen, 1993). Finally, the environmental level relates to characteristics beyond the partnerships such as unforeseen spill-over effects and regulatory changes (F. J. Contractor & Lorange, 2002; Albert N. Link, Paton, & Siegel, 2002; Eva Niesten & Jolink, 2020).

This multi-level nature of partnership characteristics encumbers analysis enormously and calls for setting creative and clear research designs (Aaboen, Dubois, & Lind, 2012; Halinen & Törnroos, 2005; Lumineau & Oliveira, 2018) to avoid risks such as *"death by data asphyxiation"* (Pettigrew, 1990, p. 281). For example, Nooteboom (2002) and Ring and Van de Ven (1994) aggregate intra-organisational level conditions to the organisational level as those related to individuals are constrained and articulated by their organisational roles. It is evident that fully comprehensive multi-level empirical analyses, whether of a quantitative and/or qualitative nature, of partnerships cannot be undertaken and continuous trade-offs by scholars have been and will be inevitable.

2.5.5 Evolving nature of partnership characteristics

In addition to the multi-level trait of partnership characteristics (conditions, processes and outcomes), another trait among them is the high number of complex interdependencies and changes they undergo throughout the lifetime of a partnership. These interdependencies and changes emerge from the relations between characteristics and the influences that partnership characteristics exert on each other over time. For example, intra-organisational, organisational and inter-organisational technology partnership characteristics are closely related and influenced by

variations in environmental conditions such as variations in policies for technology and political factors (Aldrich & Sasaki, 1995; Q. Xu & Renyong, 2009).

To illustrate the highlighted dynamic and multi-level nature of partnership characteristics as time unfolds, the model presented in Figure 4 has been developed. This figure is a three-dimensional model representing the partnership characteristics, levels and time along three axes. Since the pertinent literature is mainly based on quantitative approaches (Bergenholtz & Bjerregaard, 2013; A. L. Oliver & Ebers, 1998) with a paucity of studies on how conditions and processes influence the development and outcomes of partnerships (Delbufalo, 2012; Milagres & Burcharth, 2019; Mohr & Spekman, 1994), this model brings the following benefits:

- Aggregates prior research into a single and novel visual representation that captures the multi-level and evolving nature of partnership characteristics.
- Indicates that partnership development is mediated by the underlying characteristics across different levels as time unfolds.
- Serves as a conceptual representation for studies in the field.

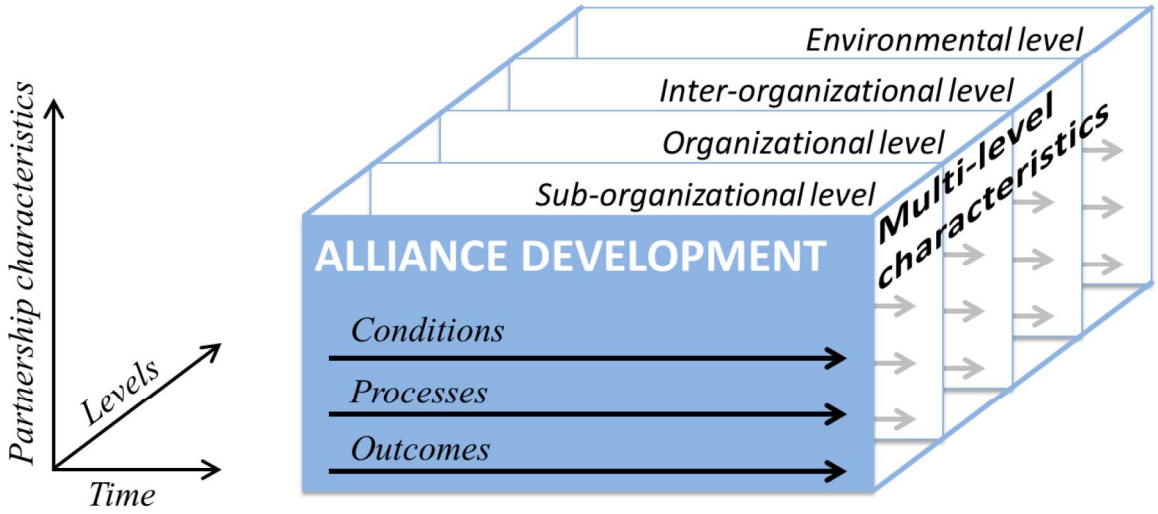


Figure 4 Relations among the partnership characteristics

The model shows how the development of partnerships consists of organisations collaborating through multi-level, co-evolutionary conditions, processes and outcomes where the conditions are

interrelated by the processes aimed to achieve the partners' desired outcomes. The three key concepts (multi-level co-evolutionary conditions, processes and outcomes) included in the model are selected because they are central to the literature on partnerships. Consequently, the model in Figure 4 serves as a starting point and sensitising device to research partnerships focused on research, development and innovation activities which are the focus of this study. The following Section continues exploring the evolving nature of partnerships by looking at how partnerships develop over time.

2.6 Dynamics of partnerships

On top of the complexity that ensues from using the term partnership as a synonym for alliances or to cover both informal and contractual inter-organisational relations (see e.g. Caloghirou et al., 2004; Hagedoorn et al., 2000; Milagres & Burcharth, 2019; Mohr & Spekman, 1994; Prange et al., 2015; Todeva & Knoke, 2005), there is also a surprisingly large accumulation of terms that are sometimes used interchangeably to describe how partnerships unfold over time and the underlying processes. Some examples of the terms used in the literature are evolution of partnerships (Fearne, 1998), alliance dynamics (Hennart, 2006; Ness, 2009), development process (Johanne Rønnow et al., 2008), alliance evolution (Ariño & de la Torre, 1998), alliance process (Koza & Lewin, 1998) and combinations of the above terms such as dynamic evolution of alliances (Gulati, 1998) and dynamic evolutionary processes (Panda, 2017). However, analysing the selected literature it is concluded that they all revolve around the following three focus areas of the dynamics of partnerships:

- *Partnership development or partnership evolution* - studies that explore how partnerships unfold over time from inception to dissolution or period(s) from inception to dissolution.
- *Partnership successions* or *succession of partnerships* - studies that focus on how partnerships emerge from or generate other partnerships.
- *Development of partnerships* or *evolution of partnerships* - studies encompassing both of the previous areas of study, partnership development and succession of partnerships.

In the next three sections, each of these focus areas is analysed. Details on the review approach of this Section can be found in Appendix A.

2.6.1 Partnership development

The literature reveals that partnership development involves a large number of heterogeneous conditions, outcomes and processes such as strategy planning, partner selection, negotiation, operation, re-evaluation and dissolution (Aarseth, Andersen, Ahola, & Jergeas, 2012; N. S. Contractor, Wasserman, & Faust, 2006; Meyer & Goes, 1988; Nooteboom, 2002). Because of this, scholars such as Koza and Lewin (1998) and Das and Teng (2002) advocate for a co-evolutionary view of partnerships where the parallel evolution of their characteristics relates to the partnership development.

To ease understanding and identify the underlying characteristics occurring at different instances of a partnership, scholars have developed a number of partnership development stages under which characteristics can be contained and analysed (see e.g., Das & Teng, 2002; Ness, 2009; Ring & Van de Ven, 1994; Zajac & Olsen, 1993). The identified partnership development stages in this review are pre-formation, formation, execution and assessment. The pre-formation stage refers to the organisational strategy development that leads to the consideration of pursuing partnerships as a viable vehicle to accomplish the needs of the firm. Before an organisation can even consider a partnership as a viable route, it must be within the prerogative of staff roles to consider the possibility of establishing partnerships (Olk, 1998).

Once partnerships are acknowledged as a viable option by an organisation, the formation stage can be started. This stage deals with the search and design of potential partnerships through processes such as the selection of partners and the negotiation of the governance mode, tasks, routines and goals. The formation stage has garnered most of the partnership research attention since it can explain the explosion of partnerships across industries, mainly in high-tech environments (F. J. Contractor & Lorange, 2002; Hagedoorn, 2002; McNamara, 2012; Mohr & Spekman, 1994). The

transition from the formation stage to the next stage, execution, is signposted by a formal agreement among the partnering organisations. This agreement typically implies the signing of a contract by all the organisations involved in the partnership.

During the execution stage the agreed plans at the formation stage are implemented by the partners. In doing so, the formation stage plans are refined and modified in response to changes in the partnership development characteristics. In a similar way as with organisational processes (Monge, 1990), partnerships are affected by complex changes over time at the intra-organisational, organisational, inter-organisational and environmental level. These changes draw the attention of the partners to rethink the formation stage plans throughout the execution. At the same time, this emphasizes the importance of analysing partnership development during extended periods. Some examples of conditions that often change throughout the duration of an partnership are trust (Delbufalo, 2012), policies (Albert N. Link et al., 2002) and industry life cycles (Rice & Galvin, 2006).

The differentiation between the execution and assessment stages is not always clearly marked in the literature and can concur (Ring & Van de Ven, 1994). The assessment stage deals with both the internal and collective appraisal of partnership outcomes by the partners. Thus, this stage often leads to either a decrease or increase in the relation among the partnership partners. Typically the assessment stage leads to the termination or continuation of the ongoing partnership as well as the formation of other partnerships which can take the form of other inter-organisational relations such as a joint ventures or licenses (Das & Teng, 2002).

Yet the termination of a partnership does not necessarily have to be considered as a failure but as a natural development when partners, for example, take outcomes in-house to undertake product development activities (Reuer & Zollo, 2005). This implies that the termination of a partnership does not necessarily mean the study of a partnership should be ended. Partners such as companies can work for long periods of time on particular partnership outcomes before being able to confirm they are relevant for future products (Narula, 2001).

As a summary of the discussed stages in the literature, Table 4 shows the specific development stages identified in each publication. As shown in Table 4, most of the publications found considered the formation, execution and assessment stages and only three the pre-formation stage as well. Furthermore, one of the analysed publications did not discuss any of the partnership development stages because, although it was focused on the dynamics of partnerships, it is focused on the topic of the succession of partnerships, covered in the next Section, as opposed to partnership development.

Table 4 Summary of the development stages in the reviewed literature on partnerships

	Identified partnership development stages			
	Pre-formation	**Formation**	**Execution**	**Assessment**
Ariño and de la Torre (1998)		✓	✓	✓
Boddy, Macbeth, and Wagner (2000)		✓	✓	✓
Das and Kumar (2011)	✓	✓	✓	✓
Das and Teng (2002)	✓	✓	✓	✓
de Rond and Bouchikhi (2004)		✓	✓	✓
Doz (1996)		✓	✓	✓
Gulati (1998)		✓	✓	✓
Hagedoorn, Carayannis, and Alexander (2001)	N/A	N/A	N/A	N/A
Koza and Lewin (1998)		✓	✓	✓
Marion, Eddleston, Friar, and Deeds (2015)	✓	✓	✓	✓
Ness (2009)		✓	✓	✓
Osborn and Hagedoorn (1997)		✓	✓	✓
Ring and Van de Ven (1994)		✓	✓	✓
Y. Wang and Nicholas (2007)	✓	✓	✓	✓
White (2005)		✓	✓	✓
Wilson and Hynes (2009)		✓	✓	✓
Zajac and Olsen (1993)		✓	✓	✓

The identified stages are of particular interest to this study because they allow to extend the model developed in Figure 4 by integrating the identified stages together with the discussed partnership multi-level characteristics discussed in Section 2 in the new model presented in Figure 5. By doing so, the new model makes it possible to represent not only how partnership development multi-level characteristics intertwine over time but also within and across stages. This is of key importance to

the study of partnership characteristics since understanding conceptually the stages at which they appear and develop provides additional contextual information to guide their study and assess their relevance at different stages of partnership development.

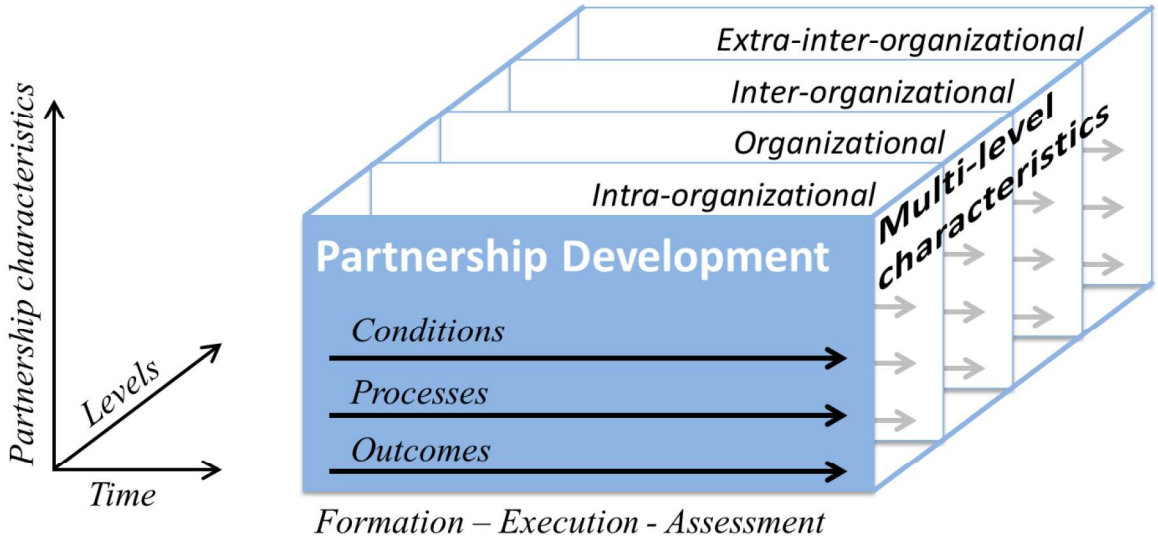


Figure 5 Relations among the partnership characteristics and stages

The model shows how the development of partnerships consist of organisations collaborating through multi-level co-evolutionary conditions, processes and outcomes where the conditions are interrelated by the processes through different stages to achieve the partners' desired outcomes. The four key concepts (stages, multi-level co-evolutionary conditions, processes, stages and outcomes) included in the model are selected because they are central to the literature on partnerships. Consequently, the new model shown in Figure 5 can be leveraged for research partnerships focused on research, development and innovation activities which are the focus of this study.

2.6.2 Succession of partnerships

In contrast to the majority of the reviewed literature focused on partnership development, only three studies are focused in the succession of partnerships phenomena. Koza and Lewin (1998) emphasize that a partnership may drive the overall population of partnerships. Marion et al. (2015) support this view through their ten year ethnographic study of fourteen start-ups that engage in

multiple and diverse new product development partnerships. They found that the succession of partnerships unfold along a continuum from outsourcing to equity-based as the partnership partners strengthen or weaken their inter-organisational relations over time. Hagedoorn et al. (2001) also support this view from a different level of analysis. They found that the sudden growth and underlying logic of 19 partnership successions between competitors IBM and Apple, was motivated by characteristics, such as the appearance of a new dominant design, at the environmental level.

2.6.3 Development of partnerships

From the review of the articles discussed in Sections 2.6.1 and 2.6.2, another potential focal area of study in the field of partnerships can be inferred, the development of partnerships or evolution of partnerships. This area results from the combination of the partnership development and succession of partnerships topics discussed in Section 2.6.1 and 2.6.2. In this way, the development of partnerships not only encompasses how individual partnerships unfold over time from inception to dissolution or a period within, but also how these individual partnerships impact other partnerships.

Given the comprehensive perspective of the development of partnerships area, its study can bring a different point of view on how partnerships unfold over time and new insights into the field. This new perspective can be of great relevance given that more and more organisations form and rely on different concurring and cascading partnerships to pursue their strategic goals (F. J. Contractor & Lorange, 2002; Hagedoorn, 2002; Koza & Lewin, 1998; H. L. Lee, 2004). Because of this, studies that take into account on-going partnerships in organisations can be key when analysing how partnerships unfold over time.

2.7 Conclusions

This chapter provided a literature review on partnership studies. After a brief introduction to the chapter, the first two sections outline the literature on partnerships within its context and provide a brief overview of where it is positioned in relation to adjacent and encompassing bodies of

literature. The following Section, 2.4, presents the main theoretical perspectives found in the literature and highlights their strengths and limitations in the context of partnerships. The next two sections review and analyse the key characteristics of partnerships and how they unfold over time by examining the dynamics of partnerships. Finally, in this Section the key findings and implications of the literature review analysis are summarized.

First, the continuous increase in partnerships has been followed by a myriad of studies across different bodies of literature such as strategy, management, economics and psychology. As a result, the field is marked by a lack of coherence and fragmentation which hinders theoretical construction and its translation to practitioners (Gulati, 1998; Martínez-Noya & Narula, 2018; A. L. Oliver & Ebers, 1998; Parmigiani & Rivera-Santos, 2011). For example, it is not unusual to find that the term partnership is used as a synonym for alliance or used to cover both informal and contractual inter-organisational relations (see e.g. Caloghirou et al., 2004; Gupta & Rosenkopf, 2019; Hagedoorn et al., 2000; Mohr & Spekman, 1994; Prange et al., 2015; Todeva & Knoke, 2005). Another example is that, interestingly, the attention has mainly focused on the study of dyads despite the abundant calls for research on triads and larger groups to confirm and extend results from the study of dyads (see e.g. Eisner et al., 2009; Gulati, 1998; Vonortas & Okamura, 2009; S. Xu et al., 2014).

In the same vein, a second finding is that the field suffers from a clear imbalance since most studies are focused on the formation or the assessment of performance by linking conditions at formation and partnership outcomes (Ariño, 2003; Bidault, 2020; Cui et al., 2011; Doz et al., 2000; Dyer et al., 2007; Gulati, 1998; Majchrzak et al., 2015). This imbalance may be attributed to the common use of quantitative methods based on a single-level of analysis which are referred to as a major blind spot in the literature (Gomes et al., 2016; Lumineau & Oliveira, 2018). The dominance of single-level quantitative approaches may also explain a lack of focus on the dynamics of partnerships (Gulati, 1995; He et al., 2020; Majchrzak et al., 2015; Stuart, 1998).

Third, none of the theoretical frameworks that have emerged in the literature has been confirmed or substantially adopted in the partnerships or inter-organisational literature (F. J. Contractor & Lorange, 1988; Das & Teng, 2002; Doz, 1996; Koza & Lewin, 1998; Ring & Van de Ven, 1994). Typically, the literature on partnerships, as well as the alliances and overarching inter-organisational relations fields, adopts theories coming from other research areas (see e.g. C. S. Lee & Vonortas, 2002; A. L. Oliver & Ebers, 1998). As a result, the main and complementary theoretical approaches identified in the review of partnerships are the transaction cost economics, resource-based view, resource dependence theory and social network theory (Delbufalo, 2012; Eva Niesten & Jolink, 2020; A. L. Oliver & Ebers, 1998; Vincent, 2008).

Fourth, prior research has uncovered different characteristics of partnerships that can be categorised in three types. The partnership conditions under which partnerships operate, the outcomes delivered by a partnership and, finally, the processes that take place as partnerships unfold over time. Interestingly, these characteristics present two features. Not only they operate at the intra-organisational, organisational, inter-organisational and environmental levels but also present a dynamic nature since *"partnerships are usually not one-off transactions but, rather, entail continuing exchange and adjustments, as a result of which process issues become salient"* (Gulati, 1998, p. 304). However, there is a paucity of studies acknowledging how characteristics evolve, co-evolve or operate at several levels influencing partnership development (Delbufalo, 2012; Lumineau & Oliveira, 2018; Milagres & Burcharth, 2019; Mohr & Spekman, 1994).

Fifth, partnership characteristics can be perceived differently by the partners involved in a partnership. For example, Ariño (2003) explains that while specific knowledge and learnings developed in a partnership may be considered an outcome by a specific partner, others who are already in possession of that knowledge and learnings or simply not interested, may not consider it an outcome. Acknowledging that characteristics such as outcomes, at least partially, depend on the partners' perceptions and aspirations for a partnership have major implications in understanding critical research areas such as the measurement and assessment of partnership performance (Milagres & Burcharth, 2019). Lumineau and Oliveira (2018) argue that single-party studies in the

overall inter-organisational literature represent a major blind spot where the view of an entity is taken as a proxy of the inter-organisational relation. For example, in line with the findings of this study, they claim that single-party approach are *"Neglecting possible asymmetries of behaviors and outcomes"* (Lumineau & Oliveira, 2018, p. 445).

Sixth, scholars have developed a number of partnership development stages under which characteristics can be contained and analysed to ease the understanding and identification of the characteristics which emerge during the partnership development (see e.g., Ness, 2009; Prange et al., 2015; Ring & Van de Ven, 1994; Zajac & Olsen, 1993). The identified partnership development stages in this review are pre-formation, formation, execution and assessment. The pre-formation stage refers to the organisational strategy development that leads to the consideration of pursuing partnerships as a viable vehicle to accomplish the needs of an organisation. The formation stage has garnered most of the partnership research attention since it can explain the explosion of partnerships across industries, mainly in high-tech environments (see e.g., F. J. Contractor & Lorange, 2002; Hagedoorn, 2002; McNamara, 2012; Mohr & Spekman, 1994). Then, the transition from the formation stage to the next stage, execution, is signposted by a formal agreement among the partnering organisations. During the execution stage the agreed plans at the formation stage are implemented by the partners. Finally, the assessment stage deals with both the internal and collective appraisal of partnership outcomes by the partners. Thus, this stage often leads to either an increase or decrease, up to termination, in the relation among the partners.

Finally, although a co-evolutionary view of partnerships is considered of great significance to advance our understanding of partnership development in relation to the multiplicity and co-existence of heterogenous interactions, it is still a poorly understood phenomenon (Bizzi & Langley, 2012; Das & Teng, 2002; He et al., 2020; Koza & Lewin, 1998; Lahiri et al., 2021; Panda, 2017). Adopting a co-evolutionary approach is of great benefit because it can allow to study partnerships with different time lenses as it is required by the heterogenous partnership characteristics analysed in the literature review in this Section. A co-evolutionary approach therefore overcomes a major blind spot identified by Lumineau and Oliveira's (2018) twenty year

review in the overall inter-organisational literature, a single time conceptualization. Lumineau and Oliveira (2018, p. 446) also highlight that – *"the interplay between multiple conceptualizations of time is particularly relevant for understanding the evolution of IORs [Inter-Organisational Relations]..."* which is the focus of this study.

In view of the significance of the multi-level, dynamic and co-evolutionary nature of partnership characteristics as time unfolds across different developmental stages, the new model presented in Figure 5 was developed. This model brings the following benefits:

- Aggregates prior research into a single and novel visual representation that captures the multi-level and co-evolving nature of partnership characteristics across different stages.
- Indicates that partnership development is mediated by the underlying characteristics across different levels as time unfolds.
- Serves as a conceptual representation for studies in the field.

The new model shows how the development of partnerships consist of organisations collaborating through multi-level co-evolutionary conditions, processes and outcomes where the conditions are interrelated by the processes through different stages to achieve the partners' desired outcomes. The four key concepts (stages, multi-level co-evolutionary conditions, processes, and outcomes) included in the model are selected because they are central to the literature on partnerships. Leveraging these four key concepts embedded in the model, allow to overcome three major blinds spots in the literature according to (Lumineau & Oliveira, 2018), undertaking studies with single-level, single-party and single time conceptualization approaches. The new model is therefore used in this study as a sensitizing device to research partnerships focused on research, development and innovation activities.

In conclusion, this chapter provides the foundation on which the next chapter builds to review partnerships focused on research, development and innovation activities. This two-phased review approach has a twofold objective. On the one hand, it guides and complements the review on RDI

partnerships by building on the findings of the review on partnerships, and on the other hand it provides a strong base for the field work in this study.

3 Literature review on partnerships focused on Research, Development and Innovation (RDI)

Chapter 2 and 3 provide the consulted and reviewed literature of this study. As indicated in Figure 6, Chapter 3 builds on the literature review on partnerships presented in Chapter 2 to undertake the literature review on RDI partnerships.

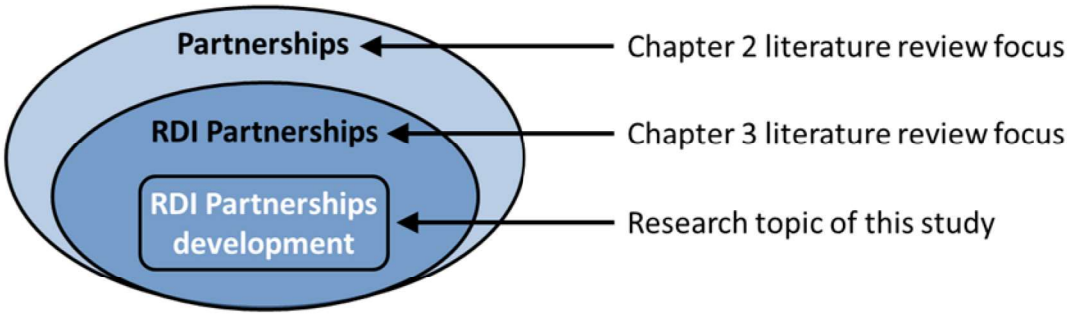


Figure 6 Overview and structure of the literature review

Chapter 3 starts by introducing in Section 3.1 the concepts of research, development and innovation (RDI) which are at the core of many partnerships and other inter-organisational relations. Section 3.2 introduces the area of RDI partnerships and key terms and Section 3.3 provides a summary of the main theoretical perspectives found in the literature on RDI partnerships. Section 3.4 details the characteristics of RDI partnerships at formation, execution and assessment stage and Section 3.5 describes the dynamics of RDI partnerships.

This chapter continues by providing in Section 3.6 with a comparative analysis of the literature review findings on RDI partnerships and the literature review findings on partnerships from Chapter 2. It then discusses in Section 3.7 the identified research gaps in the literature on RDI partnerships. Finally, the chapter ends with Section 3.8 where the conclusions on the literature on RDI partnerships are presented.

3.1 Understanding research, development and innovation activities

In the literature there are diverse views and definitions of research (see e.g., Brooks, 1967, pp. 23-26; Godin, 2004, p. 58; OECD, 1994, p. 13). Since the 14th Century the term is anchored around the idea of search where it was focused on examining phenomena in detail (Godin, 2004). In this study research is broadly defined as a process focused on the creation of knowledge to improve general or specific understanding of phenomena. As in other areas, within the nanotechnology research context of this study, the literature defines two types of research: basic research and applied research. While basic research focuses on creating new scientific knowledge, applied research focuses on finding the needed knowledge to solve practical economic, social and political problems (Roll-Hansen, 2008). Basic and applied research are typically followed by experimental development or simply development activities which consist of utilising the knowledge available from research to deliver new or improved products (OECD, 1994).

Combining and undertaking Research and Development (R&D) activities are typically regarded as a source of generating distinctive competences and technologies (Narula, 2001). These are some of the reasons why investments towards R&D are typically increased year after year in high technology industries such as the electronics, pharmaceuticals and medical devices industries (Prange et al., 2015). At the same time this has increased the attention of academia, industry and policy towards the term R&D as opposed to research over the last decades (Caloghirou et al., 2004, pp. 6-8).. Furthermore, during this time the usage of the term R&D has evolved from being used to emphasize the importance of achieving novel scientific knowledge through research to highlight the importance of providing new or improved applications of knowledge through experimental development. This can be observed for example in the development of governmental and industrial R&D programs such as the European Commission R&D Framework Programs where the emphasis shifts from research to development on an ongoing basis since its beginnings in the 1980s (Caloghirou et al., 2004, pp. 6-8).

Finally, the term innovation dates back to the 16th century (Gilley & Gilley, 2017, p. 2) and is related to the idea of renewing and change. There is currently no unified definition of innovation despite the large accumulation of studies in the fields of economics, engineering, political science and sociology among others. Some definitions of innovation from key scholars or widely used in the organisational field are...

> *"...innovation is the invention and implementation of new ideas"* (Van de Ven & Poole, 1990, p. 314)

> *"Innovation is generally understood as the successful introduction of a new thing or method. Innovation is the embodiment, combination, or synthesis of knowledge in original, relevant, valued new products, processes or services"* (Luecke, 2003, p. 48)

In these and many other reviewed definitions of innovation, there is typically the indication of using knowledge and experience to implement and bring into use a novel idea in the form of a product, process or service. Moreover, R&D and innovation can be of different degrees, incremental or disruptive, and have different foci, products, processes, services and other (Holmes & Moir, 2007; Keith Goffin & Mitchell, 2010, pp. 10-14). In the same way as development activities follows research activities, innovation follows R&D activities by leveraging the knowledge and experiences attained during the R&D efforts to bring a novel idea to the market.

The innovation activities that are not covered under the term R&D can be related to commercial activities such as marketing, engaging with potential customers, and business modelling. However, since innovation can also start with the creative activities that generate an idea, R&D is generally considered as a step in the innovation process. Figure 7 illustrates the typical Research, Development and Innovation (RDI) process steps and structure that organisations undergo to deliver innovations.

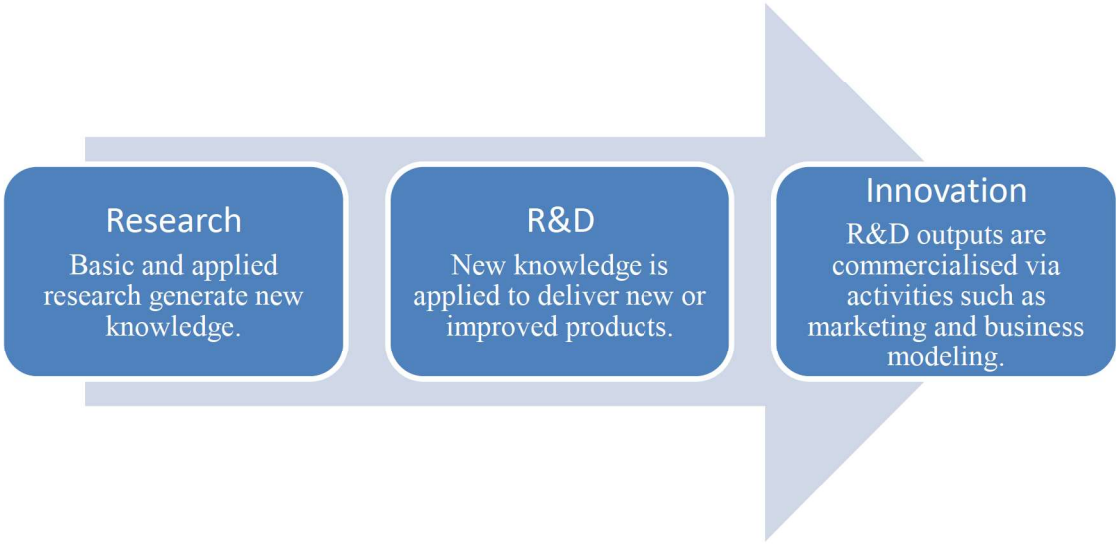


Figure 7 RDI process steps and structure

It is worth noting that the R&D steps in Figure 7 may or may not be required to innovate. In other words, when an organisation does not require developing new knowledge, either because it is already available or is insourced from a third party, organisations can innovate without undertaking the research and R&D steps shown in Figure 7 (West & Bogers, 2014).

3.2 RDI partnerships

Both R&D and Innovation (RDI) can be undertaken in-house or together with other entities. The latter is generally referred to as collaborative or open R&D and collaborative or open innovation (Albors-Garrigós, Rincon-Diaz, & Igartua-Lopez, 2013; Chesbrough, 2003; Narula, 2001). Increased technology complexity, R&D costs and competition are some of the trends pressuring organisations to focus on their core competencies and establish RDI inter-organisational relations extending from networks, to outsourcing and to joint ventures (Martínez-Noya & Narula, 2018; Prahalad & Hamel, 1990).

Organisations must therefore learn to establish and manage RDI inter-organisational relations with different entities and industry sectors to remain competitive (Chesbrough, 2003; Gibbons et al., 1994; X. Wang, Dolfsma, & van der Bij, 2019). Subsequently, academics, industry and policy makers are promoting different forms of research, R&D and RDI partnerships through internal

strategies or regional initiatives such as the Horizon 2020 program[2] in Europe and Science Foundation Ireland Strategy Agenda 2020[3] in Ireland (Caloghirou et al., 2004, pp. 1-8) .

As a result, partnerships focused on RDI activities have experienced a sustained increase since the 1970s especially in high technology industries through the establishment of partnerships under different names such as joint development programs, consortia and public-private partnerships (Duysters & Kok, 1999; Eisner et al., 2009; Hagedoorn & Duysters, 2002; M'Chirgui, 2009; Martínez-Noya & Narula, 2018; Narula & Hagedoorn, 1999; Powell et al., 1996). This multiplicity of terminology together with the lack of coherence in the partnership literature led to undesirable implications in the usage and coining of terms in the RDI partnership literature. On the one hand, terms with different meanings are often used interchangeably (Greenlee, 2005; Martínez-Noya & Narula, 2018) and on the other hand a term can be used to convey different meanings when used by scholars from different geographies.

As an illustrative example, studies by Daellenbach and Davenport (2004) and Niosi and Bergeron (1992), Hagedoorn (2002) and Hertzfeld, Link, and Vonortas (2006) mention being focused on technology alliances, on R&D partnerships and on research partnerships respectively. However, these studies are based on the same type of inter-organisational relationship: contractual or equity based arrangements focused on research, technological development and innovation activities. Similar cases of this cacophony of terms include Olk (1998) and Doz et al. (2000) studies where the term R&D consortia implies equity based inter-organisational relationships while policy makers, practitioners and scholars in Europe typically use the term R&D consortia to imply non-equity based contractual inter-organisational relationships (see e.g.Caloghirou et al., 2004, p. 36 and the European Framework Programmes from 1984 until 2020).

[2] Collaborative RDI is an important cross-cutting priority in the European Horizon 2020 program to develop socio-economic impact from RDI partnerships. Further details can be found at the following webpage: http://ec.europa.eu/research/horizon2020/

[3] A key action of the new Irish strategy for research and innovation is to develop and lead collaborations to foster the research and business community. Further details can be found at http://www.sfi.ie

The proliferation of inter-organisational relationships has led to a cacophony of terms. Consequently, analysing and integrating the findings of studies in this field is a complex task whereby a researcher must take into account that a term or similar terms across different articles may need to be interpreted differently. In the interest of clarity and given the location where this study was carried, Europe, RDI partnerships are defined as follows…

> *…non-equity contractual based inter-organizational relations established by two or more organizations to collaborate in research, development and innovation activities and share knowledge and resources to achieve common and interrelated objectives.*

This definition builds on the work of Hagedoorn (2002), Martínez-Noya and Narula (2018), Mohr and Spekman (1994), Katz and Martin (1997) and the developed categorization of inter-organisational relation types shown in Table 1. Given the cacophony of terms it is important to emphasize that when referring to contractual relations or consortia in this study equity based relations are excluded.

3.3 Theoretical perspectives on RDI partnerships

As in the partnership's literature, no dominant theoretical framework was found for RDI partnerships (Martínez-Noya & Narula, 2018). However, the literature in general and that focused on developing theory and conceptual frameworks tend to refer more frequently to knowledge based aspects in the formation and management of RDI partnerships than in the field of partnerships (Gulati, 1998; Inzelt, 2004; Joanne E. Oxley & Sampson, 2004). Hence, in addition to the highlighted theories in the partnership literature, the knowledge based theory is also considered of relevance to RDI partnerships and, thus, discussed in this Section.

The knowledge based theory builds on the resource based view and considers knowledge as the most important resource in an organisation (Kogut & Zander, 1992; Spender, 1996; Takeuchi, 2013). Nonaka (2008, p. 162) claims that *"…the only true lasting competitive advantage is knowledge…"*. In addition, the knowledge based view considers that the resource of knowledge is

contained in social communities as opposed to the resource based view where resources are contained within an organisation (Kogut & Zander, 1992). Although there are several differences between the resource and knowledge based view, the latter is sometimes not always regarded as a theory in itself but just as an extension of the resource based view which includes the resource of knowledge (R. M. Grant & Baden-Fuller, 2002).

Hence, the emphasis of the Knowledge Based View (KBV) is on the development and transfer of knowledge by the social interactions of communities within and across organisations (R. M. Grant & Baden-Fuller, 1995; Kogut & Zander, 1992; Spender, 1996). These social interactions develop new knowledge, or learning and put a focus on social conditions such as communication and trust which are typically found in the literature on RDI partnerships (Bstieler & Hemmert, 2008; Hagedoorn, Roijakkers, & Kranenburg, 2008; Hemmert, Bstieler, & Okamuro, 2014; Ring, Doz, & Olk, 2005).

The Knowledge Based View is complementary to the Transaction Cost Economics (TCE), Resource Based View (RBV), Resource Dependence Theory (RDT) and the Social Network Theory (SNT) theories discussed in Section 2.4 and aids in the understanding of RDI partnerships (R. M. Grant & Baden-Fuller, 1995). As a summary, Table 5 outlines the key theoretical implications and limitations of these theories in regard to RDI partnerships.

Table 5 Key theoretical implications and limitations in RDI partnerships

Theory	**Driver**	**Implications for RDI partnerships**	**Limitations explaining RDI partnerships**
TCE	Efficiency	Minimize internal costs via RDI partnerships	Applicability to complex and evolutionary dynamics is questionable.
RBV	Competencies	Combine internal and external resources to maximize their value	Emphasis on the organisation overlooks links with other organisations
RDT	Power and dependencies	Exchange resources with external partners to overcome internal dependencies	Prescriptive and deterministic view of the environment
SNT	Social relations	Control the interactions in a network	Social relations cannot fully explain other key aspects of the development of RDI partnerships
KBV	Knowledge	Combine internal and external knowledge to maximize its value	Not always regarded as a theory, can be considered an extension of RBV.

The highlighted limitations of these theories in explaining not only RDI partnerships but also partnerships and inter-organisational relations in general lead scholars to typically use and combine different theories. Moreover, all of these theories are based on the antecedents and structural properties of RDI partnerships and show little emphasis on agency and the underlying processes (Vincent, 2008). For example, the social network theory is focused on the ties and position of an organisation in a network to explain the partnering interactions in the network. Furthermore, it is unclear that the available research and theories around RDI partnerships constitute a distinctive theory given the fragmentation. Given the lack of a predominant line of thought among the theoretical approaches found in the literature, the field appears to be in transition from a nascent to an intermediate state of theoretical development. This may stem from the encompassing literature on alliances and inter-organisational relations since it exhibits similar challenges as concluded from the large systematic review carried by Kohtamäki et al. (2018) on alliances or Bergenholtz and Waldstrøm (2011) on inter-organisational relations. For example, in the latter study it is concluded

that RDI partnerships and the overall field on inter-organisational relations *"seems to be in need of further development and coherence, if it is to be characterized as a theory"* (Bergenholtz & Waldstrøm, 2011, p. 555).

3.4 RDI partnerships characteristics

This Section discusses the results of the literature review on RDI partnership characteristics by analysing the conditions, outcomes and processes following the structure of the review in Chapter 2. However, in this review the RDI partnership characteristics are analysed at each of the partnership development stages identified in Chapter 2. Hence, Section 3.4.1 focuses on the RDI partnership characteristics at the formation stage, Section 3.4.2 on the characteristics at the execution stage in and Section 3.4.3 on the characteristics at the assessment stage. This approach facilitates an in-depth analysis of each literature strand and cross-analysis to produce a comprehensive evaluation of the literature on RDI partnership characteristics. More details on the review approach of this Section can be found in Appendix B.

3.4.1 RDI partnership characteristics at the formation stage

The articles focused on the RDI partnership characteristics at the formation stage are discussed by analysing the following comprehensive suite of key aspects: availability of studies in this area, temporal distribution, the type of RDI partnerships included, the undertaken research methods, the types of data used, the selected units of analysis and the levels of analysis. It is important to note that the 24 selected articles for review constitute the first literature review on RDI partnership characteristics at the formation stage known by the author of this study.

Despite the undertaken comprehensive literature review approach[4] and that the formation of RDI partnerships has garnered most of the research attention in the field, the first feature noticed in this review is the limited number of selected articles (F. J. Contractor & Lorange, 2002; Doz et al., 2000; Eisner et al., 2009; Hagedoorn, 2002; McNamara, 2012; Mohr & Spekman, 1994;

[4] See Appendix B for details on the comprehensive literature review approach undertaken.

Sakakibara, 2002). In terms of the temporal distribution of the selected studies, they have increased since 2005 in contrast to the publications in the development of partnerships which declined after 2005. In total, 16 of the 24 selected articles were published after 2005.

Studies on the formation of RDI partnerships draw their data from the different types of inter-organisational relations highlighted in Section 2.1. As shown in Figure 8 the data on which these 24 articles focus is not only contractual RDI partnerships but also from contractual RDI partnerships combined with equity, equity and informal or informal RDI partnerships. Combining data from different types of inter-organisation relationships is also common in the partnership literature despite it challenges the transferability and applicability of research results. In fact, informal inter-organisational relations are typically not included in partnership studies with equity and contractual inter-organisational relations (Casson & Mol, 2006; Ratten, 2003). This may explain why the reviewed RDI partnerships studies are typically based on data from contractual and equity and contractual RDI partnerships.

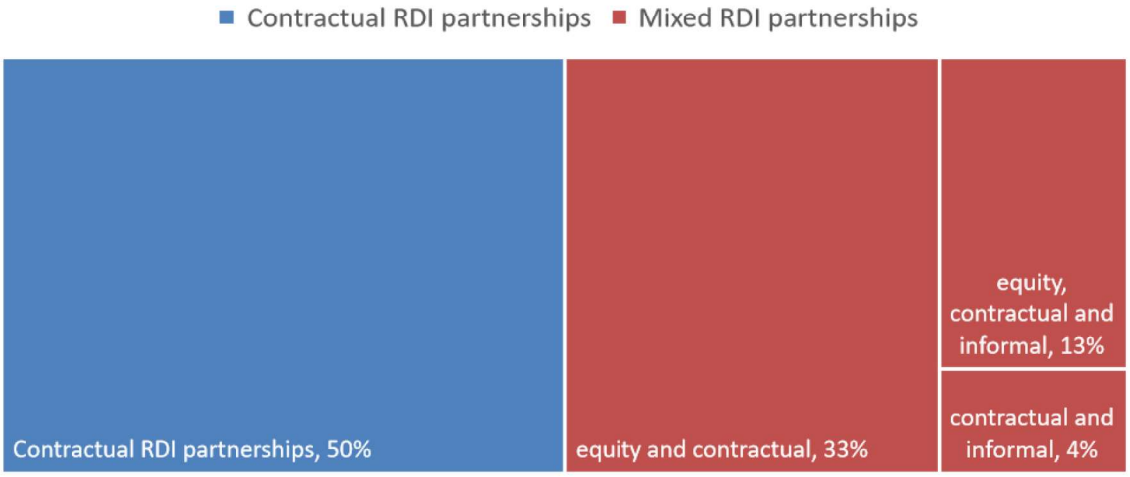


Figure 8 Types of RDI partnerships found in the RDI partnerships formation literature review

In addition, the 24 selected articles include a wide range of research methods as shown in Figure 9. The most common is the statistical analysis from secondary sources. Typically, the secondary sources are either from already available databases, such as the MERIT-CATI which includes information on worldwide RDI partnerships (Hagedoorn et al., 2008) and CORDIS which includes RDI partnerships in Europe (Constantelou, Tsakanikas, & Caloghirou, 2004), or an aggregation of

data from repositories of national institutions. For example, Sakakibara and Branstetter (2003) included records from the US Department of Commerce and the US Patent and Trademark Office in a study based on RDI partnerships in the US. Similarly, D'Este and Perkmann (2011) study on RDI partnerships in the UK includes data from academic journals and research grants provided by the UK Engineering and Physical Sciences Research Council.

The most common research methods are survey questionnaires and mixed methods which combine qualitative methods such as interviews and/or case studies with quantitative methods such as statistical analysis from secondary sources and/or questionnaires. Moreover, the least common research method used in the study of the formation of RDI partnerships is case studies. Finally, Figure 9 includes another category where studies that do not fall within the previous research methods are included. This category includes studies based on simulations, interview and document analysis or only document analysis.

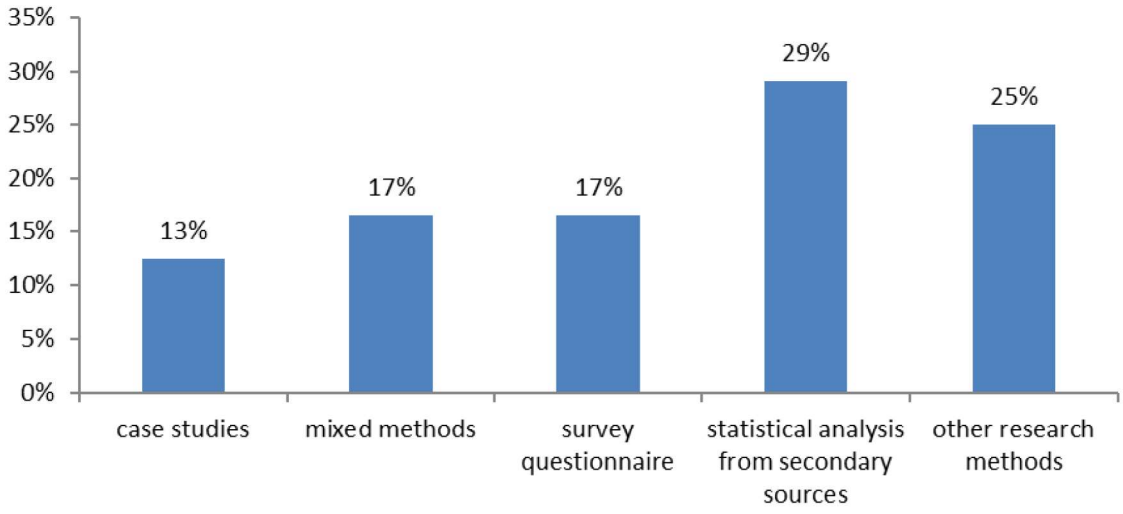


Figure 9 Research methods found in the RDI partnerships formation literature review

As shown in Figure 10, the types of data of the reviewed articles are classified according to the following four types: quantitative, qualitative, quantitative and qualitative and simulated data. Consistent with the established prevalence of quantitative research methods found, almost three quarters of the studies reviewed are based on the collection of quantitative data. There is also a surprising paucity of studies using qualitative data or both quantitative and qualitative data given the complex and rich interactions which accumulate over long periods of time in RDI partnerships

and inter-organisational relations in general (Doz, 1996; Ring & Van de Ven, 1994; Salk, 2005). Finally, among the reviewed studies there is only one article by König et al. (2011) under the simulated data category. In this study König et al. (2011) define a network model and the formation of RDI partnerships is studied via computerized simulations.

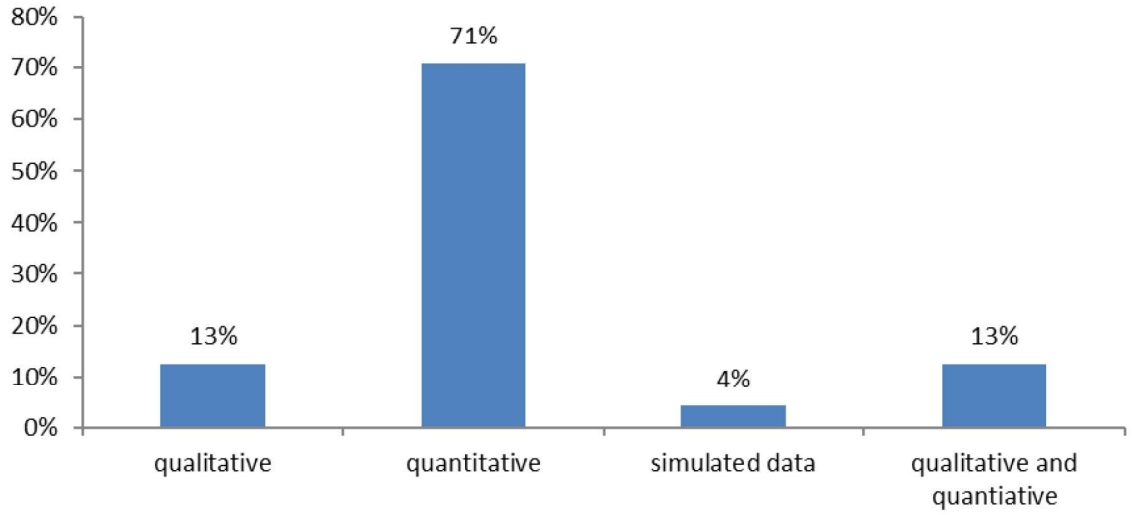


Figure 10 Types of data found in the RDI partnerships formation literature review

The data of the selected articles is typically gathered from the USA, Europe and Japan and RDI partnerships that took place between 1980 and the 2010. The latter estimate is based on 17 of the 24 articles since the data span of the studies is not always mentioned. There is limited research in studies based on data within specific countries in the European and Asian regions. Therefore, a promising avenue for future research can be to compare the differences countries exhibit when undertaking RDI partnerships.

Another interesting feature in the literature is the variety of units of analysis that can be adopted. This variety of units of analysis together with the abundance of articles not indicating the adopted unit of analysis increased the complexity of drawing conclusions. As shown in Figure 11, the vast majority of studies are either focused on the organisational or the partnership units of analysis and only the work by D'Este and Perkmann (2011) is based on the individual unit of analysis. However, no article was found that includes more than one unit of analysis. This is probably due to the increased complexity it would entail.

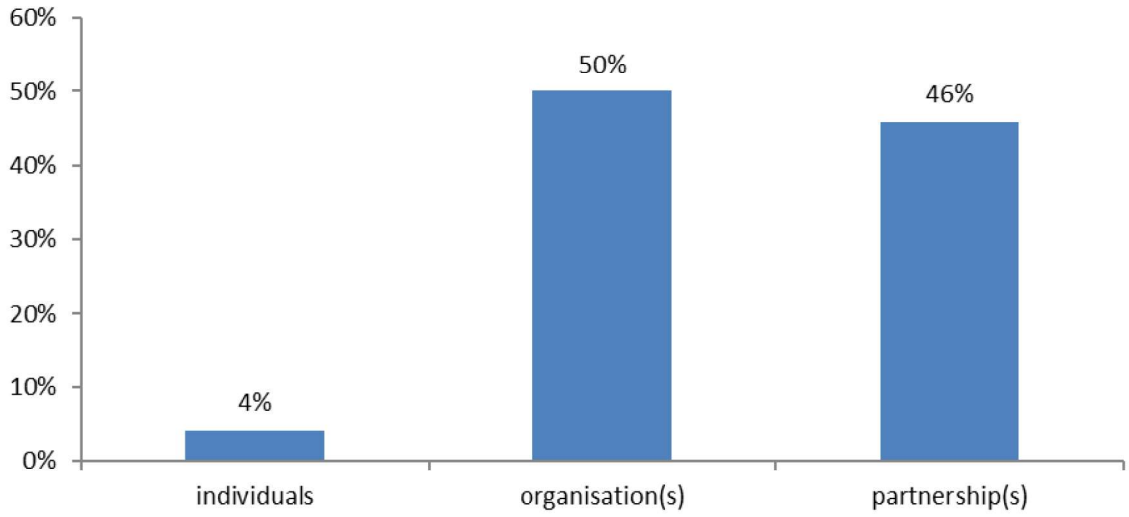


Figure 11 Units of analysis found in the RDI partnerships formation literature review

From the aforementioned units of analysis, the reviewed articles cover one or several levels of analysis. Interestingly, almost all of the studies focus on or include the organisational level. As in the encompassing inter-organisational literature (A. L. Oliver & Ebers, 1998), there is a lack of attention towards the individual level of analysis. In this literature review, only D'Este and Perkmann (2011) focuses exclusively on the individual level of analysis and others include it together with other levels of analysis at the organisational, inter-organisational and environmental level (Olk, 1998; Sakakibara & Branstetter, 2003; Sakakibara & Dodgson, 2003).

It is important to note that the levels of analysis in this review had to be inferred in most of the reviewed articles because this was typically not stated. However, the details provided in the Hemmert et al. (2014) article were insufficient to infer the level of analysis. This article is based on a survey questionnaire which is not provided and, thus, the level of analysis of the questions cannot be inferred. As a result, Figure 12 presents a summary of the levels of analysis found in 23 articles instead of the 24 articles selected for this review.

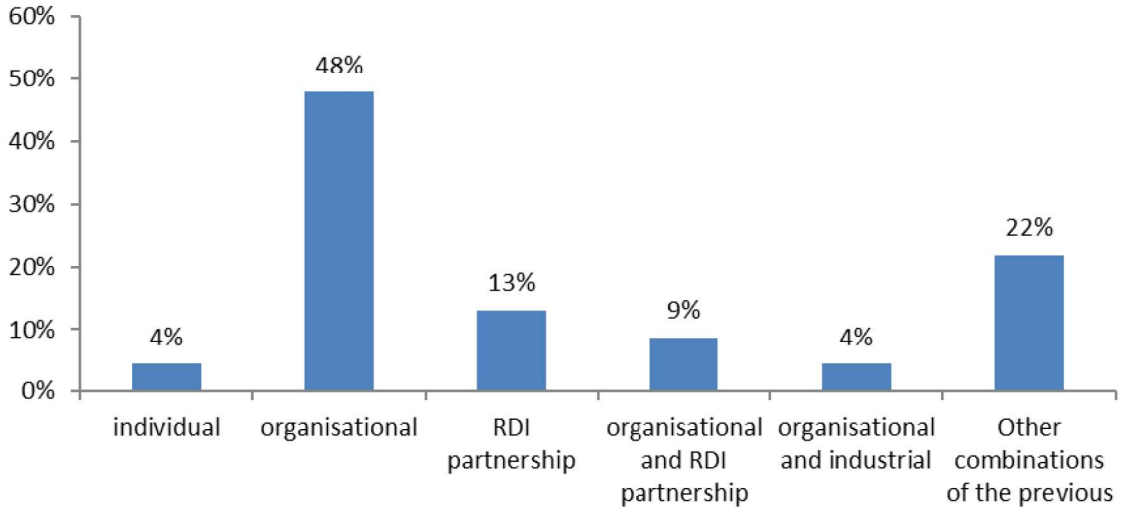


Figure 12 Levels of analysis found in the RDI partnerships formation literature review

Given the large number of key aspects discussed and the potential relationships between them, several cross tabulations were developed to identify these relations. Among the cross tabulations developed, only the cross tabulation of the unit of analysis versus the level of analysis presented in Table 6 is found to be of relevance. In this cross tabulation each row shows the percentage of studies based on a specific level of analysis and the unit of analysis used by these studies. In this way, the cross tabulation in Table 6 highlights that most of the studies rely on the organisational level of analysis and take as the unit of analysis either a partnership or one or several organisations.

Table 6 Cross tabulation of the unit of analysis versus the level of analysis

Unit of analysis / **Level of analysis**	*Individuals*	*organisation(s)*	*partnership(s)*	*Total*
Individual	4%	0%	13%	17%
Organisational	0%	43%	35%	78%
RDI partnership	0%	4%	30%	35%
Organisational and RDI partnership	0%	0%	17%	17%
Organisational and industrial	0%	4%	0%	4%
Total	4%	52%	96%	152%[5]

The rigour of this literature review is supported by the comprehensive review undertaken by Smith (2012) in a field which encompasses the focus of this review, RDI partnerships. Smith (2012) reviewed all the studies on RDI inter-organisational relations from 1995 to 2010. In his study, Smith (2012) also found that publications on RDI inter-organisational relations are also scarce, with only 44 empirical studies found, and the majority are based on quantitative and snapshot approaches.

The following three sections will further investigate the RDI partnerships characteristics at the formation stage. Each section will take an in-depth examination of one of the RDI partnership characteristics, conditions, outcomes and processes, found at the formation stage.

3.4.1.1 RDI partnership characteristics at the formation stage: conditions

The study of conditions at the formation stage have accumulated a large number of terms such as antecedents (Joshi & Nerkar, 2011; Albert N. Link et al., 2002), motives (Doz et al., 2000; Eisner et al., 2009), inducements (Hagedoorn et al., 2008), initial conditions (Carayannis, Alexander, & Ioannidis, 2000) and barriers (König et al., 2011). This was also the case for the encompassing

[5] Percentages do not add up to 100% because, as mentioned earlier on, while the reviewed studies are based on only one unit of analysis, many of them are based on several levels of analysis. This results in one article being counted in several categories (cells) of the cross tabulation.

literature in alliances and inter-organisational relationships (Gulati, 1998; A. L. Oliver & Ebers, 1998). In fact, the reviewed literature on RDI partnerships and alliances has generally focused extensively on conditions that either have a positive or negative impact on the establishment of the partnerships. This accumulation of terms may be due to the difficulties in categorizing and classifying conditions.

During the literature review it was also observed how a particular condition can manifest a dual behaviour in relation to their empirical context. This duality of conditions can explain why even though Schiavone and Simoni (2016) claim that prior experience between two organisations in RDI partnerships fosters future RDI partnerships between them, Hagedoorn et al. (2008, p. 81) found *"that repeated ties in pairs of large pharmaceutical companies and small, entrepreneurial biotechnology firms, ... have a negative effect on subsequent partnering"*. This is consistent with the critique posed by Sakakibara (2002) of Ahuja (2000) where the formation conditions are categorized as either inducements or opportunities. Sakakibara (2002) states that prior experience can be both an opportunity because of the partnering benefits derived from being part of an established network but also an inducement because of their experience in forming and managing relations with other organisations.

The duality of conditions can therefore limit the development of an overarching and detailed classification of conditions. This limitation is supported by studies within and beyond this review which indicate that geographical, cultural, organisational or sectoral conditions modulate how other conditions affect the formation of RDI partnerships (Hagedoorn, 1993; Hemmert et al., 2014; Steinmo & Rasmussen, 2016). Although in this study the type of inter-organisational relation is limited to RDI partnerships, the findings can be applicable to other types of relations such as supply chain partnerships or joint ventures.

The observed dual behaviour of conditions opens an avenue for future research. Conditions may not be identified and considered to always influence RDI partnerships in the same way as it has been done but to fluctuate in relation to other conditions and RDI partnership's characteristics.

Furthermore, these fluctuations may be dynamic as conditions and characteristics change with the development of the RDI partnership. This new approach acknowledges the duality of conditions by taking into account how different conditions can mediate the formation of the RDI partnerships differently depending on their interrelations with other conditions at a specific point of time. From the duality of conditions transpires that, as opposed to the current literature which is based on the idea of multiple causation when analysing partnership conditions, future research should look into the plurality of causes behind these conditions (Pickvance, 2001).

This review also shows that there is no agreed classification of the formation conditions. Some examples are Sakakibara (2002) which focuses exclusively on the economic and strategic inducements for formation, Lin and Lin (2012) which classifies conditions in terms of whether they are internal or external to the partners and D'Este and Perkmann (2011) which includes conditions that are either a motive or barrier to partnering. These three types of classifications based on the needs of potential partnering organisations, the multi-level nature of partnerships or the positive or negative formation impact, are also very common classifications in the alliance literature (Gulati, 1998; Sambasivan et al., 2013).

However, there are other types of classification such as the proposed by Doz et al. (2000) where conditions are classified according to their presence in the processes that unfold in the formation of RDI partnership. Another potential type which was not found in the literature is to classify conditions according to their theoretical background. In this way, conditions such as trust and friendship would be classified under social network theory and others such as increasing R&D salaries and contractual complexity under transaction cost theory.

Despite the increased complexity derived from the duality of conditions and the abundance of conditions in the RDI partnership and inter-organisational literature, their classification is of benefit for illustrative purposes and convenience as well as to facilitate the identification of interdependencies. Hence, in this study the conditions identified are classified by grouping on one hand the conditions that have a positive effect in establishing an RDI partnership and on the other

hand those which have a negative effect. The former is referred to as formation drivers and the latter as formation barriers. Classifying conditions in this way is the most common classification found in the literature by this review. Furthermore, the numerous identified conditions are aggregated in different categories as follows given the large number of conditions found under some of these categories.

Formation drivers

- **Cost:** conditions reducing RDI costs (e.g. avoid duplication of R&D activities, accelerating technological developments) (Bidault & Cummings, 1994; Campart & Pfister, 2007; Zervos & Siegel, 2008).
- **Relational:** conditions which are related to the positive aspects associated with pre-existing, existing or future inter-organisational relations (e.g. previous relations, trust and reciprocity) (D'Este, Guy, & Iammarino, 2013; Schultz, 2011).
- **Governance**: conditions that facilitate the governance of the RDI partnership (e.g. flexibility, mechanisms to sanction opportunism, protect existing IP, IP transfer mechanism, and fit for purpose) (Hemmert et al., 2014; S. Xu et al., 2014).
- **Environmental**: conditions beyond the RDI partnership which induce it (e.g. globalization of markets, technology complexity increase, industry convergence, accelerated technical changes, stability, weak/increased competition and legislative or tax background) (Lin & Lin, 2012; Zucker & Darby, 2001).
- **Proximity:** conditions related to positive perceptions on any of the proximity dimensions between the partners (e.g. cultural, spatial, cognitive, organisational and technological) (Carayannis et al., 2000; König et al., 2011).
- **Potential learning:** conditions associated to potentially developing learning which induces the intended RDI partnership (Hertzfeld et al., 2006; Niosi & Bergeron, 1992).
- **Risk minimizing:** conditions facilitating risk sharing or involving partners with key resources that reduce the risks underlying the individual and shared objectives of the intended RDI partnership. Risk may be defined in relation to the potential losses and/or

uncertainty surrounding the considered RDI partnership (Bidault & Cummings, 1994; Sakakibara, 2002).

- **Champion / lead:** conditions which enable organisations or individuals within the partnering entities or beyond which facilitate, champion or sponsor an RDI partnership (Olk, 1998; Ring et al., 2005).
- **Organisational assets:** conditions related to organisational assets within the potential partnering organisations which can accelerate their RDI activities (e.g. prior technical or marketing knowledge, infrastructure, technology and existing supply chain) (Hagedoorn, Roijakkers, & Kranenburg, 2006; Merle, Hellstrom, Adler, & Norrgren, 2000).
- **Increase collaboration:** conditions allowing to grow inter-organisational relations of interest through an RDI partnership (Carayannis et al., 2000; Zervos & Siegel, 2008).
- **Standards development:** conditions associated with the development of standards that facilitate the formation of RDI partnerships (Eisner et al., 2009; Zervos & Siegel, 2008).
- **Pre-competitive R&D:** conditions that facilitate collaboration by focusing on early stage non-commercial R&D activities which may lead to future independently developed technologies and products (Sakakibara & Dodgson, 2003).
- **External funding:** conditions which support RDI operations through external funding such as a government grant. (Hemmert et al., 2014; Niosi & Bergeron, 1992)
- **Partnership planning:** conditions that facilitate the planning and management of the RDI partnership (Hagedoorn et al., 2006; Olk, 1998).
- **R&D spill-overs:** conditions which induce the formation of RDI partnerships due to the potential to derive R&D spill-overs (Sakakibara & Branstetter, 2003).
- **New opportunities:** conditions of RDI partnerships which facilitate their partners in collaboratively addressing new opportunities and challenges more effectively (Schiavone & Simoni, 2016; S. Xu et al., 2014).

- **Potential innovation:** conditions of RDI partnerships which facilitate their partners to innovate more effectively in collaboration (Bidault & Cummings, 1994; Q. Xu & Renyong, 2009).
- **Potential product development:** conditions of RDI partnerships which facilitate their partners to undertake product development more effectively in collaboration (Campart & Pfister, 2007; Q. Xu & Renyong, 2009).

Formation Barriers

- **Cost:** conditions which increase RDI costs (e.g. extending R&D activities, accelerating technological developments) (Campart & Pfister, 2007; Carayannis et al., 2000).
- **Relational:** conditions which are related to negative aspects associated with pre-existing, existing or future inter-organisational relations (e.g. previous relations, lack of trust and deal fairness) (Bidault & Cummings, 1994; Bstieler & Hemmert, 2008; D'Este et al., 2013).
- **Proximity:** conditions related to negative perceptions on any of the proximity dimensions between the partners (e.g. cultural, cognitive, organisational and technological). (Merle et al., 2000; Ring et al., 2005).
- **Organisational assets:** conditions related to organisational assets within the potential partnering organisations which can hinder their RDI activities (e.g. pre-existing and potential technical and market knowledge which cannot be shared). (Mindruta, 2013; Sakakibara, 2002)
- **Governance:** conditions that hinder the governance of the RDI partnership (e.g. lack of flexibility, liabilities and IP access rights) (Schultz, 2011; Q. Xu & Renyong, 2009).
- **Environmental:** conditions beyond the RDI partnership which hinder it (e.g. increased competition, weak IP protection laws and technology complexity) (Albert N. Link et al., 2002; Zervos & Siegel, 2008).

- **Risk:** conditions which bring new risks to the organisations involved in an RDI partnership. Risk may be defined in relation to the potential losses and/or uncertainty underlying the considered RDI partnership (Bidault & Cummings, 1994; Hagedoorn et al., 2006).
- **Indivisibility of research outputs:** conditions which require joint ownership of RDI partnership outcomes (e.g. joint IP ownership and shared business models). (Westbrock, 2010).
- **RDI outcomes not shared:** conditions which hinder the sharing of RDI partnership outcomes (Zervos & Siegel, 2008).

Based on the previous classification of conditions, Table 7 ranks the formation drivers and barriers found in the literature review to provide, for the first time to the knowledge of the author of this study, an indication of their prevalence in the literature. The ranking is based on the number of studies in which the formation drivers and barriers are referred and shows only those which appear in three or more studies.

Table 7 Frequency of formation drivers and barriers among the reviewed articles

Formation drivers	**Frequency**
knowledge	23
relational	20
organisational assets	16
cost	15
environmental	13
governance	10
learning	9
proximity	9
new challenge	4
risk reduction/sharing	3
new opportunity	3
champion	3
increase collaboration	3
standards development	3

Formation barriers	**Frequency**
cost	11
relational	10
knowledge	10
governance	8
risk	4
proximity	4
environmental	3

Another avenue for future research found in this review relates to the varying degrees to which formation drivers and barriers influence the formation of RDI partnerships. Up to now the reviewed literature has identified variations under different contexts but further insights are required to increase understanding and allow academics and practitioners to predict them. For example, Schiavone and Simoni (2016) found that when specific types of firms are involved in the formation of RDI partnerships, specific drivers and barriers such as technological challenges and opportunities play a key role. However, Sakakibara and Dodgson (2003) found that when the formation of RDI partnerships takes place within certain industries, it is actually other drivers and barriers such as access to complementary technologies that play a key role.

3.4.1.2 RDI partnership characteristics at the formation stage: outcomes

In contrast to the interest found in the field towards conditions, outcomes in the formation stage of RDI partnerships have received scant attention. Outcomes are typically referenced in the literature during the execution stage and, particularly, when they take place towards the end of an RDI partnership. This is in line with the consulted partnership and alliances literature.

However, some key outcomes during the formation stage of RDI partnerships stand out in several articles. At this stage, the development of trust is a key outcome (Daellenbach & Davenport, 2004; Hemmert et al., 2014) since it creates strong ties among the partners and transitions into the execution stage (Doz et al., 2000). As the RDI partnership formation progresses other outcomes that will eventually take place are the selection of the partnering organisations, establishing a governance mode and signing a contract (Doz et al., 2000; Mindruta, 2013; Schiavone & Simoni, 2016). Furthermore, announcing the agreed RDI partnership can also lead to the key outcome of, typically positive, stock price variations among the organisations involved (Campart & Pfister, 2007).

3.4.1.3 RDI partnership characteristics at the formation stage: processes

The objective in this Section is to identify and classify the processes at formation. As in the general alliances literature, there is a dearth of research around processes at formation and their impact as the partnership unfolds (Doz et al., 2000; Todeva & Knoke, 2005).

Consequently, this review is based on studies focused on the RDI partnership at the formation stage and more general studies which refer to formation processes in their research on RDI partnerships. The identified processes in the literature are presented and described in Table 8. The table follows a logical and natural sequence consistent with what can ensue from the start to the end of the formation stage.

Table 8 Processes found in the literature during the formation stage of RDI partnerships

Processes at the formation stage	**Description of the processes at the formation stage**
1. Development of environmental interdependence awareness (Doz et al., 2000; Ring et al., 2005)	Recognising interdependencies derived from the analysis of the organisational context.
2. Partner search (Arranz & de Arroyabe, 2008; Daellenbach & Davenport, 2004; Doz et al., 2000; Mindruta, 2013; Olk, 1998; Ring et al., 2005; Schiavone & Simoni, 2016)	Searching for partners to establish an RDI partnership. In doing so, the organisations can be heavily influenced by the interdependencies derived from the previous process (Schiavone & Simoni, 2016).
3. Discovery of converging interests (Doz et al., 2000; Ring et al., 2005)	*"Efforts to produce consensus by sense making and understanding processes undertaken during negotiation processes."* (Doz et al., 2000, p. 241).
4. Consensus search (Doz et al., 2000; Ring et al., 2005)	Building agreement on the rationale to establish an RDI partnership. This includes clarifying some of the discussed formation conditions (e.g. establishing cost reductions and knowledge and learning goals).
5. Assessment of trustworthiness (Daellenbach & Davenport, 2004)	Evaluation of the partners trustworthiness. Daellenbach and Davenport (2004, p. 190) define the term trustworthiness *"as the compound virtue of being dependable, capable, responsive and responsible''* and argue that achieving trustworthiness entails trust among partners.
6. Governance mode establishment (Doz et al., 2000)	Selecting and developing the rules and regulations that will oversee the RDI partnership once it is started.
7. Escalation of commitment and satisfaction (Doz et al., 2000; Ring et al., 2005)	Cyclical process in which the successful RDI partnership development supports and grows the underlying collaboration which at the same time facilitates the development of a successful RDI partnership. Successful RDI partnership development is understood as the fulfilment of the partners expectations such as those of a contractual and procedural nature.
8. Learning (Doz et al., 2000)	The assimilation of knowledge. Even at the formation stage this process is key because it facilitates the RDI partnership development by for example understanding the internal processes, interests and expectations of other partners.

Despite the different processes listed, the consulted literature typically deals with the overall formation stage as it only consisted of one process (Das & Teng, 2002) or the combination of a

limited number of processes from those presented in Table 8. For example, Daellenbach and Davenport (2004) claim that the overall formation consists of three processes, the assessment of trustworthiness, the search for partners and the subsequent negotiation between the partners. An interpretation of using such a limited number of formation processes may be that some authors simplify the formation stage by integrating in one or several processes the processes found in this review.

In this way and following the previous example from Daellenbach and Davenport (2004), the partner search process could integrate the formation processes 1 and 2 in Table 8 while the negotiation process could integrate the formation processes 3, 4, 6 and 7 in Table 8. It is important to note that the last formation process in Table 8, learning, is not included in the study of Daellenbach and Davenport (2004). In fact, from the literature review it is not clear that RDI partnerships are required to include all of the processes or follow them along the sequence shown in Table 8.

However, Doz et al. (2000) discovered that most of the 53 RDI partnerships they studied were formed following two distinct paths, or sequences, of interconnected processes, the emergent and the engineered paths. The former is mainly driven by the processes of potential partners developing awareness of their environmental interdependence and converging interests. In this way, the emergent formation path for RDI partnerships starts with the development of environmental interdependence awareness process, followed by the discovery of converging interests and then the consensus search process. After that, the emergent formation path ends with the development in parallel of the governance mode establishment and the escalation of the commitment and satisfaction processes.

According to Doz et al. (2000), the other most common sequence of processes for the formation of RDI partnerships is the engineered path. They found that this path takes place when the environmental interdependencies are low and is driven by an organisation coordinating all the processes. In this way, the engineered formation path for RDI partnerships starts again with the

development of environmental interdependence awareness process but is followed with a partner search process. The latter process is driven by a coordinating organisation because, when there are low environmental interdependencies, these are not sufficient to trigger an RDI partnership. Finally, the engineered formation path ends with the development in parallel of the governance mode establishment and the escalation of commitment and satisfaction processes under the supervision of the coordinating organisation.

The study of the processes whereby RDI partnerships are formed is key in the RDI partnerships literature because of its overarching implications. The formation of RDI partnerships is considered of key importance because understanding and selecting a path of processes can influence not only the design and emergence of RDI partnerships but also the outcomes that arise during their execution (Doz, 1996; Doz et al., 2000).

3.4.2 RDI partnership characteristics at the execution stage

In this Section, the focus shifts towards the discussion and analysis of the RDI partnership characteristics at the execution stage. In terms of the conditions, this review found the following characteristics in studies on RDI partnerships: trust (Newell & Swan, 2000), knowledge (Faems, Janssens, & Bart van, 2007; X. Wang et al., 2019), inter-organisational and organisational capabilities(Kohtamäki et al., 2018; K. Lee & Yoo, 2019; Petricevic & Verbeke, 2019), governance (Choi & Contractor, 2019) and proximity dimensions (e.g. geographical, cognitive, organisational, and social proximity) (Steinmo & Rasmussen, 2016). These conditions are also mentioned in the literature on partnerships and as in the formation stage their interdependency and contexts play a key role according to the highlighted scholars.

Moreover, this review found no articles explicitly commenting on outcomes at the execution stage. Most of the outcomes found are mentioned in RDI partnerships publications which are either generic or focused on other stages. Nonetheless most of these outcomes, like new products or publications, apply to the execution stage since this is the stage where they take place. Hence, the

following list summarizes the most common outcomes found in articles even if they are not exclusively focused in the execution stage of RDI partnerships:

- New knowledge (Campart & Pfister, 2007; Niosi & Bergeron, 1992; Petricevic & Verbeke, 2019; Sakakibara & Dodgson, 2003)
- Learning (Bäck & Kohtamäki, 2015; Mindruta, 2013; Q. Xu & Renyong, 2009)
- IP such as patents, licenses or trade secrets (D'Este & Perkmann, 2011; Hertzfeld et al., 2006; Messeni Petruzzelli, Albino, Carbonara, & Rotolo, 2010; Palomeras & Wehrheim, 2021)
- Innovation such as new or improved products and new processes (Martínez-Noya & Narula, 2018; Petricevic & Verbeke, 2019)
- New or improved technologies (Hertzfeld et al., 2006; Mindruta, 2013)
- Socio-economic such as employment growth, cost reduction, reduce social and economic disparities among stakeholders and increased competitiveness and productivity (García-Terán & Skoglund, 2019; Niosi & Bergeron, 1992; Q. Xu & Renyong, 2009; Zervos & Siegel, 2008)
- Subsequent inter-organisational relations such as joint ventures or follow-on collaborative R&D projects (Lin & Lin, 2012; Albert N. Link et al., 2002; Messeni Petruzzelli et al., 2010; Niosi & Bergeron, 1992; Schiavone & Simoni, 2016)
- Training undertaken by participants (Sakakibara & Dodgson, 2003)
- Publications (Mindruta, 2013; Schultz, 2011)
- Standards development and adoption (Niosi & Bergeron, 1992; Q. Xu & Renyong, 2009; Zervos & Siegel, 2008)
- Spill-overs (Campart & Pfister, 2007; Petricevic & Verbeke, 2019; Sakakibara & Branstetter, 2003; Q. Xu & Renyong, 2009)

From the outcomes listed it is important to highlight that not all of them are pursued by the same stakeholders in RDI partnerships. Even more, in some cases stakeholders will try as hard as

possible to prevent the occurrence of specific outcomes. For example, while universities and public organisations will strive to create spill-overs around new technologies, private companies will take measures such as embargoing publications to prevent disclosures of sensitive information.

In terms of the RDI partnership characteristics related to processes, only the processes knowledge transfer (Faems et al., 2007), learning (Doz, 1996) and alliance capabilities such as alliance management (He et al., 2020; Petricevic & Verbeke, 2019) were found in this review. The learning process is of special interest since it has been mentioned not only as a process but also as an outcome depending on the point of view taken by the different scholars. In some cases learning is considered as an outcome (Mindruta, 2013) because it is the objective and expected result from a partnership and in other cases as a process because it is seen as a series of events that unfold throughout the partnership development (Doz, 1996). In the same way trust and alliance capabilities could also be considered as a condition as suggested by Newell and Swan (2000) and Kohtamäki et al. (2018) respectively but also as a process when trust is been developed and alliance capabilities leveraged in RDI partnerships.

Given the similarities found between the characteristics on partnerships and RDI partnerships during the execution stage, it can be concluded that the characteristics in the partnership literature can also be considered relevant to the RDI partnerships. This should be done with caution as not all the partnership characteristics may be applicable to RDI partnerships and, depending on the specific context, others may only apply depending on the specific context of the RDI partnership. Likewise, it can also be concluded that many of the identified RDI partnership characteristics at the formation stage transition into the execution stage because they are mentioned in the literature when discussing the formation and execution stages. In this way, an outcome that could be added to the previous list given its cross cutting nature is whether or not partners adhere to the agreed RDI partnerships processes (Ariño, 2003). Again, the applicability of RDI partnership characteristics at the formation stage in the execution stage should be approach with caution.

3.4.3 RDI partnership characteristics at the assessment stage

Continuing with the analysis of the RDI partnership characteristics, in this Section the focus is on those characteristics that arise during the assessment stage. As in the previous Section, it is not possible to undertake a thorough study of each of the RDI partnership characteristics at the assessment stage as it was done for the formation stage because of the paucity of research dedicated to this stage. In fact, no publication on the assessment stage was found using a similar search string as the one used for the literature review on the formation stage[6].

Hence, no specific characteristics are found in the assessment stage. Though it can be inferred that some of those found in the formation and execution stages transfer and, are thus relevant, in the assessment stage. Furthermore, as in the case of partnerships, it can be assumed that these characteristics will lead to the termination or continuation of the ongoing RDI partnership as well as the formation of other inter-organisational relations such as a joint ventures or licenses (Das & Teng, 2002).

3.5 Dynamics of RDI partnerships

The literature on the dynamics of RDI partnerships also captures similar dynamics to the one on partnerships. Hence the literature covers the identified areas of RDI partnership development, succession of RDI partnerships and the development of RDI partnerships (Faems et al., 2007; M'Chirgui, 2009; Steinmo & Rasmussen, 2016). However, it provides additional insights into particularities of the dynamics of RDI partnerships.

Towards the end of the last century, the dynamics of RDI partnerships have been mediated by a paradigm shift on how knowledge is produced and research carried out. Gibbons et al. (1994, p. 3)

[6] The search string used in ABI/INFORM Global on 15/03/2018 is as follows: AB,TI((interorgani?ational OR inter-organi?ational OR interinstitutional OR inter-institutional OR inter-firm OR intercompany OR intercompany OR interfirm OR inter-firm OR industry-university OR university-industry OR universities AND industry OR industry AND universities OR triple helix OR quadruple helix OR multi-institutional OR multinstitutional OR consort* OR multi-institutional OR multinstitutional OR "public-private partner*" OR "publicprivate partner*" OR partnership) AND (termination) AND ("R&D" OR research OR innovation)) AND cc("54??")

describes this paradigm shift as moving from 'mode 1' to 'mode 2': *"in mode 1 problems are set and solved in a context governed by the, largely academic, interests of a specific community. By contrast, mode 2 knowledge is carried out in a context of application. Mode 1 is disciplinary while mode 2 is transdisciplinary. Mode 1 is characterized by homogeneity, mode 2 by heterogeneity"*. This increased emphasis in context-driven and heterogenous knowledge production with a view to innovation and commercialisation contributed to the sustained increase in university and industry partnerships supported by government funding and RDI partnerships in general (Duysters & Kok, 1999; Eisner et al., 2009; Etzkowitz & Leydesdorff, 2000; Hagedoorn & Duysters, 2002; M'Chirgui, 2009; Martínez-Noya & Narula, 2018; Narula & Hagedoorn, 1999; Powell et al., 1996). As modelled by Dooley and Kirk (2007), university partners are shifting from mode 1 arms-length relations with industry to mode 2 partnerships where there is a close collaboration and fit between the university and industry partners RDI activities.

In terms of the relational structures resulting from the dynamics of RDI partnerships, empirical studies have shown that there are three similarities across the industries examined. Firstly, organisations undertake a very limited amount of RDI partnerships from the large number of possible relations. Secondly, organisations tend to cluster RDI partnerships around specific geographical areas and few RDI partnerships are undertaken across different regions. Finally, the connectedness of organisations is mixed and only a small number of organisations are significantly interconnected with many others. (König et al., 2011)

These RDI partnerships structures and dynamics are highly mediated by the evolution of the industries in which they take place. In the analysis of the smart card industry by M'Chirgui (2009), it was observed that the number of RDI partnerships increased or decreased significantly as the industry underwent different phases of development. Furthermore, the formed RDI partnerships would tend to be either vertical or horizontal partnerships (as previously defined in Section 2.3) depending on the state of the smart card industry evolution.

The review of the dynamics of RDI partnerships also confirms the initial findings and conclusions that unfold from the duality of conditions in Section 3.4.1. In Steinmo and Rasmussen (2016, p. 1250) longitudinal study of 15 cases, they show *"that the types of proximity that facilitate collaboration depend on firm's characteristics"* and how the conditions of cognitive and organisational proximity between industrial and academic partners developed as the RDI partnership unfolds. The observations by Steinmo and Rasmussen (2016) demonstrate that single-party studies overlook the different perspectives each partnering organisation has towards the same condition in line with the review findings of Lumineau and Oliveira (2018) and Martínez-Noya and Narula (2018) as well as the conclusions – Section 2.7 – from the previous literature review. Their observations also confirm that, as it was suggested in Section 3.4.1, conditions are dynamically co-evolving and can mediate RDI partnerships in relation to their interdependencies with other conditions and characteristics.

Although a co-evolutionary view of inter-organisational relations is considered of great benefit in their study (Bizzi & Langley, 2012; Das & Teng, 2002; He et al., 2020; Koza & Lewin, 1998; Lahiri et al., 2021; Panda, 2017), the literature on RDI partnerships shows a lack of attention towards it. Only (Prange et al., 2015) review on RDI partnerships was found to call for a co-evolutionary view. In their review study, they claim that *"firms that collaborate for NPD [New Product Development] purposes need to balance their knowledge complementarity based on clear signals of what is expected from the partner and engage in co-evolutionary processes of knowledge development"* (Prange et al., 2015, p. 360).

Moreover, the reviewed papers[7] emphasized the importance of knowledge transfer and exploitation in sustaining RDI partnerships and subsequent relations such as partnerships, joint ventures and mergers and acquisitions (Dooley & Kirk, 2007; Faems et al., 2007; Gibbons et al., 1994; König et al., 2011; M'Chirgui, 2009; Prange et al., 2015; Steinmo & Rasmussen, 2016; X. Wang et al.,

[7] More details on the review approach of this Section can be found in Appendix B.

2019). Knowledge transfer and exploitation can thus be considered to play a critical role in the overall dynamics of RDI partnerships and their development. Following this idea, the role of other RDI partnerships characteristics can be considered to mediate this transfer of knowledge and exploitation in different ways. For example, in some cases the transfer of knowledge and exploitation is facilitated by conditions such as legal safeguards (Faems et al., 2007; Martínez-Noya & Narula, 2018), close proximity (Steinmo & Rasmussen, 2016) and trust (Bäck & Kohtamäki, 2015) while in other cases it is hampered by conditions such as strong market threats (Faems et al., 2007; M'Chirgui, 2009) and IP ownership arrangements (Dooley & Kirk, 2007; Palomeras & Wehrheim, 2021).

3.6 Comparative analysis of partnerships and RDI partnerships

Given that the literature on RDI partnerships is scarce and contained within the overall literature on partnerships (see e.g., Ariño & de la Torre, 1998; F. J. Contractor & Lorange, 2002; Jenssen & Nybakk, 2013; Martínez-Noya & Narula, 2018; Narula & Hagedoorn, 1999; Nooteboom, 2002; Peeters et al., 2020; Todeva & Knoke, 2005), this Section undertakes a comparative analysis to understand the variations between the literature on partnerships and RDI partnerships. This is done with the objective of establishing the underlying logic for these variations so that the findings in the literature on partnerships, if relevant, can be used with caution to overcome limitations of the literature on RDI partnerships.

RDI partnerships are more recent in time than partnerships since they were largely triggered by changes in legislation and policy across regions to address increased economic competition from countries such as South Korea, China and Taiwan (Hagedoorn, 2002; Narula & Hagedoorn, 1999). For example RDI partnerships boomed in the 1980s across Europe and the US and in the 1960s in Japan (Duysters & Kok, 1999; Hagedoorn et al., 2000). Hence, the majority of the RDI partnerships and, thus, findings in the literature are based on studies from partners in the US, Japan, and Europe (Hagedoorn, 2002). In line with this over 70% of all the RDI partnerships worldwide

between 1960 and 1998 took place in or between US and European organisations according to the MERIT-CATI database (Hagedoorn, 2002). Hagedoorn (2002, p. 489) mentions that *"...companies from the developed economies participate in 99% of the R&D partnerships and 93% of these partnerships are made amongst companies from North America, Europe, Japan and South Korea, little appears left for companies from other regions"*. In contrast, partnerships and the encompassing area of alliances have been studied across a wider range of countries (Beamish & Lupton, 2016).

The focus on RDI activities also brings along big differences in the theoretical approaches used in the literature and the characteristics exhibited in RDI partnerships. Whereas the dominant theories in the partnership literature are transaction cost economics, resource-based view, resource dependence theory and social network theory, over the last decades scholars are also applying the knowledge based view to explain RDI partnerships (R. M. Grant & Baden-Fuller, 1995; Gulati, 1998).

In terms of the RDI partnerships characteristics, there is a higher emphasis on knowledge, learning and IP related conditions, outcomes and processes. The prevalence of these characteristics makes the consideration and measurement of outcomes even more challenging in RDI partnerships than in partnerships. Thus, outcomes in RDI partnerships can require longer periods of time than in partnerships to surface and may often be intangible, for example tacit knowledge and increased reputation. As a result, the identification and assessment of outcomes in RDI partnerships is very challenging. (Ariño, 2003; A. N. Link, Teece, & Finan, 1996; Milagres & Burcharth, 2019; Smart, Bessant, & Gupta, 2007)

The dynamics of RDI partnerships follow the same formation, execution and assessment steps as partnerships with the possibility of forming subsequent RDI partnerships (Hagedoorn et al., 2008). However, the unpredictable nature of RDI activities is suggestive of RDI partnerships involving larger and faster changes during their development (Choi & Contractor, 2019; Martínez-Noya & Narula, 2018).

Another peculiarity of RDI partnerships is that they tend to involve more than two partners (Duysters & Kok, 1999). Regardless of the type of inter-organisational relation (Nippa & Reuer, 2019), multilateral arrangements involve a higher level of complexity derived from, among other, a larger number of interdependencies, interactions and characteristics(Milagres & Burcharth, 2019). This together with the unpredictable nature of RDI activities, suggests that the study of partnerships focused on RDI poses greater challenges than the study of partnerships.

3.7 Research gaps

The review on RDI partnerships revealed research gaps across the literature in the areas of terminology, methodology, availability of data, theoretical approach and RDI partnerships' conditions, outcomes, processes and dynamics. Overall the literature suffers from a lack of coherence and cacophony of concepts and terms that are often used interchangeably (Greenlee, 2005; Martínez-Noya & Narula, 2018). Accordingly, several terms such as alliances and partnerships are used interchangeably or convey different meanings when used by scholars from different geographies. This may have derived from the literature on partnerships and inter-organisational relations which exhibit similar deficiencies (see e.g. Beamish & Lupton, 2016; Caloghirou et al., 2004; Hagedoorn et al., 2000; Mohr & Spekman, 1994; Nippa & Reuer, 2019; Todeva & Knoke, 2005).

In terms of the methodological gaps, there is a prominent lack of studies based on cases, qualitative methods, process research approaches and longitudinal multi-level analysis (Bergenholtz & Waldstrøm, 2011; Gomes et al., 2016; A. L. Oliver & Ebers, 1998). For example, Smith (2012, p. 43), highlights that *"research on inter-organizational R&D is… based on snapshot studies at the management or firm level of analysis that leave open questions regarding the actual inter-organizational innovation practices"*. This at the same time heightens another gap which is the scarcity of studies focused on the following three research strands: RDI partnership development, from formation to dissolution, the formation of subsequent RDI partnerships and the development of RDI partnerships which consists of the previous two strands. As a result, most of the articles

found are quantitative snapshot studies, typically concentrating in the formation conditions and the inter-organisational level of analysis. These gaps hamper reaching in-depth insights into the changes and dynamics of RDI partnerships as they unfold over time.

The field also suffers from limited availability and access to data which results in different research gaps. First, most of the studies focus on data from the US, Europe and Japan within specific industries such as electronics, semiconductor, pharma and biotechnology (Milagres & Burcharth, 2019). This minimizes the applicability of the research findings since in the overall inter-organisational relations literature it has been noted that different empirical settings show major differences (Bergenholtz & Waldstrøm, 2011; Nippa & Reuer, 2019). Hence, given their cultural differences, there is a need for research based on data within specific areas of the US and Europe and the Asian region. This would allow the consideration of whether previous findings can be applied across different regions and would also highlight the peculiarities of RDI partnerships in specific regions (Beamish & Lupton, 2016).

Second, most of the studies in the literature are based on data from bilateral engagements despite the abundancy of multilateral RDI partnerships in practice (Eisner et al., 2009; Rampersad, Quester, & Troshani, 2010; Vonortas & Okamura, 2009; S. Xu et al., 2014). This is an important gap since the literature acknowledges potential differences between bilateral and multilateral RDI partnerships (J. E. Oxley, 1997). Third, there is a paucity of research data on failed RDI partnerships (Oliveira & Lumineau, 2019). This represents a significant gap in the literature since the encompassing literature on alliances has stressed the high failure and reported failure rates of up to 70% (Campart & Pfister, 2007; Duysters & Kok, 1999; Lahiri et al., 2021; Park & Ungson, 2001; M. E. Porter, 1987). Increasing the availability of data on failed RDI partnerships is of great importance for academics and practitioners because it can strengthen the literature focused on the performance of not only RDI partnerships but also inter-organizational relations in general (Oliveira & Lumineau, 2019).

Another important area for future research is in relation to the theoretical development. Although there are a number of theoretical frameworks developed in the literature and theories borrowed from other bodies of literature to explain the phenomenon of RDI partnerships, there is no dominant theoretical approach and those which are most commonly used exhibit different limitations as summarised in Table 5. This may transpire from the encompassing literature on inter-organisational relations since, according to Bergenholtz and Waldstrøm (2011, p. 555) systematic review, it *"seems to be in need of further development and coherence, if it is to be characterized as a theory"*. He et al. (2020, p. 24) highlights that *"some of the most exciting and challenging advances in understanding SAs [Strategic Alliances] (including their dynamics) potentially can also arise from combining the insights of existing theories"*.

A number of research gaps in the literature are also found within the three identified RDI partnerships characteristics, conditions, outcomes and processes. In connection with the literature on conditions, research is mainly gathered around the formation stage and there is thus limited attention to the conditions that arise during the execution and assessment stages (F. J. Contractor & Lorange, 2002; Doz et al., 2000; Eisner et al., 2009; Hagedoorn, 2002; Majchrzak et al., 2015; McNamara, 2012; Mohr & Spekman, 1994; Sakakibara, 2002).

There is also limited understanding on the identified phenomena of the duality of conditions. Conditions may no longer be identified and considered to always influence RDI partnerships in the same way as it has been done but to fluctuate in relation to other conditions and characteristics. For example, the observations by Steinmo and Rasmussen (2016) demonstrate that single-party studies overlook the different perspectives each partnering organisation has towards the same condition in line with the review findings of Lumineau and Oliveira (2018) and Martínez-Noya and Narula (2018) as well as the conclusions – Section 2.7 – from the previous literature review. Their observations also confirm that, as it was suggested in Section 3.4.1, conditions are dynamically co-evolving and can mediate RDI partnerships in relation to their interdependencies with other conditions and characteristics. Moreover, there is little indication on the importance or degree of influence that the identified conditions have on the development of RDI partnerships. In the same

way, there is no indication of how the outcomes identified in the literature influence the development of RDI partnerships.

As in the partnership literature (Ariño, 2003), the consideration and measurement of outcomes is also challenging for RDI partnerships. In fact, these challenges can be higher in RDI partnerships because of the time it can take for outcomes to impact on the performance of an organisation and the difficulties associated with the assessment of intangible outcomes. The latter are very common in RDI partnerships since outcomes such as tacit knowledge and know-how are often targeted.

There is also a paucity of research articles focused on the processes involved in RDI partnerships. Similarly, the literature on the dynamics of RDI partnerships is also scarce. Then there is a need to identify and analyse the different processes that RDI partnerships follow during their development (Doz et al., 2000). The literature in this area is so scarce that only very few articles were found to analyse the RDI partnership development, from formation to dissolution, the formation of subsequent RDI partnerships or the development of RDI partnerships, which consists of the previous two strands.

Finally, although a co-evolutionary view of inter-organisational relations is considered of great benefit in their study (Bizzi & Langley, 2012; Das & Teng, 2002; He et al., 2020; Koza & Lewin, 1998; Lahiri et al., 2021; Panda, 2017), the literature on RDI partnerships shows a lack of attention towards it. Only Prange et al. (2015) review on RDI partnerships was found to call for a co-evolutionary view. As in the inter-organisational relations and partnership literature, this represents a major blind spot since a co-evolutionary view goes beyond single time conceptualizations of RDI partnerships which neglects the perception of time intrinsic to each of the involved partners and the RDI partnership created. A co-evolutionary approach therefore overcomes a major blind spot identified by Lumineau and Oliveira's (2018) twenty year review in the overall inter-organisational literature, a single time conceptualization.

The research gaps discussed along with the high failure rates highlighted in the literature suggest more research must be devoted to understanding the relation and interrelations between the multi-

level and co-evolving conditions, outcomes and processes which take place throughout the development of RDI partnerships. This would benefit not only the management but also the effective design of RDI partnerships to decrease the existing high failure rates and deliver the outcomes sought by each partner.

3.8 Conclusions

This chapter provided a review of the RDI partnerships by building on the partnership literature. The first two sections of the chapter focused on the underlying topics of the research question, the characteristics and dynamics of RDI partnerships. As the literature on RDI partnerships and partnerships share a lot of similarities, the chapter followed with a comparative analysis section highlighting the differences between them and a section analysing the research gaps found. Finally, in this Section the key findings and implications of the literature review are summarized.

First, the sustained increase of RDI partnerships since the 1970s together with the lack of coherence in the partnership literature has resulted in a terminology where terms can be used interchangeably (Greenlee, 2005; Martínez-Noya & Narula, 2018) and to convey different meanings when used by scholars from different geographies (see e.g.Caloghirou et al., 2004; Doz et al., 2000). Given the ongoing fragmentation of the literature and the need to integrate the available findings, chapters 2 and 3 not only defined different areas of study and identified terms which are used interchangeably but also defined relevant terms for this study such as alliances, partnerships, RDI partnerships and others. This terminology serves to define the boundaries of this study as well as to avoid prolonging confusion and fragmentation in the field.

Second, the key theoretical perspectives are identified along with their limitations in explaining not only RDI partnerships but also partnerships and inter-organisational relations in general. It is unclear whether the available research and theories around RDI partnerships constitute a theory because scholars typically use and combine different theories. Because of this and the lack of

predominant lines of thought among the theoretical approaches, the field seems to be in transition from a nascent to an intermediate state of theoretical development.

Third, this review observes a paucity of multi-level, qualitative and longitudinal studies in the literature on RDI partnerships as it occurs in the encompassing literature on inter-organisational relations (Lumineau & Oliveira, 2018). For example, almost three quarters of the studies on the formation of RDI partnerships are based on quantitative data in line with prior reviews on inter-organisational relations by A. L. Oliver and Ebers (1998), Bergenholtz and Waldstrøm (2011), Smith (2012) and Gomes et al. (2016).

This review also provides different contributions related to the study of RDI partnerships characteristics at the formation stage. In terms of the conditions, it identifies and analyses the different ways of classifying formation conditions and lists the formation conditions found in the literature indicating which ones have a positive and negative influence in the formation of RDI partnerships. For the first time to the knowledge of the researcher, the formation conditions found are also ranked according to their prevalence in the literature. This provides guidance for future research in the area by providing the first quantitative view of what are the key formation conditions and which ones are rarely observed and studied. Furthermore, this ranking can be of great benefit for practitioners because it not only clarifies what are the dominant formation conditions that must be monitored but also which ones have to be nurtured and which ones avoided or mitigated.

During the identification and analysis of the formation conditions in Section 3.4.1, it was also found that conditions can manifest a dual behaviour in relation to their empirical context or the perception of an organisation in an RDI partnership. This observation on the dual behaviour of conditions opens a novel avenue for future research and emphasizes the benefits of collecting data from different parties in inter-organisational relations such as RDI partnerships. Conditions may no longer be identified and considered to always influence RDI partnerships in the same way as it has been done but to fluctuate in relation to other conditions and characteristics. Furthermore, these

fluctuations may be dynamic because conditions as well as other characteristics can change with the development of RDI partnerships. In fact, arising from the literature review on the dynamics of RDI partnerships in Section 3.5, the case study in Steinmo and Rasmussen (2016) shows that conditions are dynamic and can mediate RDI partnerships in relation to their interdependencies with other conditions and characteristics.

With regards to the formation processes found in the literature, they are identified, discussed and organized in a logical and natural sequence as they could ensue from the early start of a forming RDI partnership to the start of the execution stage (see Table 8). To the knowledge of the researcher, it is the first time that the formation processes in the literature are identified and analysed. Moreover, from the analysis of the formation processes it is concluded that not all the identified processes must be followed during the formation of RDI partnerships. This and raising awareness of the available processes is of key importance for scholars and practitioners because understanding and selecting a process path during formation can influence not only the design and emergence of RDI partnerships but also its outcomes (Doz, 1996; Doz et al., 2000).

Furthermore, the most common outcomes found in the literature of RDI partnerships across the formation, execution and termination stages are identified and discussed. In addition, it was found that not all of the outcomes are pursued by the same stakeholders in RDI partnerships. Depending on the attributes and aspirations of the organisations involved in an RDI partnership, it was found that in some cases stakeholders can even try as hard as possible to prevent the occurrence of specific outcomes (Easterby-Smith, Lyles, & Tsang, 2008; Faems et al., 2007).

Given the similarities found between the literature on partnerships and RDI partnership characteristics during the execution stage, it can be concluded that the characteristics in the partnership literature can also be considered relevant to the RDI partnerships. This should be done with caution as not all the partnership characteristics may be applicable to RDI partnerships and, depending on the specific context, others may only apply depending on the specific context of the RDI partnership. Likewise, it can also be concluded that many of the identified RDI partnership

characteristics at the formation stage transition into the execution stage because they are mentioned in the literature when discussing the formation and execution stages. Even more, the findings in the review of partnerships and RDI partnerships can be applied with caution to other types of relations such as networks or joint ventures.

It is also important to highlight that in the review of the dynamics of RDI partnerships, knowledge transfer and exploitation are observed to mediate the overall dynamics of RDI partnerships and their development. This is also supported by the ranking of RDI partnership formation conditions where the most prevalent condition is knowledge. The papers examined emphasize the importance of knowledge transfer and exploitation in sustaining not only RDI partnership development but also subsequent relations such as partnerships, joint ventures and mergers and acquisitions (Dooley & Kirk, 2007; Faems et al., 2007; Gibbons et al., 1994; König et al., 2011; M'Chirgui, 2009; Steinmo & Rasmussen, 2016). These findings suggest that the role of other RDI partnership characteristics is to mediate the knowledge transfer and exploitation. This should be confirmed by future research and, if needed, a framework should be developed to analyse the development of RDI partnerships.

Finally, although a co-evolutionary view of inter-organisational relations is considered of great benefit in their study (Bizzi & Langley, 2012; Das & Teng, 2002; He et al., 2020; Koza & Lewin, 1998; Lahiri et al., 2021; Panda, 2017), the literature on RDI partnerships shows a lack of attention towards it. This represents a major blind spot since a co-evolutionary view goes beyond single time conceptualizations of RDI partnerships which neglects the perception of time which is intrinsic to each of the involved partners and the RDI partnership created (Lumineau & Oliveira, 2018).

The above key findings and implications along with the identified research gaps in Section 3.7, point to a comprehensive and extensive number of limitations in the literature and avenues for future research. Based on these and the emerging context of nanotechnology, the developed research question for this study is as follows.

> ***How can the characteristics of nanotechnology RDI partnerships mediate their development?***

Finally, considering the highlighted state of the literature and particularly the limitations of the extent theoretical approaches, no conceptual frameworks are derived from the analysis of the literature in this relatively nascent field. Instead, the intend of the research is to advance the theory from the analysis of field data. Hence, the inquiry and empirical research analysis will be guided, where applicable, by the reviewed theories borrowed from other fields and the model developed in Figure 5 which serves as a sensitizing device. This model has been developed in Chapter 2 from the analysis of the partnership literature and confirmed in this Chapter from the analysis of the RDI partnerships literature.

The model is phenomenon driven and has a low level of detail to avoid preconceptions. Yet at the same time it accounts for the findings in this chapter – e.g. the multi-level and dynamically co-evolving nature of RDI partnerships – which provides a vantage point to overcome major blind spots – single-party, single-level and single time conceptualization – in previous studies as well as other limitations highlighted in this Chapter (Lumineau & Oliveira, 2018; Martínez-Noya & Narula, 2018). The next chapter will build on the reviewed literature to establish a methodological fit and establish the research design that guides the subsequent parts of this study (Edmondson & McManus, 2007).

4 Research methodology

Chapter 4 describes and justifies the research methodology undertaken in this study. Section 4.1 outlines different research philosophies and justifies the ontological, epistemological and methodological views the researcher adopts to investigate the phenomena of RDI partnerships and answer the research question of this study – "*How can the characteristics of nanotechnology RDI partnerships mediate their development?"*

Following the adoption of the critical realism research philosophy, Section 4.2 justifies the selection of a critical realist longitudinal explanatory case study research methodology and describes the state of research and theorising implications of conducting such a methodology. To undertake this methodology, Section 4.3 develops a research framework which includes the case study approach and selection, data collection methods, coding techniques and analysis selection steps. Finally, the chapter conclusions are presented in Section 4.4.

4.1 Research philosophy

Undertaking social research entails a set of beliefs and assumptions implicit in the way a researcher views and adopts to investigate phenomena. This set of beliefs and assumptions define the research philosophy undertaken by a researcher. These beliefs and assumptions can be of an ontological, epistemological and methodological nature and deal with the researcher's perspectives of the social world and how it can be investigated (Burrell & Morgan, 1979).

Ontological assumptions relate to the nature of reality. Hence, ontological assumptions refer to the researcher's view of

> *"…What is the form and nature of reality and, therefore, what is there that can be known about it?"*(Guba & Lincoln, 1994, p. 108)

Ontology determines the researcher's view of the essence of reality and how it is like. In contrast, epistemology deals with the relationship between the researcher and reality and what is acceptable

knowledge (Burrell & Morgan, 1979; Saunders, Lewis, & Thornhill, 2012). Subsequently, Guba and Lincoln (1994) refer to the following as the epistemological question…

> *"…What is the nature of the relationship between the knower or would-be knower and what can be known?"* (Guba & Lincoln, 1994, p. 108)

Ontological and epistemological assumptions are intimately related and are typically discussed together. Furthermore, methodological assumptions are more practical and deal with how the social world, which is defined by the ontological and epistemological assumptions of a researcher, can be investigated. Hence, these assumptions refer to the researcher's view of

> *"How can the inquirer (would-be knower) go about finding out whatever he or she believes can be known?"* (Guba & Lincoln, 1994, p. 108)

Again, the researcher's methodology must tie in with the previous ontological and epistemological assumptions. Typically, the union of the ontological, epistemological and methodological assumptions is referred as the research paradigm of a study (Eriksson & Kovalainen, 2008).

Despite the large range of research philosophies and, thus, assumptions that can be adopted, they all range in a continuum from a subjectivist to an objectivist approach (Saunders et al., 2012). Ontologies for example go from a nominalist view where reality is socially constructed and decided by convention to a realist view where reality is independent to individuals and society. In the epistemological continuum the anti-positivism end advocates for the need to develop knowledge through experiencing and contextualising phenomena. However, the positivism end considers that knowledge can be produced via the observation and measurement of phenomena. Associated with a nominalist and anti-positivist view, the ideographic methodology emphasizes the need for interactions between the researcher and the subject under study to deliver interpretations of the findings. In contrast, realism and positivism is associated with the nomothetic methodology which relies on experiments to derive quantitative evidence. (Burrell & Morgan, 1979; Guba & Lincoln, 1994)

Each of these ontological, epistemological and methodological assumptions and ultimately, paradigmatic choices provide a different way of seeing the phenomena under investigation and, thus, lead to different types of research outputs (Saunders et al., 2012, p. 126). Subsequently, the research philosophy selection of this study seeks alignment between the ontological, epistemological and methodological assumptions and the researcher's own beliefs as well as with the specific research aim of this study. To aid in this selection, the researcher's stance and research aim of this study is identified along the continuum of ontological, epistemological, methodological and research aim choices as shown in Figure 13. This facilitates and ensures rigour in the selection of the research philosophy.

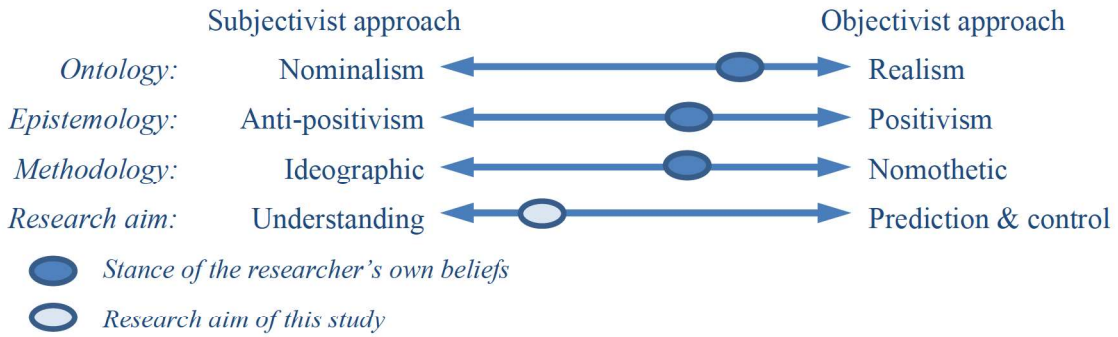


Figure 13 The subjective and objective dimensions in social science research and the stance of the researcher's own beliefs (adapted from Burrell & Morgan, 1979)

As shown in Figure 13, there is a divergence between the researcher's beliefs inclination towards the objectivist approach and the subjectivist inclination of the research aim in this study. This leads to the selection of critical realism as the research philosophy since it is between the objectivist and subjectivist polar approaches and ensures a high degree of flexibility in the subsequent selection of research methods and data types (Eriksson & Kovalainen, 2008, p. 19; Seale, 1999).

4.1.1 Critical realism

Critical realism originates from the work of Roy Baskhar in the 1980s as a response to the polar approaches of combining assumptions around realism and positivism or nominalism and anti-positivism (Saunders et al., 2012, p. 132). Being somewhere in the middle between these polar

approaches critical realism refers to the existence of an independent reality to individuals and society like realism. At the same time, it considers that this reality is not observable and is only apprehended through the conceptualisation of sensations as in an anti-positivist approach. Furthermore, critical realism views reality as stratified in three domains as shown in Figure 14. The first domain, the real, deals with the causal structures and mechanisms which underpin all the events which are observed or not and are independent from the social world. The second domain, the actual, consists of the events generated by the mechanisms of the real domain. Finally, the third domain, the empirical, consists of a subset of events from the actual which are sensed and experienced by individuals and society.

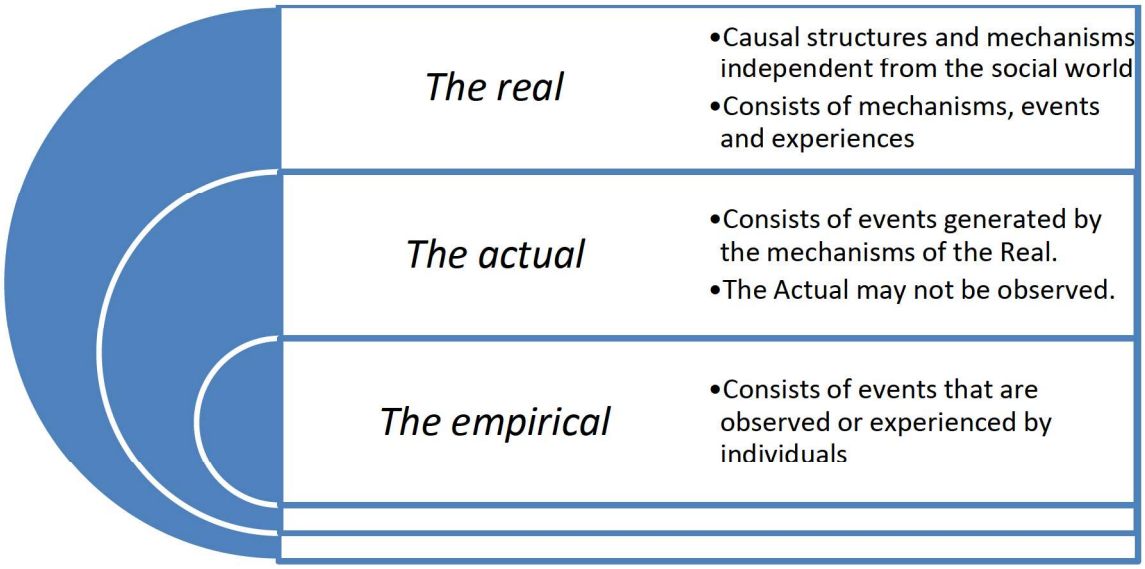


Figure 14 The domains of reality in critical realism (Bhaskar, 2008, p. 2)

These domains of reality in critical realism entail that the development of knowledge goes through a process where the researcher initially experiences events in the empirical domain and then conceptualises the underlying possible structures and mechanisms in the real domain to the experienced events. Bhaskar (1975, p. 2) describes that…

> *"we will only be able to understand – and so change – the social if we identify the structures at work that generate those events and discourses… These structures are not*

spontaneously apparent in the observable pattern of events; they can only be identified through the practical and theoretical work of the social sciences".

Hence, understanding of phenomena is based on the inference of the structures and causal mechanisms which operate independently from the social world and explain a given event or sets of events (Wynn & Williams, 2020). Additionally, this middle ground between objectivism and subjectivism allows researching for these structures and causal mechanisms with any research method and analysis technique based on quantitative, qualitative or both types of data (Vincent & O'Mahoney, 2018). Bergin, Wells, and Owen (2008, p. 173) argue that being in between objectivism and subjectivism approaches allows critical realism to unveil *"factors that are often invisible to existence, not capable of being measured or not expressed by the researched are quite often missed during the research process".*

4.1.2 Inference in critical realism studies

In scientific studies four different methods of inference can be distinguished: deduction, induction, abduction and retroduction (Danermark, Ekström, & Karlsson, 2002). While most of the scientific studies are based on deduction and induction, critical realism studies are based on abduction and retroduction (Bhaskar, 2008; Danermark et al., 2002; Vincent & O'Mahoney, 2018).

Deduction is a logical form of inference that is based on deriving conclusions on individual phenomenon from general laws or premises. In contrast, induction is based on drawing general laws from individual observations. In this way, deduction goes from the general to the individual and induction from the individual to the general. However, the use of deduction or induction in research comes with limitations. On one hand, deduction is limited to what is known and on the other, induction does not warrant the inferred general laws and is limited to empirical observations.

Given these limitations, the use of abduction and retroduction is proposed in critical realism studies (Bhaskar, 2016, p. 46; Danermark et al., 2002; Lennox & Jurdi-Hage, 2017). Abduction or theoretical re-description was introduced by the American philosopher Charles Sanders Peirce towards the end of the nineteenth century. In this type of inference, what is known of an individual phenomenon is interpreted through the introduction of new ideas which redescribe or recontextualise it. Hence, abduction is based on the creativity and relational ability of the researcher *"to think about something in a different context, an ability to 'see something as something else'"* (Danermark et al., 2002, p. 93).

Retroduction, follows abduction and is a type of inference where individual phenomena is explained by the conceptualization of the essential, transfactual characteristics which, if they existed, would produce it (Danermark et al., 2002; Lennox & Jurdi-Hage, 2017). In this way, retroduction unveils the essential, transfactual conditions, mechanisms and outcomes which provide a plausible causal explanation to the individual phenomena present in the abducted context (Danermark et al., 2002; Fletcher, 2017; Vincent & O'Mahoney, 2018). Because of this, new and existing theory plays a key role in finding the essential, transfactual characteristics which can explain the phenomena under study (Vincent & O'Mahoney, 2018). Critical realism studies are therefore based on causal explanation where the activating conditions and outcomes of the identified mechanisms are identified.

As a relatively new philosophy of science and its methodological openness due to its epistemological relativism (Eriksson & Kovalainen, 2008, p. 19; Seale, 1999), the methodological implications of critical realism are still developing and there are different views towards the definition and use of abduction and retroduction as well as data analysis (Fletcher, 2017; Hoddy, 2019; Vincent & O'Mahoney, 2018).

Critical realism can be considered as a philosophy in search of guidelines and techniques to apply existing and new research methods (Fletcher, 2017; Hoddy, 2019) because *"researchers*

have not yet identified a standard formula for conducting retroductive analyses" (Wynn & Williams, 2020, p. 60) and *"the existing gap between the philosophical foundation, methodological recipes and hands-on practices of applied critical realism…"* (Frederiksen & Kringelum, 2021, p. 18).

4.2 Methodological approach

Following the adoption of a research philosophy, a key aspect of any research is to select an appropriate methodological approach that will result in the best possible outcomes. In this study the selection of the methodological approach is based on the analysis of the state of prior theory, the research question and the expected contributions of this study. Finding a fit between these three elements *"promotes the development of rigorous and compelling field research"* (Edmondson & McManus, 2007, p. 1169).

First, the research focus of this study, RDI partnership development, is within the field of inter-organizational relations which has received significant attention among different sets of literature since it is associated with positive aspects such as increased competitiveness, innovation and organizational learning (Sakakibara, 2002). As a result, it is heavily fragmented and sometimes considered as a theory (A. L. Oliver & Ebers, 1998) or in the need of further development and consistency (Bergenholtz & Waldstrøm, 2011; Katz & Martin, 1997). If a continuum is drawn from nascent to mature theory, the state of prior theory and research is somewhere close to the centre but still tilted towards the nascent side of the continuum. To fit with this state of prior theory and research, Edmondson and McManus (2007) found that the methodological approach should typically involve both qualitative and quantitative data.

Second, the research question of this study is: *"How can the characteristics of nanotechnology RDI partnerships mediate their development?"* Hence, this study focuses on a "how" question which is process theory oriented (Edmondson & McManus, 2007) and revolves around the phenomena of RDI partnerships. This phenomena is highly complex because it develops during relatively long

periods of time, typically over a year, takes place at different levels of an organization and involves different individuals, processes, industries and types of organizations with their own underlying and particular characteristics. Subsequently, the complex nature of RDI partnerships highlights the appropriateness of adopting a longitudinal research approach which is suited for studies that observe the development of a phenomenon over extended periods of time (Pettigrew, 1990).

Finally, the expected contributions to the literature fall within the following five areas: conceptual, theoretical, practical, empirical and methodological. However, only the conceptual and theoretical contributions are considered in selecting the methodological approach in line with the framework provided by Edmondson and McManus (2007). From a conceptual and theoretical stance, this study aims to enhance our understanding of RDI partnership development by providing process theory. As a result, the expected contributions of this study fall into the category of explanatory studies (Singleton & Straits, 2005, p. 69; Yin, 2009, p. 9).

From the analysis of the state of prior theory, research questions and expected contributions, it is clear that the methodological approach should be based on a research method with an explanatory nature and capable of developing process theory from longitudinal qualitative and quantitative data. Furthermore, the research method must also fit with the previously selected philosophical perspective for this study, critical realism.

4.2.1 Research method selection

There are a large number of research methods being used in the field of business and management studies. To select the most appropriate for this study, different research methods were considered based on their fit with the selected philosophical perspective, critical realism, and the methodological approach, explanatory and capable of developing process theory from longitudinal qualitative and quantitative data. To narrow down the potential appropriate research methods, the fourteen key research methods shown in Table 9 are considered along with their associated philosophical approach and data type. This allows finding a research method that fits with the selected philosophical and methodology approach which are characterized by being positioned

towards the centre of the subjectivist-objectivist continuum and relying on both qualitative and quantitative data. Accordingly, in Table 9 the only research methods that fit these conditions are the case study and field experiment. Hence, these two research methods are described in more detail to select the most appropriate.

Table 9 Research methods and their associated philosophical approaches and types of data (based on Remenyi, Williams, Money, & Swartz, 1998)

Research method	Philosophical approach	Type of data
Action Research	Subjectivist	Qualitative / quantitative
Case studies	Objectivist / Subjectivist	Qualitative / quantitative
Ethnographic	Subjectivist	Qualitative
Field experiments	Objectivist / Subjectivist	Quantitative / qualitative
Focus groups	Mostly subjectivist	Quantitative / qualitative
Forecasting research	Objectivist	Quantitative
Futures research	Objectivist / Subjectivist	Quantitative emphasis
Game or role playing	Subjectivist	Quantitative / qualitative
In-depth surveys	Subjectivist emphasis	Quantitative / qualitative
Laboratory experiments	Objectivist	Quantitative
Large-scale surveys	Objectivist	Quantitative
Participant-observer	Subjectivist	Quantitative / qualitative
Scenario research	Subjectivist emphasis	Qualitative emphasis
Simulation and stochastic modelling	Objectivist	Quantitative

The goal of the field experiment research method is to determine the causation connectivity between the dependent and the manipulated independent variables of a study (N. Lee & Lings, 2008). In contrast to laboratory experiments take place in laboratories where there is a high degree of control over all the variables involved, field experiments take place in natural settings where controlling the variables is often cumbersome (Remenyi et al., 1998). Despite the different empirical settings of the laboratory and field experiments, both are based on the establishment of at least two objects of study where their dependent and independent variables are assessed before and after one or several independent variables are manipulated (Bryman & Bell, 2011). However, the

ability to control variables in a natural setting is always questionable and field experiments stance can be viewed as less positivistic than laboratory experiments. Because of this, field experiment results can be interpreted in a subjectivist manner (Remenyi et al., 1998).

Field experiments are rare in social sciences in general because they require controlling one or several independent variables. Having to control one or multiple independent variables makes them very complex to design and this complexity increases rapidly as the number of independent variables grows (Remenyi et al., 1998). As a result, they are not typically implemented in business and management studies and considered impractical for studies where controlling independent variables is not possible or there are a large number of dependent and independent variables (N. Lee & Lings, 2008). That is the case of the focus of this study, RDI partnerships. Typically their development takes place over long periods of time at different levels of analysis and involves different individuals, processes, industries and types of organizations which bring along a large number of variables. Some of these variables may not even be known at the beginning of a study.

In contrast, the use of the case study research method is widespread in business and management not only for research purposes but also as a teaching tool (Remenyi et al., 1998; Yin, 2009, p. 4). According to Yin (2009, p. 18), a *"case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident"*. This research method also allows the use of multiple sources of evidence from where both qualitative and quantitative data can be drawn. In addition, case studies arise from how and why questions where there is a focus on contemporary situations which take place naturally and cannot be controlled by the researcher (Yin, 2009, p. 2).

In evaluating the most suited research method, the field experiment and case study methods are compared in Table 10 along with the seven characteristics that are already fixed for this study, the philosophical perspective, research question, context, research motivation and type of data and contribution. As shown in Table 10, the field experiment method does not fit with this study

because it requires controlling, at least, some variables of the focus of this study, RDI partnerships, and this would be extremely difficult. However, the case study research method does not require this and shows a good fit with all the characteristics which have already been fixed for this study as shown in Table 10. Consequently, the proposed research method to be used is the case study.

Table 10 The field experiment and case study methods compared along with seven key characteristics that have been selected for this study (based on Eisenhardt, 1989; Remenyi et al., 1998; Yin, 2009, p. 8)

	Field experiment	Case study	Selected stance for this study
Philosophical perspective	In between subjectivism and objectivism	In between subjectivism and objectivism	Critical realist (in between subjectivism and objectivism)
Form of research question	How and why.	How and why.	How question
Research motivation	Exploratory, descriptive and explanatory.	Exploratory, descriptive and explanatory.	Explanatory
Purpose	Generate and test theory	Generate and test theory	Generate process theory
Focus and control	Contemporary situations which can be controlled	Contemporary situations which take place naturally	Contemporary situations which are difficult to control (RDI partnerships)
Type of data	Qualitative and quantitative	Qualitative and quantitative	Qualitative and quantitative
Type of contribution	Generate and test process and variance theory	Generate and test theory, mainly process theory	Generate process theory and identify causal relations between the formation stage and outcomes of RDI partnerships.

The selection of the case study research method is also supported by the experience and findings of other scholars:

1. Pettigrew (1990, p. 271) stresses how the selected longitudinal methodological approach coupled with a case study research method *"provides the opportunity to examine continuous processes in context and to draw in the significance of various interconnected levels of analysis"*.

2. Intended and particularly suited for analysing complex phenomena and processes developing over time (Pettigrew, 1997) and addressing "how" questions (Bizzi & Langley, 2012).
3. Required to increase understanding of inter-organizational R&D collaboration (Smith, 2012).
4. *"focuses on understanding the dynamics present within single settings"* (Eisenhardt 1989 p. 534).
5. It is *"best suited to provide a rich account of inter-functional communication and processes (...) and obtain access to potentially sensitive and confidential (...) information"* (Inglis 2008 p. 694) which is commonly the case in inter-organisational collaboration.
6. Has been successfully used in inter-organizational collaboration on R&D and innovation studies (Albors-Garrigós et al., 2013; Davis & Eisenhardt, 2011) as well as in critical realist studies on inter-organizational relations (Easton, Ackroyd, & Fleetwood, 2000; Ryan, Tähtinen, Vanharanta, & Mainela, 2012; Vincent, 2008).

The fit among the analysed characteristics involved in this study and, in particular, between the state of prior theory, research questions of this study, expected contributions and the research method provides *"an overarching criterion for ensuring quality field research"* (Edmondson & McManus, 2007, p. 1155).

4.2.2 Applying critical realism in case study research

As a relatively new philosophy of science and its methodological openness (Eriksson & Kovalainen, 2008, p. 19; Seale, 1999), the methodological implications of critical realism are still developing and can be considered as a philosophy in search for guidelines and techniques to apply existing and new research methods (Fletcher, 2017; Frederiksen & Kringelum, 2021; Hoddy, 2019). It may be due to these challenges that *"the application of critical realism to case studies remains "underdeveloped"* (Welch, Piekkari, Plakoyiannaki, & Paavilainen-Mäntymäki, 2011, p. 749) compared to other approaches to theorising.

Because of this, scholars from different areas of knowledge and fields continue to advance the application of critical realism research. The available publications to guide the conduct of critical realism in case studies can be categorised around four areas. First, those focused on providing general guidance on the critical realism research process (Bhaskar, 1975; Danermark et al., 2002). Second, publications which provide guidance specific to the conduct of critical realism case study research (Gebre-Mariam & Bygstad, 2019). Third, research articles which not only provide guidance to conduct critical realism case studies but also detail the application of data analysis techniques, typically grounded theory techniques (Fletcher, 2017; Hoddy, 2019). The last category consists of publications which provide a structured and comprehensive framework for case study research. These publications extend and integrate previous guidance in a coherent and step by step basis spanning the entire research process and, as in the previous category, detail the implementation of different data analysis techniques (Alwadain, Fielt, Korthaus, & Rosemann, 2014; Williams & Karahanna, 2013). These step by step and comprehensive critical realist case study research frameworks provide a toolkit which contributes significantly to facilitate the introduction of researchers into applied critical realism and reduce the highlighted challenges in the conduct of critical realist case studies.

Table 11 provides a summary of the highlighted four areas of research in critical realism case study research and provides some illustrative examples.

Table 11 Guidance to conduct critical realist (CR) case studies – some illustrative examples

Critical Realism (CR) research process guidance	CR case study research process guidance	CR case study research process and data analysis techniques guidance	Comprehensive CR case study research framework with data analysis techniques
Seven stages process Danermark et al. (2002)	Wynn and Williams (2012, 2020) Critical Realism (CR) principles	Fletcher (2017) based on flexible deductive coding technique	**This study** – based on directed content analysis informed by Wynn and Williams (2012) and Fletcher (2017) process and principles
RREI process by Bhaskar (1975)	Easton (2010)	Hoddy (2019) based on grounded theory technique	Williams and Karahanna (2013) based on a hybrid approach combining theory-driven template coding and inductive coding informed by Wynn and Williams (2012) CR principles
Critical realist research spiral by Ryan et al. (2012)	Bygstad and Munkvold (2011)	Alwadain et al. (2014) based on thematic analysis combining deductive and inductive coding	

As a result of the analysis in this Section, the methodology of this study can be defined as a critical realist longitudinal explanatory case study research informed by Wynn and Williams' (2012, 2020) critical realism principles and Fletcher's (2017) process and based on the directed content analysis technique. Critical realist case studies provide contextualised explanations where the contextual conditions under which the identified causal mechanisms generate different outcomes. Yet at the same time, the derived causal mechanisms can only be claimed in the analysed context because context is integrated into the causal explanation.

In what follows, Section 4.3 describes and justifies the step by step and comprehensive critical realist case study research framework developed for this study. The subsequent chapters 5 and 6 demonstrate how the framework can be implemented to research RDI partnerships.

4.3 Research framework

As highlighted in Section 4.2.2, conducting critical realism case study research is challenging because of being *"still in its empirical infancy"* (Wynn & Williams, 2020, p. 65), *"underdeveloped"* (Welch et al., 2011, p. 749), the different views on abduction and retroduction (Bhaskar, 2008, 2016; Danermark et al., 2002; Vincent & O'Mahoney, 2018) and its methodological openness (Eriksson & Kovalainen, 2008, p. 19; Seale, 1999). In addition, this type of research is challenging because of the lack of general guidance (Lennox & Jurdi-Hage, 2017), integration of previous findings, clear criteria to search for mechanisms (Gebre-Mariam & Bygstad, 2019) and clarity on the implementation of data analysis techniques (Hoddy, 2019) and particularly those which are not focused on grounded theory (Fletcher, 2017).

Hence, this study developed a research framework for critical realism case study research which integrates previous guidance in a coherent and step by step basis. This research framework was developed by drawing from the bodies of literature on research design, critical realism and case study research. For example from Yin's (2009) book on case study research, Pan and Tan's (2011) article on a methodology to conduct case study research, Singleton and Straits' (2005) book chapter on elements of research design and the articles referenced in Section 4.2.2 on applying critical realism in case study research. The resulting research framework presented in the next sections is informed by Wynn and Williams' (2012) critical realism principles and Fletcher's (2017) process with the idea of complementing typical data analysis approaches which leverage the grounded theory technique. In doing so, the research framework also follows methodological recommendations of Wynn and Williams (2020) by focusing on explanations, developing detailed case narratives, exposing the elements of structure, employing emerging techniques, identifying activating conditions, leveraging prior research, and demonstrating full causal logic and transparency.

Moreover, the developed steps in the research framework combine and arrange the key components of case study research (Yin, 2009, pp. 46-64) in a simple and structured manner which is easy to

follow and overcomes practical barriers of case study research while taking principled decisions. These barriers include access and case selection, data complexity and when to conclude data collection (Pan & Tan, 2011; Pettigrew, 1990). A clearly and structured research process ensures rigour and quality in undertaking case study research while strengthening the reliability of the research outputs (Yin, 2009, p. 45).

4.3.1 Step 1: Conceptualizing and accessing the phenomenon under study

This step consists of two parallel activities. On one hand conceptualizing the phenomenon of study and on the other hand exploring access to potential cases related to the phenomenon. To do this, this study combines the views of the predominant literature on case studies, starting with some initial research questions (see e.g.Eisenhardt, 1989), and a pragmatic approach since accessing cases such as in the context of this study, nanotechnology R&D, can be a very challenging task (Pan & Tan, 2011).

During the conceptualization of the phenomenon under study, the research topic of study is analysed through the review presented in Chapter 2 and 3. This review was done not only within the literature focused on the research topic of this study but also on adjacent bodies of literature to ascertain relevant constructs, propositions, literature gaps and theories which will be of use in later steps of the research framework. This familiarization process with the research topic also brings other key advantages in line with critical realists which advocate that *"active thought experimentation is needed before research even begins"* (Hart, New, & Freeman, 2004, p. 166) and allows to *"Enhance CR [Critical Realism] explanations by leveraging prior research."* (Wynn & Williams, 2020, p. 61).

Not only it enables building focused and relevant research questions aligned with the state of prior theory and the phenomenon under study (Edmondson & McManus, 2007), but it also guides the definition and operationalization of the unit of analysis under study (Pettigrew, 1990) as well as the data collection, coding and analysis (Fletcher, 2017; Pan & Tan, 2011). As a result, at this stage it

is already clear from the aim of the selected research question and the literature that RDI partnerships operationalized via consortia agreements is a suitable, viable and promising avenue to conduct this research (see e.g. Aldrich & Sasaki, 1995; Arranz & de Arroyabe, 2006; Mothe & Quelin, 2001; Roijakkers, 2003; Sakakibara, 1997; Todeva & Knoke, 2005).

In parallel, it is essential to explore and negotiate access to potential relevant cases that will facilitate answering the selected research question. There is no point in developing research questions if potential relevant cases cannot be found and accessed. Finding and negotiating access to potential cases related to the study can also bring along research opportunities where unconsidered areas of study and research questions can be addressed.

This parallel approach in the first step of the research framework brings several advantages. It allows to target the research towards areas where case study research is meaningful and in line with practice (Yin, 2009, pp. 26-30). This increases the chances of making contributions to theory (Langley, 1999) and focuses the research on the available data (Pan & Tan, 2011; Pettigrew, 2012). Finally this parallel approach also stimulates creative thinking on topics and research questions that arise around the search and negotiation of potential case opportunities (Siggelkow, 2007) and is in line with critical realism emphasis on leveraging *"pre-existing theoretical knowledge, hunches and hypotheses as necessary 'points of departure' and building blocks for the development of more abstract theory"*(C. Oliver, 2012, p. 380).

4.3.2 Step 2: Case study approach and selection

Yin (2009, p. 46) identifies four types of case study research approaches depending on whether single or multiple cases are involved and if this or these cases present one or multiple embedded units of analysis. Figure 15 represents in a two by two matrix these four types of case study approaches attending to the number of cases and units of analysis. Additionally, within each of the four types it shows the underlying context of each case.

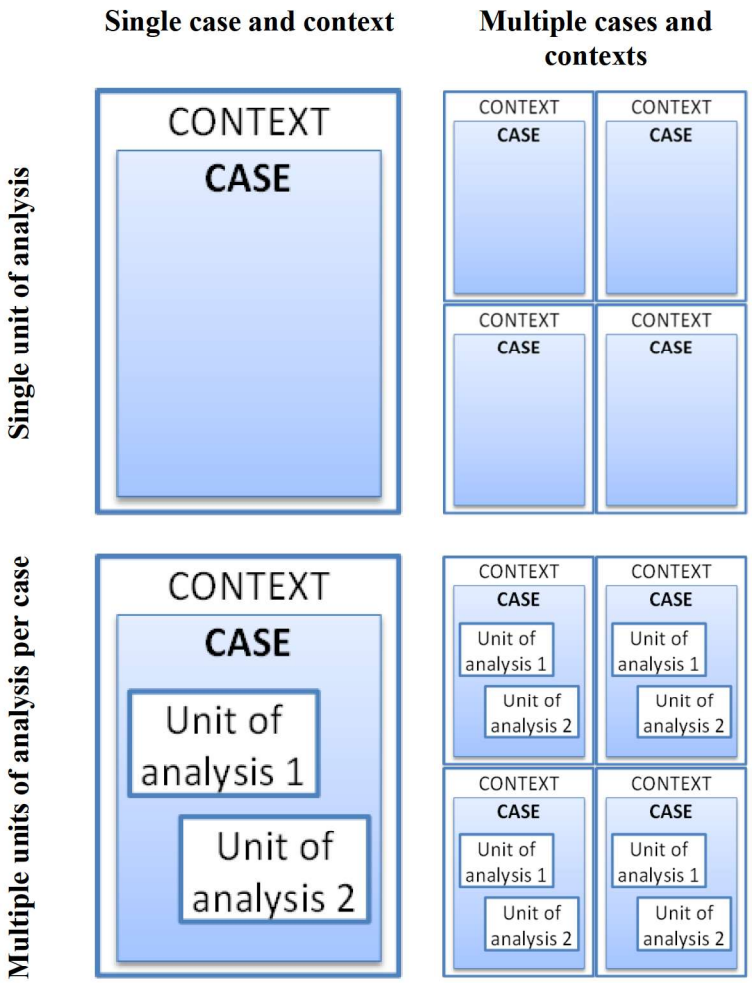


Figure 15 Yin (2009, p. 46) types of case study approaches.

In determining the type of case study approach the first decision to undertake is whether single or multiple cases should be adopted. In doing so, the search and access negotiation to cases was extremely valuable since no *"talking pig"* case (Siggelkow, 2007, p. 20) was found and access to several potential cases was agreed during the first step. This combined with the general preference to consider *"evidence from multiple cases…more compelling"* (Yin, 2009, p. 93) and the available resources in this study, justified adopting a multiple case study approach. In addition, studying different cases allows comparing and contrasting each other during the data analysis. Once again the search and negotiated access to case studies in the first step suggested using a single unit of analysis per case study since no case was found with several embedded units of analysis. Furthermore, no added value was found in answering the research question of this study with cases embedding more than one unit of analysis, multiple RDI partnerships.

With the multiple case study approach comes the question of the required number of cases. In finding an answer it is considered not only the available resources but also the maximum possible number of replications across cases to strengthen the generalization of the findings. According to Pettigrew (1990, p. 276), *"reasonably high standards of input and output can be sustained if each experienced full time researcher conducts no more than four to six cases over a three-year period"*. As in this study there is only one researcher available over approximately two years to investigate the cases, the number of cases that will be pursued is four. The selected number of cases is in line with other scholars such as Eisenhardt (1989, p. 545) who claims that *"while there is no ideal number of cases, a number between 4 and 10 cases usually works well."*.

The selection of case studies is done on the basis of five characteristics that maximize the prospects of answering the research question and deriving novel findings by increasing comparison and contrasts across cases within a novel setting in practice (Pettigrew, 1990). The first an obvious characteristic given the established case study approach is that each case can only contain one unit of analysis (Yin, 2009, p. 46). Given the research question of this study, the unit of analysis is the RDI partnership. Second the RDI partnerships must include more than two partners to increase the novelty of the research results since most studies in the literature are based on dyads (see e.g. Eisner et al., 2009; Gulati, 1998; Vonortas & Okamura, 2009; S. Xu et al., 2014). Third, all of the partnerships must be based on nanotechnology RDI activities which is an emerging area within a high technology environment. Using a specific technological context as opposed to an industrial is selected because of its novelty and the potential to bring new insights (Müller-Seitz, 2012).

Fourth, the nanotechnology RDI partnerships were operationalized through publicly funded RDI consortia by the NanoAble agency in Europe which only funds vertical partnerships. This is a key advantage of this study because the selection is carried over the same type of RDI partnerships; vertical exploitative RDI partnerships which went through an exhaustive review process by technology and business experts to assess their merit and excellence (Osborn & Hagedoorn, 1997). Furthermore, this operationalization ensures concrete boundaries in the RDI partnerships since they are clearly defined by the consortia agreements (Narula & Hagedoorn, 1999).

Finally, the selection of the case studies is based on the literal replication[8] of RDI partnerships and their polar types to not only ease the observation of patterns and their similarities but also address a gap in the literature (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Pettigrew, 1990). As Steinmo and Rasmussen (2016, p. 1258) explain, "*because R&D collaborations frequently fail.... Future studies should therefore… include both successful and unsuccessful collaborations*". Hence, the polar types selected are successful and unsuccessful RDI partnerships. In this way, the sampling is undertaken based on the number of RDI outcomes by considering successful partnerships to be those that delivered more than 50% of the targeted RDI outcomes and unsuccessful those that delivered less than 50% of the targeted RDI outcomes. From a critical realist view, this approach allows to deepen and generalize causal explanations by identifying cases which show *"fundamentally different outcomes in settings where structural, contextual, and environmental factors may lead us to expect some generally similar manifestations of mechanisms."* (Wynn & Williams, 2012, p. 794).

This approach towards the selection of case studies is in line with critical realism and implies that the sampling must be undertaken on RDI partnerships which have finalised or are already very advanced (Wynn & Williams, 2012). A limitation of selecting case studies retrospectively is that it limits the opportunities to collect data through direct observation and requires to select interviewees who are no longer engaged in these RDI partnerships. However, the advantages of using polar type cases and addressing a gap in a field which is, as discussed in Sections 2.4, 3.3 and 3.7, in a relatively immature state of theory development compensate these limitations. Furthermore, the use of literal replication among the cases strengthens the external validity of the research design (Yin, 2009, p. 41).

Additionally, the sampling of a pair of successful and unsuccessful RDI partnerships is done within the same industry, electronics, and the sampling of the other pair from a different industry, medical devices. This allows to compare high and low performing RDI partnerships within and across high

[8] Refers to the selection of case studies where similar results are predicted due to predictable reasons (Yin, 2009, p. 54)

technology industries to increase confidence in the theoretical findings of this study. Another aforementioned key aspect in the selection of the cases for this study is that all of them share the same context, nanotechnology.

Despite the selected cases are not involving the same partners and take place in two different industries, they all share the same context imposed by the NanoAble agency guidelines and regulations that the partners adhered to in order to receive grants which supported their planned nanotechnology RDI activities. Consequently, the RDI partnerships are, to a great extent, constrained and articulated by similar targets, interactions, procedures and arrangements. For example, all the RDI partnerships in this study are governed by the same NanoAble agency grant and IP agreements and overseen by the Board of the NanoAble agency.

Beyond the four case study types provided by Yin (2009, p. 46), the cases selected and data collected suggest there is a fifth case study type since the cases only have one unit of analysis and share the same context. With this finding in mind, also a sixth case study type emerges where several cases share the same context and include different units of analysis. For example, if the unit of analysis of this study were the relations between organisations in RDI partnerships, each of the selected four cases would include at least two units of analysis since a requirement for the selection of RDI partnerships is that they include at least three partners. With this in mind, the previously presented Figure 15 with the four case study types introduced by Yin (2009, p. 46) is complemented with two more types in Figure 16.

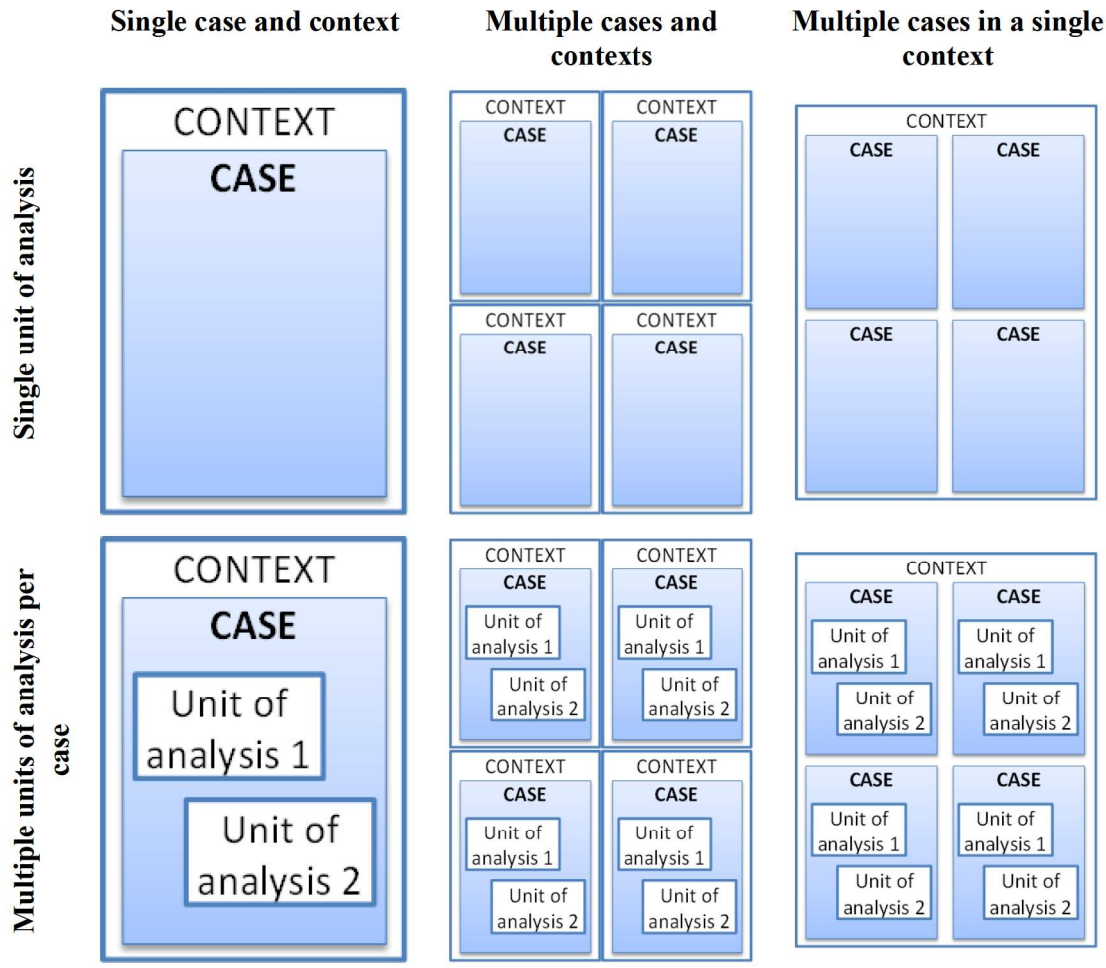


Figure 16 Four types of case study approaches and two additional types suggested in this study where multiple cases are within a single context. Adapted from Adapted from Yin (2009, p. 46).

Consequently, this study falls within the category shown in Figure 16 of case study types where multiple cases share the same context and each case study has one single unit of analysis. The two new case study types and categorisation shown in Figure 16 is presented not only for the framing of this study but more importantly for the benefit of future case study research.

4.3.3 Step 3: Data collection

In this step, the data collection is considered and determined by building on the literature reviews presented in Chapter 2 and 3 and undertaken as part of step 1 of this research framework. According to Eisenhardt (1989), case studies can include qualitative and quantitative data and typically combine a number of collection methods. In case study research there are six data collection sources with their own strengths and weakness as summarized in Table 12.

Table 12 Six Sources of evidence: strengths and weaknesses (Yin, 2009, p. 142)

Source of evidence	**Strengths**	**Weaknesses**
Documentation	• Stable – can be reviewed repeatedly • Unobtrusive – not created as a result of the case study • Exact – contains precise details of names, positions, events • Broad coverage long span of time, events and settings	• Access – problems of confidentiality in many organizations • Reporting bias – reflects (unknown) bias of document author
Archival records	• (Same as those for documentation) Precise and quantitative	• (Same as above for documentation) • Accessibility due to privacy reasons
Interviews	• Targeted – focus directly on case study topic • Insightful – provide original and illuminating data	• Bias due to poorly constructed questions • Response bias • Response bias • Inaccuracies due to poor recall • Reflexivity – interviewee gives what interviewer wants to hear
Direct observation	• Reality – covers events in real time • Contextual – covers context of "case"	• Time-consuming and costly • Selectivity – broad coverage difficult without a team of observers • Narrow focus – unless broad coverage • Reflexivity – event may proceed differently because it is being observed
Participant observation	• (Same as those for direct observation) • Insightful into interpersonal behaviour and motives	• (Same as for direct observation) • Bias due to participant observer's manipulation of events
Physical artefacts	• Insightful into cultural features • Insightful into technical operations	• Selectivity • Availability

Acknowledging the value of using different sources of evidence due to their inherent strengths and weaknesses and the limitations imposed by the available resources and access to the four cases, this study adopted the following sources of evidence: documentation, archival records, interviews and direct observation. The latter source of evidence was not planned initially and was incorporated as it emerged during the field work of some cases. Triangulation among these and other data sources

enables assessing the convergence of the data sources and increases the validity of the data analysis in the next step (Bryman & Bell, 2011, pp. 402-405).

The data collected is longitudinal, common in explanatory process research (Van De Ven, 1992), since it is mainly drawn from long periods of time where the unit of analysis evolves from the start to the end of the RDI partnership execution and ultimately to dissolution. Moreover, given the focus of the research question, the data is collected mainly from the organisational and inter-organisational levels in line with the literature (Olk, 1998; Sakakibara & Branstetter, 2003; Sakakibara & Dodgson, 2003).

Furthermore, the execution of the RDI partnerships within the selected cases spanned from one to two years. However, additional data generated before or after the RDI partnerships including previous or succeeding partnerships, products and licenses as well as general organisational information and industry data was also collected whenever it was deemed necessary. Doing so is of great value because the selected RDI partnerships rely on Mode 2 knowledge production and, thus, the partners have a great potential to extend and derive new inter-organizational relations after the end date of the RDI partnership (Coughlan, Coghlan, Rigg, & O'Leary). As a result, the collected data covers periods of up to eight years. Moreover, most of the data was gathered during an extensive length of time, between February 2014 and September 2015, and across different regions due to the different locations and availability of the interviewees. Overall the data was mainly of a qualitative nature, however, when of benefit parts of it can also be turned into quantitative data by counting.

All of the cases are very rich in data from documentation and archival records sources because the RDI partnerships were supported through public funding and, thus, extensively documented for auditing purposes. This data came from a large number of either public and private files including webpages, mails, announcements, minutes of meetings, admin documents, RDI partnerships governing structures, progress reports, budgets and contracts. The gathering of documentation and archival records resulted in a total page count of between 100 – 250 pages for each case. The

collected data included sensitive and confidential information which, whenever referenced in this study, is anonymised so the persons and organisations involved are not identified. Table 14 shows an overview of the documentation and archival records collected across the case studies

Table 13 Overview of the documentation and archival records collected across the case studies.

	Documentation and archival records				
	NanoGlide case study	NPMaterial case study	Piezopower case study	Connect case study	Context of the case studies
Public documents	Web, news, reports…	Web, news, reports…	Web, news, reports…	Web, news, reports…	Web, news, reports…
Private documents	>200 pages	>150 pages	>150 pages	>100 pages	>150 pages
Meetings	2 recorded	1 recorded	0	0	NanoAble agency board minutes

In determining the type of interview data collection technique, the structured, semi-structured and unstructured or in-depth interviews were considered (Bryman & Bell, 2011). As indicated in Table 14, each of these interview types is implemented depending on the nature and objectives of the research.

Table 14 Use of interview types according to the nature of the research (Adapted from Saunders et al., 2012)

	Exploratory	**Descriptive**	**Explanatory**	**Evaluative**
Structured		✓✓	✓	✓
Semi-structured	✓		✓✓	✓✓
Unstructured	✓✓			✓

✓✓ = more frequent, ✓ = less frequent

Given that the most common type of interviews used in explanatory research are semi-structured and the large accumulation of documentation and archival records, a semi-structured interview type is adopted in this study to ensure being able to gain insights and explain doubts that can originate from the extensive written evidence collected for each case study.

The undertaken semi-structured interviews were prepared in advance to ensure acquiring background knowledge of the cases and interviewees' organisation as well as to cover the key research themes and concepts. These included the identified RDI partnership characteristics (conditions, processes and outcomes) unfolding throughout the RDI partnership stages. These themes and concepts were selected by building on the literature review carried during the step 1 of the methodological approach and considering the research question of this study (Saunders et al., 2012, pp. 401,402). Subsequently, all the interview questions were framed around 12 themes (see Table 15) underlying the events and contexts behind RDI partnership development, including formation and prior experience in RDI partnerships, as well as the research model of this study which was introduced in Figure 5. The events and contexts of the case studies were identified in the extensive documentation accessed prior to the interviews. Focusing on the events and contexts during the interviews reduces the biases of interviewees when discussing the case studies retrospectively (Faems et al., 2007; Steinmo & Rasmussen, 2016). Given the focus of this study, the interview questions and focus of the interviews was centered around the execution stage.

Table 15 Themes covered by the interview questions

1. Motivation to form an RDI partnership	7. Conditions during the development
2. Barriers to form an RDI partnership	8. Development processes
3. Formation processes	9. Changes during the development
4. Conditions during the formation	10. Major events during the development
5. Major events during the formation	11. Achieved outcomes
6. Changes during the formation of a RDI partnership	12. Unfulfilled outcomes

Interview questions were typically framed in an open-ended style but sometimes included close-ended and probing style questions to confirm interpretations from previously collected data through documents, archival records or other interviews. Table 16 shows a sample of interview questions

which illustrates how the mentioned styles were used to inquire about different stages of RDI partnership development, including formation, around the underlying themes shown in Table 15 and previously collected data.

Table 16 Sample of interview questions

1. What motivated the formation of this RDI partnership?
    a. Was there any prior history of collaboration with the involved partners?
        i. Did this RDI partnership follow the NANO-POLYMERS RDI partnership?
2. What barriers were encountered to form the RDI partnership?
3. How was the RDI partnership formed?
    a. What were the conditions that influenced the formation?
    b. What were the major events during the formation?
4. Was there any key event that changed the formation of the RDI partnership
5. How did the RDI partnership develop?
    a. What were the conditions that influenced the development?
    b. Were there any major events that impacted the development?
        i. For example… the change of worker at your organisation in June?
    c. Did any of the potential risks identified at the formation of the RDI partnership emerge during the development?
    d. Why did the project go from the planned 6 months to 11 months?
    e. Did the monthly face to face or by telecom meetings to review progress take place? How did they go?
    f. How would you describe the development of the partnership from the perspective of your organisation?

Whenever it was deemed helpful, the questions were supported with graphics and tables to refresh the interviewees' memories and increase the vividness of the discussions. Some typical tables that were used in all the interviews were the work plans and potential risks presented in the cases

agreements and RDI partnerships' management documentation. In this way, for example Table 17 was shown when question 5.c was raised.

Table 17 Potential risks and mitigations of a case study

Rank	Risk Description	Mitigation
1	Poor improvement in surface friction	Team has chosen multiple approaches using different chemistries and blends
2	Mechanical stiffness increase in polymer behaviour with desired surface friction level	Combination and use of use of multiple polymers to be able to "pre-tune" target properties
3	Dispersion of additives	Can apply functionalization chemistry to achieve better dispersion
4	Commercialization timeframe if feasibility is successful	Shortlisted commercially ready and other niche laboratory materials for evaluation

The interviewee selection was guided by the extensive archival records collected for each of the selected RDI partnerships. These archival records identified key representatives from different business areas within the partnering organisations, typically management and engineering areas. Consequently, each RDI partnership selected as a case study includes interviews from the management and engineering areas and from two organisations to address the feature of inter-organisational settings (Coghlan & Coughlan, 2015) and account for different perspectives (Lumineau & Oliveira, 2018; Martínez-Noya & Narula, 2018; Steinmo & Rasmussen, 2016). In addition, the Managing Director from the NanoAble agency was also interviewed because he supported and monitored the selected RDI partnerships. Furthermore, an additional interview was conducted with the Chair of the NanoAble agency board because the selected case studies unfold within the NanoAble constraints and conditions. This interviewee selection approach strengthens the findings, theory building and construct validity by drawing from multiple views and levels of the same phenomena across different organisation involved in the selected RDI partnerships as case studies (Davis & Eisenhardt, 2011; Smith, 2012; Yin, 2009, p. 41).

As shown in Table 18, overall a total of 17 interviews with participants from 11 different organisations were conducted. The role of interviewees included CEOs, Country leads, Directors of R&D, Senior R&D engineers, engineers, and Principal Investigators from either large multinationals, SMEs, research centres and universities.

Table 18 Role of the interview participants in relation to the different case studies.

	Number of interviews				
	NanoGlide case study	NPMaterial case study	Piezopower case study	Connect case study	Context of the case studies
Role of interviewees					
1. Management	2	2	2	3	1
2. Engineering	2	1	2	1	1
Total	4	3	4	4	2

In scheduling the interviews shown in Table 18 and before starting the interviews, the researcher always communicated over the phone or in person the purpose of this study, the voluntary nature of participating in the interview and other details and other details contained in the ethical statement of this research (see Appendix C). All the interviews were recorded except in one case when it was not permitted. Recorded interviews were transcribed verbatim to facilitate coding and analysis as well as following up with the interviewees on specific comments that required further clarifications. For the interview which was not recorded, detailed notes were taken during the interview.

In some occasions, the researcher of this study was also able to observe directly the working environment and events of the organisations involved in the RDI partnerships. These events consisted of progress updates and appraisal meetings of the RDI partnerships as well as presentations at public and private conferences. In most cases, the data collected from direct observation was done through note taking and audio recordings. However, audio recordings were not always possible or did not cover the full duration of the observation because they involved

informal and unexpected discussions or took place over extensive lengths of time, over four hours. Table 19 shows all the direct observations undertaken in this study.

Table 19 Direct observations and types across the different case studies

	Number of direct observations				
Types of direct observations	NanoGlide case study	NPMaterial case study	Piezopower case study	Connect case study	Context of the case studies
Meetings	1	0	0	1	2
Conference presentations	1	0	2	0	3
Working environment	2	3	2	2	1
Total	4	3	4	3	7

4.3.4 Step 4: Identify and detail events from the data collected through case narratives.

In parallel with step 3, a detailed narrative of the cases is developed as the data is collected. The narrative is focused on describing the context conditions, events and outcomes. In this way, critical realists aim to organise the collected data and explicate the events as they unfold over time (Bygstad & Munkvold, 2011; Williams & Karahanna, 2013; Wynn & Williams, 2012, 2020). These sequences of events and initial causal explanations not only support the interviews in the previous step of the research framework but also provide the basis to identify the structural components and tendencies among the identified events in each case. As a result, in step 4 each case is developed in a narrative form following a chronological order of events and temporal bracketing according to the RDI partnership stages identified in the literature review (Langley, 1999). Moreover, the narrative of each case is re-written as more data is collected to develop accurate descriptions and provide the basis to identify tendencies and structural components in the subsequent analysis of the data carried in the next step. In critical realism these tendencies are understood as patterns of events and are also referred to as demi-regularities.

In doing so within the area of RDI partnerships and inter-organisational relations in general, there are key contextual implications where this critical realism case study-based approach can

complement previous research. The emphasis on individual experiences and agency of critical realism (Lennox & Jurdi-Hage, 2017; Mingers, Mutch, & Willcocks, 2013) suits RDI partnerships and inter-organisational relations in general. As inter-organisational relations unfold, inter-related events not only take place at different levels but also across different organisations. As a result, critical realism case study-based approaches are a powerful method to unveil multi-level "causal stories" which are inter-related in a linear or parallel sequence among groups of organisations within an inter-organisational relation. Because of this, Delanda (2006) approach to build explanations through the interplay of the micro-macro and macro-micro mechanisms[9] can be of particular relevance.

Doing so, can be of great value because research in the area of inter-organisational relations typically takes the view of only one organisation (Ariño, 2003; Lumineau & Oliveira, 2018) although they can involve a large number of concurring "causal stories" and it has been shown that inter-organisational relations tend to involve more than two organisations and are dynamic, open systems (Duysters & Kok, 1999; Eisner et al., 2009; Vonortas & Okamura, 2009; S. Xu et al., 2014).

4.3.5 Step 5: Directed content analysis and pattern coding to identify the key components and demi-regularities of the cases.

In this step, this study leverages the detailed narratives developed and implements a directed content analysis technique based on flexible deductive and pattern coding to unveil the structural components and demi-regularities of the case studies (Volkoff & Strong, 2013; Wynn & Williams, 2020).

Since there is no a clear consensus regarding the appropriate approach and coding technique to identify the structural components and demi-regularities, in what follows the available options and

[9] The types of mechanisms defined by Delanda (2006) are as follows.

- Micro-macro mechanisms which explain how the interplay of different components generate an outcome at a higher level.
- Macro-micro mechanisms which explain how the higher level facilitates and limit the different components.

undertaken decisions to take the selected approach and coding technique are explained and justified to increase research transparency following the calls by Wynn and Williams (2020).

The extent and complex data collected is codified in codes to handle and organise the data. According to Saldana (2009, p. 3) *"A code in qualitative inquiry is most often a word or short phrase that symbolically assigns a summative, salient, essence capturing, and/or evocative attribute for a portion of language-based or visual data"*. These codes can be broadly categorized into either deductive codes, those that are identified before the data analysis, or inductive codes, those that arise throughout the data analysis. In the literature, the most typical technique is grounded theory which is based on inductive codes (Hoddy, 2019). However, using grounded theory has been criticised in the literature. First, *"CR aims to find the best explanation of reality through engagement with existing (fallible) theories about that reality"* (Fletcher, 2017, p. 186). Secondly, grounded theory is primarily inductive whereas critical realism is based on abduction and retroduction as highlighted in Section 4.1.2. Finally, because grounded theory is inductive it is driven by the available data and reflects an empiricist approach rather than a critical realist (Fletcher, 2017).

Given that the state of prior theory and research in this field is somewhere in between nascent and mature theory and the highlighted mismatch between inductive techniques and critical realism, the selected coding approach is directed content analysis which is mainly based on deductive codes and incorporates, as needed, inductive codes as they emerge from the data (Fletcher, 2017; Hsieh & Shannon, 2005). The deductive coding is based on the literature review results of this study where conditions, processes, outcomes and dynamics of RDI partnerships were identified. This coding contributes to avoid data asphyxiation derived from the richness and multiplicity of data sources and forms (Pettigrew, 1990). This coding is complemented with simultaneous coding to identify the different levels at which the characteristics of RDI partnership are presented in the data. The resulting code list of the directed content analysis complemented with simultaneous coding is presented in Appendix D.

Following Miles, Huberman, and Saldana (2014) and Saldana (2009), after the directed content analysis this study adopts a second cycle coding with the aim of identifying demi-regularities in the data. For this, the individual codes created in the first cycle are, as much as possible, arranged into pattern codes during the second cycle. To ease the identification of the pattern codes, the most frequently occurring codes from the first cycle are used as a starting point. To implement the two cycle coding approach coded presented in this Section and manage the large amount of data collected, this study uses NVivo Computer Assisted Qualitative Data Analysis Software (CAQDAS).

4.3.6 Step 6: Theoretical re-description (abduction)

In line with the critical realism principles of Wynn and Williams (2012) and the clear distinction between abduction and retroduction by Danermark et al. (2002), this step of the research framework is based on the abductive process of inference described in Section 4.1.2. Through abduction, also known as theoretical re-description, what is known of an individual phenomenon is interpreted through the introduction of new ideas which redescribe or recontextualise it. Hence, abduction is based on the creativity and relational ability of the researcher *"to think about something in a different context, an ability to 'see something as something else'"* (Danermark et al., 2002, p. 94). It is a process of abstraction where existing or new theories and concepts (Eco, 1984) are leveraged to analyse, from a different frame of reference, the key components and demi-regularities identified in the previous step of the research framework (Wynn & Williams, 2012).

In this way, theoretical re-description allows to go beyond the individual analysis of the RDI partnerships and inter-organisational relations structural components and apprehend the new phenomena that, according to critical realism, stems from the structural synergies of these components (Easton, 2010; Sayer, 2000; Wynn & Williams, 2012, 2020). This emergence of properties characterizes the critical realism view of the world (Sayer, 2000, pp. 13-14). As a result, each case was theoretically re-described and the theoretically re-description of each case was validated against the others to enhance theoretical validity similarly to the with-in and cross-

case validity checks undertaken in positivistic studies (Yin, 2009, pp. 42-43). Moreover, this step is conducted in parallel with the previous step of the research framework since both steps contribute to the identification and explication of structure, components and context in the selected case studies.

4.3.7 Step 7: Identify the key originating conditions and outcomes of the demi-regularities and retroduce the causal mechanisms

Retroduction infers causal mechanisms from the collected data by building on prior knowledge and theories, new ideas and the undertaken theoretical re-description (Danermark et al., 2002; Wynn & Williams, 2012). In doing so, retroduction hypothesises different causal mechanisms from the empirical observations and establishes the links between the conditions which activate these causal mechanisms as well as the outcomes derived from the causal mechanisms. Through retroduction the researcher advances from the empirical domain of events and individual experiences to the real domain of structures and mechanisms by conceptualising the transfactual conditions[10] of the phenomena under study.

Hence, this step of the research framework starts with the identification of the activating conditions of the demi-regularities in the data and follows by hypothesising causal mechanisms and their outcomes to explain how the characteristics of the nanotechnology RDI partnership cases mediate their development. For this, the study starts the retroductive analysis at the RDI partnership level of one case and ends when the identified conditions, mechanisms and outcomes accounts for the observations in the data collected[11]. To visualize how the identified conditions, mechanisms and outcomes reconstruct the observations in the data collected, the study develops "construct tables" similarly to those in inductive case research (Eisenhardt & Graebner, 2007). In this way, this study *"Demonstrate[s] full causal logic"*, *"Identify[es] activating conditions"* and *"Demonstrate[s] transparency"* in line with Wynn and Williams (2020, p. 61) recommendations.

[10] "Transfactual conditions are conditions for something (a social structure) to be what it is and not something different" (Danermark et al., 2002, p. 78)
[11] This process is implemented in Section 6.3.

4.3.8 Step 8: Validate the causal mechanisms across the cases and data collection sources.

Following Wynn and Williams (2012, 2020), this step validates the hypothesized conditions, mechanisms and outcomes in one case by corroborating them across different cases and data collection sources. In doing so, *"the temporal unfolding of events and longitudinal data"* (Wynn & Williams, 2012, p. 802) from primary and secondary sources is examined to validate that the hypothesized mechanisms, contextual conditions and outcomes in one case study are empirically corroborated across the other three cases[12]. If they are not corroborated, new sets of conditions, mechanisms and outcomes are hypothesized by repeating the previous step and, then, validated in this step until the best possible causal explanation for the observations in all the cases is found. Finally, in this step the validated conditions, mechanisms and outcomes across the four cases are visualized through the highlighted "construct tables" which reconstruct the observations in the data collected. This validation process refines the hypothesized conditions, mechanisms and outcomes in the previous step by enhancing generalisability in a similar process as with-in and cross-case validity checks are carried in positivistic studies (Yin, 2009, pp. 42-43). However, in critical realism case study research, generalisation is understood as *"generalisation to theory via case research carried out under critical realist conventions occurs by virtue of clarifying the theoretical nature of the entities involved, the ways in which they act and the nature and variety of mechanisms through which they exert their powers or acted upon by other entities"* (Easton, 2010, p. 127).

4.4 Conclusions

This chapter outlines the available philosophical, methodological and research methods options and justifies in detail the developed approach in an emerging research setting. In doing so, in Section 4.1 it starts by taking a critical realist stance given the researcher's beliefs and the research aim in

[12] If they had been available, the validation would have also been based on other analytical methods and investigators as it has been done in other studies (Zachariadis, Scott, & Barrett, 2013).

this study and describing the modes of inferences in critical realism. Then in Section 4.2, the chapter follows with the selection of the methodological approach. From the analysis of the state of prior theory, research questions and expected contributions (Edmondson & McManus, 2007), it is concluded that the methodological approach will have an explanatory nature and be based on the case study research method to develop process theory from longitudinal qualitative and quantitative data.

Given that that *"the application of critical realism to case studies remains "underdeveloped"* (Welch et al., 2011, p. 749) and it *"still in its empirical infancy"* (Wynn & Williams, 2020, p. 65), Section 4.3 develops a structured and detailed step by step framework to conduct the selected critical realist case study research method. This framework integrates and extends previous guidance in a coherent and detailed step by step basis by drawing from the bodies of literature on research design (Miles et al., 2014; Singleton & Straits, 2005; Yin, 2009), critical realism (Bhaskar, 2016; Danermark et al., 2002; Eco, 1984) and case study research (Bygstad & Munkvold, 2011; Easton, 2010; Fletcher, 2017; Pan & Tan, 2011; Wynn & Williams, 2012, 2020). Finally, in Section 5.1 the emerging research setting of nanotechnology is described along its novelty, an emerging, multidisciplinary context of rapid technological change focused on mode 2 knowledge development supported by regional policies. In what follows, Chapters 5 and 6 implement the research framework developed in this chapter and discuss the results.

5 Case narratives

Chapter 5, identifies and details the events within the data collected from four sources of evidence – documentation, archival records, interviews and direct observation – and develops the case narratives of four case studies focused on RDI partnership development during their execution. The structure of each case study narrative starts with an introduction to the partners and environment of the case and then follows the empirical evidence chronologically. In doing so, not only the execution of the RDI partnership development is presented, but also relevant contextual details of the partners involved, previous inter-organisational relations, the formation and the outcomes derived from the RDI partnerships even if they took place beyond the execution.

Given the novel and emerging context in which the selected case studies unfold, the Chapter starts with Section 5.1 which provides an overview of the key contextual characteristics of nanotechnology, nanotechnology RDI partnerships and the nanotechnology RDI program where the case studies unfold. Then, the following two sections present the narrative of the polar case studies that unfold in the semiconductor industry, a successful RDI partnership in Section 5.2 and unsuccessful RDI partnership in Section 5.3. Finally, the subsequent two sections present the narrative of the polar case studies that unfold in the in the nanomaterials industry, a successful RDI partnership in Section 5.4 and unsuccessful RDI partnership in Section 5.5.

5.1 Research setting – context of the case studies

While the importance and influence of context in different areas of science such as anthropology, philosophy, behavioural sciences and neuroscience has been thoroughly analysed (Baker & Welter, 2018; Welter, 2020), management studies have only focused on it during the last 30 years or so (Cappelli & Sherer, 1991). Context-oriented research is driven by different reasons such as the internationalisation of the management domain and community (Rousseau & Fried, 2001) and to advance theorising (Welch et al., 2011). However studies which take into account context are still scarce and its adoption is slow and relatively new in many management fields of study such as

information systems (Avgerou, 2019), entrepreneurship (Baker & Welter, 2018) and international business (Welch et al., 2011).

In this study, context is defined as *"the surroundings associated with phenomena which help to illuminate that phenomena"* (Cappelli & Sherer, 1991, p. 56) and has been accounted throughout the research process, from the question formulation which highlights the importance of nanotechnology to the case study reporting and contributions. The key contextual considerations of the phenomena under study are related to the emergence of nanotechnology, the nuances of partnerships focused on nanotechnology RDI, and the nanotechnology RDI program where the selected case studies unfold.

In fact, the motivation to study RDI partnerships in this emerging research setting arises from the novelty contextual considerations which prompt organisations to collaborate through RDI partnerships as a means to develop sustainable competitive advantage. This also allows to advance research in adjacent bodies of literature because studies which have dealt with how teams from within and across disciplines collaborate (see e.g. Battard, 2012; Bellotti, Kronegger, & Guadalupi, 2016; Porac et al., 2004; Zuo & Zhao, 2018) are typically based on collaborations which juxtapose different disciplines and focus on mode 1 knowledge development (Gibbons et al., 1994)[13]. Hence, there is limited understanding on how multidisciplinary collaborations focused on mode 2 knowledge development use and integrate different efforts and results from different disciplines (Battard, 2012; Pennington, 2015). Nanotechnology thus represents an interesting research setting since it is considered to have a multidisciplinary nature where several disciplines are currently converging to address specific problems (Islam & Miyazaki, 2009; Dovev; Lavie & Drori, 2012). In what follows, the highlighted key contextual considerations of the cases are described and summarised.

[13] Gibbons et al. (1994, p. 3) describes *that knowledge development "in mode 1 problems are set and solved in a context governed by the, largely academic, interests of a specific community. By contrast, mode 2 knowledge is carried out in a context of application. Mode 1 is disciplinary while mode 2 is transdisciplinary. Mode 1 is characterized by homogeneity, mode 2 by heterogeneity".*

5.1.1 Nanotechnology

One of the areas which has recently caught the attention of diverse stakeholders such as social scientists and garnered large industrial and governmental RDI investments is nanotechnology (Funk, 2014; OECD, 2009; A. L. Porter & Youtie, 2009; Shapira et al., 2010; Youtie et al., 2008). Although there is still no commonly accepted definition, nanotechnology is considered to start back in 1959 when Richard Feynman proposed the concept. Later on, Norio Taniguchi in 1974 coined the term nanotechnology. Typically, nanotechnology is used as an umbrella term to describe a wide range of technologies leveraging the manipulation of materials at the scale of atoms and molecules or the nanometre scale. To put this in perspective, you can consider that a human hair is about 60,000 nanometres in diameter, a nanometre is one billionth of a meter and most atoms are 0.1 to 0.2 nanometres. Figure 17 shows an image of a looped wire with the diameter of the order of a nanometre superimposed on a human hair.

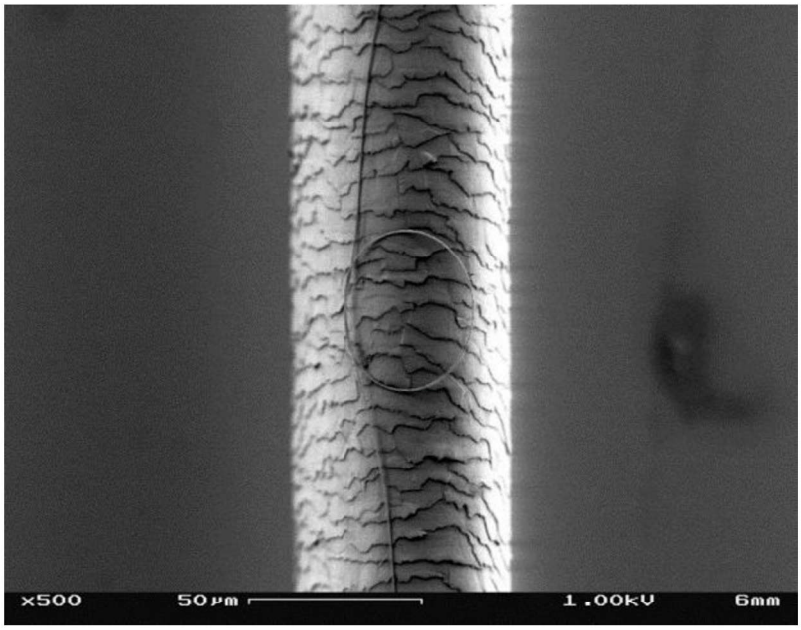


Figure 17 Image of a looped wire with a diameter of the order of a nanometer superimposed on a human hair (Tong, 2008)

In this study, the adopted definition of nanotechnology is based on Forfas (2010) as follows:

> *"The purposeful engineering of matter at scales of around or less than 100 nanometres (nms) to achieve size-dependent properties and functions."* (p. 19)

Hence, the differentiation and value of nanotechnology mainly resides in the property changes and functions which arise from the modification, handling and processing of materials at the nanoscale. At the nanoscale materials behave differently because surface forces dominate over bulk properties. Consequently, changes in the properties and functions of materials arise from different factors such as their increased ratio between surface area and volume which makes smaller particles more chemically reactive than larger particles.

For example, conventional optical components are based on refraction, reflection or diffraction of light with the use of optics that are rotationally symmetric and typically have spherical forms such as the lenses used in glasses or conventional microscopes. However, the ability to nanostructure materials is now enabling to develop ultrathin and flat optics capable of altering light even beyond what is possible with conventional optics. This opens up new possibilities in the field of optics such as the creation of perfect lenses which always provide sharp images, optic for augmented reality, the development of cloaking devices and reduce the dimensions and weight of camera lenses (Pendry, 2000; Schurig et al., 2006).

Nanotechnology can be traced back to the second half of the 20th century, the full potential of nanotechnology is still not well known, and the societal and economic impact is still being explored. Given the foreseen innovations and large impact of nanotechnology across virtually all industry sectors, it is often also considered as a General Purpose Technology comparable to electricity and ICT (Youtie et al., 2008) and has been identified as a Key Enabling Technology of strategic importance to Europe by the European Commission. According to AlliedMarketResearch (2018), the global nanotechnology market was valued at $1 trillion in 2018 and is forecasted to reach over $2 trillion by 2025. Some examples of existing commercial applications for nanotechnology are antimicrobial wound dressings with silver nanoparticles, gold nanoparticles for targeted drug-delivery to tumours, nanostructured coatings for self-cleaning windows and stain

resistant fabrics, water filtration with nanometre pore membranes for water purification filters and the use of single atom thick materials like graphene in tennis rackets and electronics.

Because of this, nanotechnology has attracted the attention of numerous governments and regions leading to the establishment of the over one billion euro National Nanoscience & Nanotechnology Program running from 2003 to 2014 in Taiwan, the development of the international campus on micro and nanotechnology research in France, MINATEC, with an operating budget of €300 million in 2018, and the US National Nanotechnology Initiative which is expected to incur around $30 billion up to 2021[14]. Furthermore, industry is also very active in this field and between 1990 and 2008 their rate of publications and patenting has been faster than that of academia and research institutes (Youtie & Kay, 2014).

5.1.2 Partnerships focused on nanotechnology RDI

During the last years the development of nanotechnology is transitioning from academic and discipline-based contexts triggered in the second half of the 20th century to application driven and multidisciplinary contexts (Gibbons et al., 1994; LuxResearch, 2014). This has been reflected for example in the nanotechnology research articles between 1991 and 2008 which were found to be gradually drawing from more and more sources of knowledge and disciplines such as physics, chemistry, material science, engineering and medicine (A. L. Porter & Youtie, 2009). This transition and the resulting need to draw knowledge from different sources has resulted in a growing number of nanotechnology inter-organizational relationships focused on RDI activities which put together expertise from different disciplines (Islam & Miyazaki, 2009).

Furthermore, the development of nanotechnology is partly facilitated by highly specialized equipment for the observation and manipulation of materials such as the scanning tunnelling microscope which allows to image surfaces at the nanometric scale. As the equipment required demands research institutes, companies and governments to carry very large investments,

[14] A breakdown of US National Nanotechnology Initiative budget per year may be found at the following US government webpage: https://www.nano.gov/nanodashboard

nanotechnology knowledge tends to be scattered across clusters and countries which have developed the required infrastructure (Forfas, 2010). For example, leading worldwide nanotechnology research institutes and companies are typically spending in excess of a €100M annually in upgrading their facilities and equipment to deposit, remove and analyse materials at the nanoscale. Given the numerous applications and capital intensity of nanotechnology, countries and clusters are typically specialised in different sub-areas and application fields (OECD, 2009). Subsequently, inter-organizational relations on nanotechnology RDI can be triggered due to the need to access specific resources such as equipment or specialised knowledge beyond the boundaries of organisations and regions.

Organisations are thereby inclined to establishing interorganizational relations such as RDI partnerships. Whether it is the multidisciplinary nature of nanotechnology, the highly specialised resources or both, nanotechnology developments tend to require the involvement of different organisations such as universities, companies and government partners (Funk, 2014; OECD, 2009). Because of this, many national and regional policy initiatives such as NanoNextNL in the Netherlands, the Framework Programmes in Europe and the National Nanotechnology Initiative in United States facilitate and fund partnerships focused on nanotechnology RDI (Islam & Miyazaki, 2009).

5.1.3 The nanotechnology RDI program where the cases unfold

Against the backdrop of the potential economic impact and collaboration needs of nanotechnology, a national nanotechnology RDI program, NanoAble[15], supported by the regional government was launched in 2010. This nanotechnology RDI program constitutes the main data source for this research study since the case studies are selected from it using the methodology discussed in Chapter 4. The objective of NanoAble is to increase the competitiveness of companies based in the country through the development of nano-enabled products and the transfer of nano-expertise

[15] Names, addresses and all other identifying information has been modified or removed to ensure confidentiality.

among stakeholders. The operations of NanoAble are funded by the government and the companies involved.

Companies that joined the program benefit from a range of support actions offered by NanoAble to develop and commercialise nano-enabled products. Among these support actions, NanoAble provides grants to cover part of the costs of industry-led nanotechnology RDI partnerships. These partnerships are selected among the nanotechnology RDI partnership proposals submitted to a yearly competitive call of proposals issued by NanoAble in their webpage. To be eligible to apply to these calls, all the nanotechnology RDI partnership proposals must comply with the following requirements:

- The applicants must have sufficient resources to undertake potential follow-up commercialisation activities.
- The applicants must cover part of the partnership costs through direct cash, in kind contributions or both.
- The applicants involved must have a track record of commercial success within the industry related to the partnership.

Once all the proposals are submitted, they are evaluated, typically by three evaluators. These evaluators score the proposals across the following five categories: RDI excellence, work plan, level of collaboration, market need and impact. The RDI excellence category should demonstrate the merit for the identified RDI goals and the underpinning ideas and concepts which will lead to them. In addition, the work plan must describe and justify the plan and management of the activities, expected results and resources involved in the RDI partnership to achieve the identified RDI goals. The level of collaboration category should describe and justify that the expected interactions and relations among the partners, preferably more than two, are appropriate and that the partners are committed to the proposed RDI partnership. Furthermore, the market need category should demonstrate a clear need for the identified RDI goals. Finally, the impact category should

clearly describe the identified lead application(s) and IP management to commercialise the expected results.

These categories are scored from zero to five in relation to how the evaluators perceive the proposal addresses the criteria in each category. The score of zero means that the proposal does not address the category or lacks information. The score of one indicates that the category is poorly addressed. The score of two denotes that the proposal addresses too generally the category and exhibits significant weaknesses. The score of three indicates that the category is well addressed but includes a number of weaknesses. The score of four denotes that the category is addressed very well and there are only a small number of minor weaknesses. Finally, a score of five is used to show that the category is successfully addressed and, if any, there are only very minor weaknesses in the proposal.

Taking into account the evaluations of all the submitted proposals, the NanoAble Board ranks and selects the best proposals to receive a grant. Figure 18 illustrates the highlighted selection process that the proposals submitted to NanoAble undergo. This process was designed by NanoAble to ensure that all the proposals are evaluated objectively and according to their individual merit.

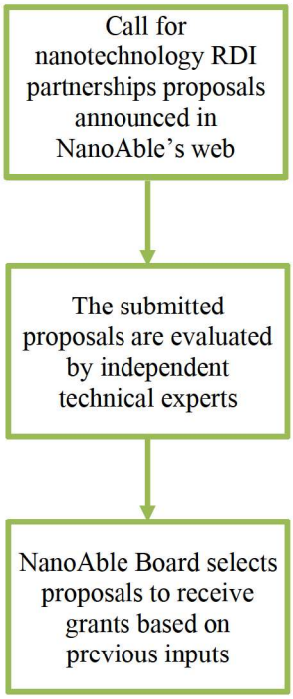


Figure 18 NanoAble selection process to allocate grants to nanotechnology RDI partnerships

In addition, all partners included in a proposal selected to receive a grant from NanoAble have to sign a pre-defined NDA and IP agreement provided by NanoAble as well as comply with the monitoring process. This process includes holding bi-annual calls, providing documentation on the work undertaken, requesting approval for deviations from the submitted scope of work in the proposal, and providing details on the costs incurred during the nanotechnology RDI partnerships.

As the case studies in this research are taken from the NanoAble nanotechnology RDI program, it is important to highlight that the discussed selection and monitoring process established in NanoAble mediates, to some extent, their development.

5.1.4 Novelty of the research setting

As highlighted, the novelty of the research setting under which the selected RDI partnerships unfold brings key contextual characteristics which can be summarised as follows. First, nanotechnology has a disruptive nature since it has the potential to transform industries by creating new competencies while obsolescing others (Flynn, Hwang, & Holman, 2014; Dovev; Lavie & Drori, 2012; LuxResearch, 2014; NSF, 2014; OECD, 2009). Given the path-dependent nature of

high-tech sectors and their unpredictability (Colombelli, Krafft, & Quatraro, 2014), it is an interesting context for the analysis of RDI partnership development and how unexpected events and changing conditions can modify inter-organisational relations and the outcomes of these relations. Second, the emergence and high growth of nanotechnology-focused collaborations together with its novelty and multidisciplinary nature (Battard, 2012; OECD, 2009; A. L. Porter & Youtie, 2009; Shapira et al., 2010), fosters collaboration in RDI partnerships by minimising the effects of collaborative barriers such as lack of trust and IP appropriability (Daellenbach & Davenport, 2004; Niosi & Bergeron, 1992; Zajac & Olsen, 1993).

The nanotechnology RDI program in which the RDI partnerships under study unfold also prompts for collaborative dynamics by providing different supports such as government grants and established IP frameworks and governance structures. These environmental conditions also contribute to decreasing the impact of transactional barriers to collaboration related to RDI partnerships' governance, risk aversion, and the high costs of undertaking nanotechnology RDI activities (Bidault & Cummings, 1994; Schultz, 2011; Westbrock, 2010; Q. Xu & Renyong, 2009). Furthermore, the interdisciplinary nature of nanotechnology and the convergence of different disciplines towards nanotechnology (Battard, 2012; Islam & Miyazaki, 2009), drives organisations towards establishing and sustaining inter-organisational relations such as RDI partnerships. This again favours the observation and appearance of dynamics in RDI partnership development. Finally, there is limited understanding on how multidisciplinary collaborations focused on mode 2 knowledge development[16] use and integrate different efforts and results from different disciplines (Battard, 2012; Pennington, 2015). Nanotechnology thus represents an interesting research setting since it is considered to have a multidisciplinary nature where several disciplines are currently converging to address specific problems (Islam & Miyazaki, 2009; Dovev; Lavie & Drori, 2012).

[16] Gibbons et al. (1994, p. 3) describes *that knowledge development "in mode 1 problems are set and solved in a context governed by the, largely academic, interests of a specific community. By contrast, mode 2 knowledge is carried out in a context of application. Mode 1 is disciplinary while mode 2 is transdisciplinary. Mode 1 is characterized by homogeneity, mode 2 by heterogeneity"*.

As a result of the highlighted key contextual considerations in nanotechnology, the competitive advantage of organisations can be highly dependent on increasing and combining RDI efforts and outcomes from heterogenous organisations rather than classical elements of business success such as unique resources, minimising costs and industry position (C. S. Lee & Vonortas, 2002). Hence, studying RDI partnership development in this context can unveil novel dynamics among partners which collaborate in an emerging, multidisciplinary context of rapid technological change focused on mode 2 knowledge development supported by regional policies.

5.2 The Piezopower RDI Partnership case study

Many electronic devices are deployed to enhance products and services in the transport, health, construction and energy industries among others. Although these devices are typically powered by an external power source and a battery, a number of novel solutions to generate energy from the environment are being developed for a wide variety of applications. The ability to harvest energy from the environment eliminates the need for batteries in many applications and thus removes the cost of replacing batteries in hard to access locations as well as the environmental impact of producing and disposing batteries. Furthermore, continuous miniaturisation of electronics and lower energy consumption enables powering electronic devices with energy harvesters in remote locations such as implantable medical devices where batteries cannot be replaced.

Energy harvesting solutions include gathering electrical energy from the sun through solar cells, from temperature differences through thermoelectric materials and from mechanical energy through piezoelectric materials. The latter is the focus of the Piezopower RDI partnership presented in this Section.

Energy harvesters based on piezoelectric materials are referred to as mechanical or piezoelectric energy harvesters and transform mechanical energy such as the vibration of an engine and human movement into electric energy. The typical structure of a mechanical energy harvester is designed around a beam covered with a piezoelectric material layer of several hundred nanometres that

vibrates with the mechanical movement in the environment. With this design, mechanical energy harvesters use piezoelectric materials to transform the vibration generated in the beam by the environment into electric energy. Figure 19 illustrates the highlighted mechanical energy harvester design structure based on a vibrating beam and a piezoelectric material layer.

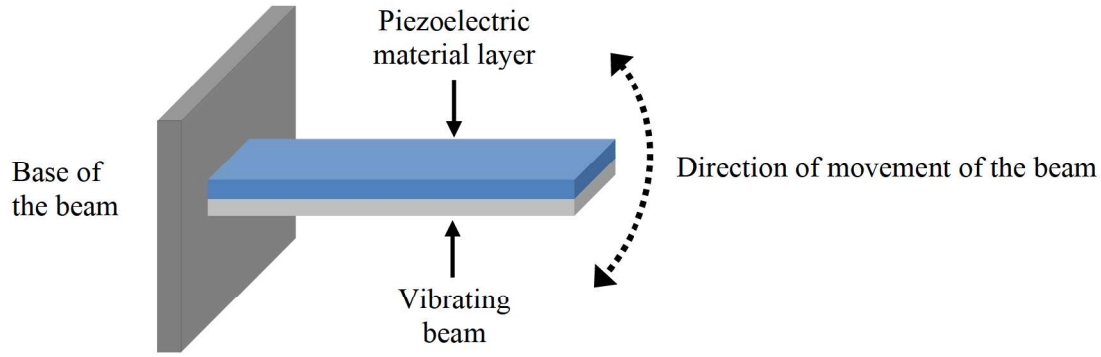


Figure 19 Schematic of a common mechanical energy harvester design structure based on a vibrating beam and a piezoelectric material layer

Mechanical energy harvesters can be designed to generate electric energy at specific vibration frequencies by modifying different parameters of the mechanical energy harvester structure such as the beam length, piezoelectric material thickness and adding a mass at the end of the beam. Consequently, the main goal of the Piezopower RDI partnership was to develop a novel piezoelectric energy harvester by designing an energy harvester vibrating structure and depositing a piezoelectric material layer that maximizes harvesting mechanical energy from the environment.

5.2.1 Introduction to the partners of Piezopower

The Piezopower RDI partnership consisted of the inter-organisational collaboration of three partners, a research institute and two companies. First, the research institute partner Research Institute A (RIA) is an independent multisectoral and multidisciplinary public research organisation carrying RDI activities in areas such as micro-nanoelectronics for the electronics, automotive and health industries among others. RIA employs over one hundred researchers and leverages multi-million research facilities to develop leading research for the benefit of society and industry.

Within RIA, the research group involved in the Piezopower RDI partnership involves researchers in areas such as electronics design, process development and device integration. In carrying out this research, RIA's staff leverages different laboratories with simulation software tools and equipment to fabricate and analyse materials and electronic devices. Throughout the Piezopower RDI partnership development, RIA mainly involved a Principal Investigator, Mia, and two Postdoc researchers, Oliver and Benjamin.

In addition, Piezopower involved the partner Electronics Device Producer (EDP) which is a leader in the design and manufacture of innovative electronic devices used in a wide range of applications for the automotive, industrial, medical and consumer electronics industries among others. The annual revenue of EDP is several hundreds of million euros of which over 10% is invested in research, development and innovation to develop new generations of electronic devices that meet the needs of its customers across the globe.

EDP employs several thousands of workers at various locations one of which is in the same region as RIA. This location includes a large number of highly specialized staff, labs and manufacturing facilities. Hence, the subsidiary of EDP involved in Piezopower did not require to communicate with their headquarters for approvals, guidance or resources during the Piezopower development. During the execution of Piezopower it mainly involved an R&D Director, Olga, and a Senior Research Engineer, Harry, both of whom were from the subsidiary of EDP collocated in the same region as RIA. Furthermore, to increase collaboration between EDP and RIA, Harry spent approximately two days a week in RIA working side by side with Oliver in the same office.

The other partner is Medical Device Manufacturer Co. (MDM) which is a large organization focused on the design and manufacture of medical devices for patients around the world. As a global leader, MDM generates an annual revenue of several thousand million euros and employs several thousand employees at various locations. However, during the evolution of Piezopower, MDM only involved one site that is located in the same region as RIA. This site includes a large number of employees within an R&D Center, Customer Innovation Center and a medical device

manufacturing plant. During the partnership, MDM mainly involved an R&D Program Manager, Laura, and an R&D Engineer, Logan.

5.2.2 Previous inter-organisational relations among the Piezopower partners

The Piezopower RDI partnership originates from the R&D partnership Biointegrate between EDP, RIA and MDM. Biointegrate was focused on the development and validation of a miniaturised wireless sensing device for biomedical applications where a number of components such as sensors, actuators and power supplies had to be integrated. In fact, Piezopower emerged partly from a task of Biointegrate's work plan where they had to integrate a tailored energy source to power the overall miniaturised wireless sensing device.

Prior to Biointegrate, EDP and RIA had a long history of previous inter-organisational relations such as R&D and RDI partnerships and unilateral contractual agreements where EDP subcontracted RIA. However, none of them had been in the focus areas of Biointegrate and Piezopower. Furthermore, it was also relatively common that workers at RIA moved to EDP since some of their areas of expertise in electronics design, process development and manufacturing overlapped. For example, Olga and Mia who defined and coordinated Biointegrate and Piezopower had been working together at RIA for a number of years before Olga was hired by EDP.

In contrast, prior to Biointegrate MDM had never been involved in a partnership with either EDP or RIA. Nonetheless, both EDP and RIA were very interested in collaborating with MDM because it brought key expertise and infrastructure in the area of medical devices which was complementary to the expertise and infrastructure of EDP and RIA in the area of electronics. Because of this, Biointegrate and Piezopower where conceived to support the ongoing technological convergence of electronics and medical devices whereby new features such as pressure, humidity and optical shape sensing are introduced in medical devices such as catheters, implants and bandages which have typically been passive and mechanical devices.

5.2.3 The formation of PiezoPower

Towards the start of 2012 RIA, MDM and EDP started to discuss a potential follow-up partnership under the NanoAble program which would start in August 2012 after the end of Biointegrate. Hence RIA led the proposal writing of a new RDI partnership named Biointegrate_v2. In addition, EDP supported and reviewed the proposal writing and expressed interest in including different areas of focus such as mechanical energy harvesting. In contrast, MDM level of activity was minimal during the proposal preparation in line with its involvement during the Biointegrate development. This was highlighted in a Biointegrate report as follows.

> *"...need to stimulate more interaction with MDM and will be hoping to encourage more face to face visits and meetings as results become available"* (Biointegrate Final Report)

In spite of this, the Biointegrate_v2 RDI partnership proposal was submitted in April 2012 building on the Biointegrate R&D partnership results and focusing on closer to market activities for developing a miniaturised wireless sensing device for biomedical applications. Subsequently, in mid-May the initial evaluations received recommended the Biointegrate_v2 proposal for approval and funding at the NanoAble Board. However, at the end of May MDM informed the partners that they were exiting the Biointegrate_v2 RDI partnership. Harry at EDP and the NanoAble Board documentation, described MDM's withdrawal in the following way:

> *"...they [MDM staff] weren't operating in full view of their corporate headquarters and felt they would be cut off."* (Harry at EDP)

> *"A competing project within MDM is closer to product and has another electronic supplier already in place making it impossible [for MDM] to overlap the two"* (NanoAble Board meeting minutes)

In light of this, in May the NanoAble Board allowed RIA and EDP to modify the submitted proposal and resubmit it by October. Hence, RIA led the proposal writing again and tried to replace MDM with other medical device manufacturers. As this was not possible, EDP decided that RIA

should focus the proposal on a specific area within the Biointegrate_v2 proposal, mechanical energy harvesters. Hence, Mia, Oliver and Benjamin at RIA started to assess different types of mechanical energy harvesters and materials that could be used to collect mechanical energy from the environment. As Oliver was the main proposal writer and he had a key interest in undertaking material and process development, he decided to focus the proposal on a specific piezoelectric material that was compatible with RIA's micro-nanofabrication facilities. In fact, the selection of this specific piezoelectric material was also of key interest to EDP since when Oliver presented an initial draft of the proposal at EDP he left with the following impression:

> *"I think that [the selected piezoelectric material] was what they were more interested since it was compatible [with their semiconductor manufacturing facility and]… they'd tried it in the past [unsuccessfully]."* (Oliver at RIA)

Furthermore, Olga at EDP also highlighted this as follows.

> *"From EDP's point of view, it was the selected piezoelectric material that we were interested in. The development of the selected piezoelectric material, the applications of that. I could see there was going to be interest within EDP in that area."* (Olga at EDP)

Because of this, the new RDI partnership proposal between RIA and EDP was renamed to Piezopower and submitted in early October for evaluation and approval by the NanoAble Board.

The Piezopower RDI partnership proposal was evaluated by three experts and got mixed views on whether it should be approved to receive support from the NanoAble program.

> *"Overall, this is a project that has a good chance of success, if the selected piezoelectric material can give sufficient output to drive the electronics and periodic radio transmission. [The evaluation report recommended support from NanoAble]"* (Evaluation report 1)

> *"Further work required to understand what existing competence will be drawn upon for the selected piezoelectric material. Also deliverables need to have some more details on*

target specifications. [The evaluation report did not recommend support from NanoAble]" (Evaluation report 2)

"[Piezopower] has a clear direction and goal, to provide for a working energy harvesting device/solution. If successful, this project has great IP and commercialization potential. I therefore have no hesitation in recommending proposal for funding. [The evaluation report recommended support from NanoAble] (Evaluation report 3)

Consequently, after the Piezopower team addressed a number of questions that were raised in the evaluation reports, the evaluators and the NanoAble Board agreed to recommended Piezopower to be implemented as planned, from the end of October 2012 to July 2013, and receive support from NanoAble which included a € 110 000 grant.

5.2.4 The execution of Piezopower

Piezopower started in October 2012 to develop a mechanical energy harvester leveraging the properties of the selected piezoelectric material to convert mechanical energy into electric energy. Overall, the execution of Piezopower was designed to sequentially follow the four main activities outlined below in line with the Piezopower RDI partnership proposal.

1. Design, deposit and analyse different variations of the selected piezoelectric material to identify the key parameters that produce nanometer thick layers that maximise the conversion of mechanical energy into electric energy.
2. Design different piezoelectric energy harvesting structures and model their behaviour to predict the energy it can collect and other parameters under different frequencies of vibration.
3. Develop a process to fabricate the most promising piezoelectric energy harvester structures.
4. Fabricate and test different piezoelectric based mechanical energy harvesters.

As the Piezopower RDI partnership started to work on these four activities it faced three key challenges. First, the highlighted activity number one above was delayed because the equipment in the laboratory was often unavailable or not performing as expected. This was very disappointing to Harry and EDP in general since in their industrial environment it would have never happened.

> *"Machines not being available, consumables not being ordered in advance, maintenance activities ordered late and just taking a long time. That was a very frustrating part of the project."* (Harry at EDP)

Second, as RIA and EDP had little or no experience in the fabrication of mechanical energy harvesters or piezoelectric materials they were not able to build on their internal knowledge bases as they usually do. Finally, the withdrawal of MDM also meant that Oliver's motivation was very low because the Piezopower RDI partnership was not matching his background and expectations when joining RIA, carrying research on electronics for biomedical applications.

> *"I told Mia I'll work on it until they find a replacement."* (Oliver at RIA)

As a result of these challenges, Piezopower went soon behind schedule by 3 months and EDP requested RIA to assign a project manager that ensured Piezopower met the work plan, reports and milestones agreed at formation in Piezopower proposal as shown in Table 20. The assignment of a project manager by RIA and the support of Harry at RIA were very helpful and, during the March 2013 NanoAble Board meeting, Olga highlighted that Piezopower continued to be of great interest and had gained significant momentum.

In fact, at that time the deposited layers of selected piezoelectric material had demonstrated reasonable performance. These promising results even motivated and convinced Oliver to stay in Piezopower.

> *"I ended up working 6 months or so in the project. And then I realised this is actually something interesting and I decided to stay on it… We were surprised because first time*

you try to do anything it doesn't work. It didn't work great but it worked. This gave us [RIA] a lot of motivation and EDP too." (Oliver at RIA)

Leveraging on these results, Oliver and Benjamin started to design different energy harvesting structures. This activity was informed by the patent search carried by RIA and EDP to avoid designing structures which infringed other organisations IP and could, therefore, not be commercialised.

In addition, Benjamin modelled the expected behaviour of the designed energy harvesting structures to estimate the amount of electric energy they could harvest when exposed to a vibrating environment. The most promising structures, in terms of maximizing the delivery of energy, were then considered and tweaked by Oliver to develop a process to fabricate these structures in different mechanical energy harvesting device prototypes. Towards the end of May all the prototypes were available for testing and Benjamin decided to terminate his contract with RIA to start working in a private company.

As a result, the remaining modelling activities required to complete the planned report *R3.1 Report on modelling latest mechanical energy harvesting structures in the literature* within Piezopower's work plan, shown in Table 20, could not be accomplished. Hence, the underlying activities of this report were included in a subsequent RDI partnership, Lowpiezopower, that RIA and EDP started to prepare around May 2013 to build on the promising results of Piezopower. Furthermore, EDP had never been too interested in report R3.1 so the full focus of Piezopower was shifted towards testing the fabricated mechanical energy harvesting prototypes.

As some of the fabricated prototypes came out damaged and broken from the micro-nanofabrication laboratory, probably due to handling issues, and other defects, only a total of 14 mechanical energy harvester structures were tested. Both the fabrication and testing ended up requiring more time and resources than planned in the budget agreed at formation in the Piezopower proposal. From one of the researchers at RIA it transpires that the need for additional

time and resources was due to the lack of knowledge among RIA and EDP in the area of piezoelectric-based mechanical energy harvesters.

> *"...right from the beginning from Piezopower we knew okay we are going to work on piezoelectric, we are going to look at developing the materials... Now we didn't think it take as long as it did... This was a new area for us, RIA, and also EDP."* (Oliver at RIA)

Nonetheless the results were of great interest and Oliver was accepted to present them at an international workshop. These additional fabrication, testing and conference travelling activities were enabled thanks to the budget that was freed up by the departure of Benjamin.

However, the extra work and travelling also meant that there was not enough time and resources to develop a packaging structure for the energy harvesting prototypes or the activities and reports, *R3.1* and *R4.1*, under *Work Package 5 Modelling comparisons and market study*. Because of this, the packaging and Work Package 5 activities were included in a subsequent RDI partnership, Lowpiezopower, that was planned by RIA and EDP towards the end of Piezopower. As a summary of the execution of Piezopower, Table 20 shows the highlighted activities along the work plan agreed in the Piezopower proposal at formation and what was their status at the end of the partnership according to the Piezopower Final Report and the interviewees.

Table 20 Piezopower work plan along with the list of Work Packages (WP), Reports (R) and Milestones (M) in order of delivery from the partnership start date

	Description of work packages, reports, and milestones in Piezopower (leader)	Planned timing	Status at the end of Piezopower
WP1	**Review mechanical energy harvesting materials and structure (Mia at RIA)**	Quarter 1 & 2	Achieved in quarter 3
R1.1	Report on the various piezoelectric materials that could be used and the possible architecture (Mia at RIA)	Quarter 1	Delivered in quarter 3
R1.2	Report on the characteristics of the piezoelectric materials deposited at RIA (Mia at RIA)	Quarter 2	Delivered in quarter 3
WP2	**Design energy harvesting device/process flow and FEM model (Mia at RIA)**	**Quarter 1**	**Achieved, timing not reported**
WP3	**Patent Search (Mia at RIA)**	**Quarter 1**	**Achieved, timing not reported**
WP4	**Fabricate, package and test device (Mia at RIA)**	**Quarter 2 & 3**	**80% achieved by quarter 3**
M2.1	Mechanical energy harvesting device prototypes (Mia at RIA)	Quarter 2	Achieved in quarter 3
R2.1	Report on the testing of the first year's prototypes potential applications and future work (Mia at RIA)	Quarter 3	Delivered in quarter 3
WP5	**Modelling comparisons and market study (Mia at RIA)**	Quarter 3	Not started
R3.1	Report on modelling latest mechanical energy harvesting structures in the literature (Mia at RIA)	Quarter 3	Not started
R4.1	Report on the possible market applications that the prototypes could be used for given the frequency and power density (Mia at RIA)	Quarter 3	Not started

5.2.5 The outcomes of Piezopower

Piezopower delivered a large number of technical outcomes which changed the operations of RIA and EDP through the introduction of new teams, RDI activities and process development equipment. Furthermore, it forged a very strong relation among RIA and EDP which crystalized in different types of inter-organisational relationships such as a licence, new partnerships and subcontracting as well as social conditions such as new relations and trust between individuals at RIA and EDP. This close relation and interactions was highlighted by both Harry at EDP and Oliver at RIA.

"I think what was unusual from a RIA point of view was to have someone so close having weekly meetings." (Harry at EDP)

"Harry was always there to ask him a question but we also felt you know that ... the person made a difference. He was very good at... even just helping with other issues. I don't know... I grew up being a friend of Harry. I always talked him about other stuff outside of work" (Oliver at RIA)

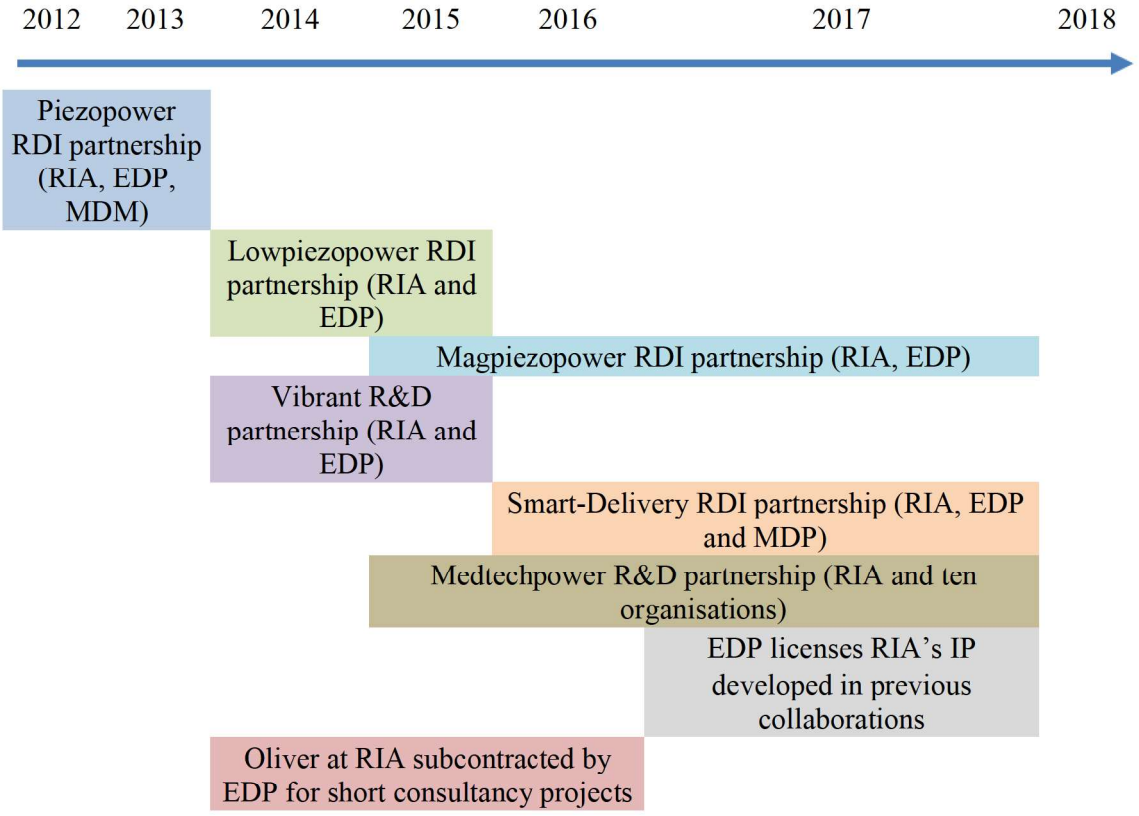
RIA and EDP key RDI outcomes from Piezopower were the developed new knowledge and learnings around the deposition of piezoelectric materials and the overall area of mechanical energy harvesting devices. This allowed RIA to develop three trade secrets in the deposition and testing of the piezoelectric material and license the piezoelectric materials deposition technology to EDP. Building on the new knowledge, learnings and license resulting from Piezopower, RIA established an R&D team focused on piezoelectric materials and both RIA and EDP introduced for the first time the deposition of piezoelectric materials in their fabrication facilities. In doing so, EDP carried a large investment to acquire a new deposition tool and established a new in-house technology to deposit piezoelectric materials and fabricate mechanical energy harvesting devices.

Following on the new knowledge and learnings of Piezopower, RIA and EDP were also able to establish new trade secrets through independent work in their fabrication facilities and the seven subsequent inter-organizational relations shown in Table 21. These subsequent inter-organizational relations included a wide range of types. Building on the Piezopower results, RIA and EDP established two RDI partnerships, Lowpiezopower in 2014 and Magpiezopower in 2015, to further improve the results of Piezopower and apply them in two different energy harvesting applications. In 2015, RIA also established an R&D partnership, Medtechpower, with ten partners to further improve the results of Piezopower and integrate complementary research activities and capabilities which could enable the use of energy harvesters in medical implants.

In addition, RIA and EDP also ventured into applying the deposition process learnings and knowledge for drug delivery applications in the 2014 Vibrant R&D partnership. This partnership

turned out to be very successful and was followed in 2016 with the Smart-Delivery RDI partnership which on top of RIA and EDP included the medical device manufacturer MDP, an expert in drug delivery. Finally, between 2014 and 2016 EDP subcontracted Oliver at RIA for different short-term consultancy projects and in 2017 licensed RIA's piezoelectric deposition technology to accelerate EDP's technology development around piezoelectric deposition and the manufacturing of energy harvesters.

Table 21 The subsequent inter-organisational relations among EDM, MDM and/or RIA derived from the Piezopower RDI partnership



Furthermore, Piezopower allowed RIA to deliver five publications of which two were international conference papers and three conference abstracts. One of the international conference papers focused on describing the deposited piezoelectric materials and testing their quality and the other on frequency response of the piezoelectric materials and different energy harvesting designs. Furthermore, the three conference abstracts dealt with the deposition process and the developed energy harvester.

In September 2013 during a NanoAble Board meeting, the extraordinary quality of the achieved publications and results in Piezopower were highlighted as follows.

> *"EDP is very happy with the quality of the piezoelectric layers being deposited at RIA with results being presented at international energy harvesting conferences and comparing well to published examples."*

As a summary of the outcomes derived from Piezopower, Table 22 presents the highlighted outcomes along with other outcomes types that were not delivered as a result of the Piezopower RDI partnership.

Table 22 Summary of outcomes derived from Piezopower

Outcome types	**Description of Connect outcomes by type**
New knowledge and learnings	New knowledge in the deposition of piezoelectric materials and mechanical energy harvesting devices developed at RIA and EDP which enabled them to reach state of the art results. In addition, RIA and EDP established an understanding of the IP landscape and freedom to operate in the area of mechanical energy harvesting.
IP	Three trade secrets at RIA for piezoelectric material deposition and testing which led to a license and other trade secrets in subsequent inter-organizational relations.
Innovation	RIA and EDP introduced a new deposition process for piezoelectric materials in their fabrication facilities.
New or improved technologies	Developed new fabrication processes for the deposition of piezoelectric materials and mechanical energy harvesting device structures which can be applied for a wide range of products and markets.
Socio-economic	Triggered new investments by EDP in the form of equipment and services.
Subsequent inter-organizational relations	Three RDI partnerships, two R&D partnerships, one license and a subcontracting inter-organizational relation were triggered as a result of Piezopower.
Training	None.
Publications	Five of which two in international conferences and three conference abstracts.
Standards development and adoption	None.
Spill-overs	RIA and EDP developed academic and industrial leadership in the area through publications, new products and talent development. This enabled RIA to establish a new R&D team, capture follow-on investments and grants and establish different types of inter-organisational relations with EDP and others. RIA and EDP also leveraged the results of Piezopower with other partners and in other fields beyond mechanical energy harvesters. Furthermore, the key Piezopower stakeholders in RIA and EDP established strong interpersonal relations and trust.

5.3 The Connect RDI partnership case study

Since the invention of the integrated circuit in the late 1950s, society has seen a revolution in the way our life is influenced by Information and Communication Technologies (ICT). This revolution was greatly enabled by the continuous miniaturization and performance improvements of electronic devices such as integrated circuits. Each new generation of integrated circuits has typically benefited from the continuous miniaturization and increase in the number of electronic components within it. To enable this trend, the electronics industry is always introducing higher performance manufacturing processes and materials in the fabrication of integrated circuits that can deliver the same performance with smaller features. Consequently, the number of materials used in semiconductor manufacturing since 1960 is almost growing at an exponential rate and material deposition manufacturing processes can deposit materials at around atomic resolution.

For example, this continuous increase and miniaturization of electronic components in an integrated circuit requires the introduction of new materials and manufacturing processes so the interconnecting wires between these electronic components maintain their electrical performance with smaller sizes. As a result, the material initially used in the electronics industry to fabricate these wires, aluminum, was replaced with aluminum copper alloys, then with copper and eventually with layers of copper and other materials. The electronics industry refers to these wires as interconnects and the total length of the interconnects found in half an inch square of an integrated circuit can be over 30 kilometers.

Within in this context, the Connect RDI partnership focused on better understanding the limits of copper as an interconnect material and the different combinations of materials and material deposition processes that can deliver the interconnects required for future integrated circuits.

5.3.1 Introduction to the partners of Connect

The Connect RDI partnership consisted of the inter-organisational collaboration between three partners, a research institute and two companies. First, the partner Research Institute B (RIB) is an independent multisectoral, multidisciplinary public research organisation carrying RDI activities in

areas such as micro-nanoelectronics for the electronics, automotive and health industries among others. RIB employs over three hundred researchers and leverages multi-million research facilities to develop leading research for the benefit of society and industry. Within RIB, the research group involved in the Connect RDI partnership is the Theoretical Modelling and Simulation group with support from the staff at the electronics and characterization laboratories. The Theoretical Modelling and Simulation research group employs a wide range of theoretical modelling and simulation approaches to predict, guide and explain experimental observations. To do so, the group leverages high performance computers, specialised software and other resources available or accessible by RIB. Furthermore, the staff at the electronics and characterization laboratories supported the Connect RDI partnership by providing equipment and expertise to fabricate and analyse materials and electronic devices up to the atomic structure. Throughout the Connect development, RIB mainly involved the Head of R&D, Rachel, and a researcher, Roger, from the Theoretical Modelling and Simulation research group. RIB also involved a Technician, Ray, from the staff at the electronics and characterization laboratories.

As part of its remit, RIB carries leading research, development and innovation activities to transfer knowledge to industry and develop products and processes with industry. Consequently, RIB has developed a long track record of licensing agreements and collaborations with industry. An example is that RIB's industry partners can place employees in their facilities to collaborate more closely. In fact, the two industry partners involved in the Connect RDI partnership had employees at RIB during the execution of Connect.

One of these industry partners is Electronics Device Manufacturer (EDM). This organisation is a large corporation focused on the design and manufacture of electronic devices and components for different electronics products such as those found in cars, medical devices, consumer electronics, personal computers and mobiles. EDM has an annual revenue of hundreds of million euros and employs several thousands of professionals most of whom are engineers specialised in the semiconductor industry. A large portion of its employees and revenue is dedicated to RDI activities around the development and manufacture of novel electronic devices.

Furthermore, EDM establishes close inter-organizational relationships with different research institutes to accelerate research, development and innovation activities. Consequently, some employees are based temporarily or permanently in research institutes such as RIB. During the execution of Connect, EDM mainly involved two employees from the subsidiary they have in the region where RIB is located. These two employees were an R&D Director, Laura, and a Senior Process Engineer, Lucas, which was based in RIB. Both Laura and Lucas worked in close collaboration with their R&D headquarters as the Connect RDI partnership unfolded.

The other industry partner is Semiconductor Material Supplier (SMS). This company is a large organisation focused on the development of materials and processes for the electronics industry. SMS continuous focus and investments in research, development and innovations have resulted in the development of different materials used by hundreds of semiconductor customers worldwide. The applications of the materials produced by SMS span from consumer electronics to automotive and personal computers. Similar to EDM, SMS establishes close inter-organizational relationships with research institutes and locates a number of its employees in some of these research institutes. In the Connect RDI partnership SMS involved a Business Director, Sarah, and a Senior Process Engineer, Sean, who was based in RIB within a materials development lab. These employees were part of an EDM subsidiary located in the same region as RIB and were in close contact with their R&D headquarters during the Connect duration.

Overall, the partners of Connect represent different roles in the electronics industry value chain which is characterized by the following four key activities: material suppliers, tool suppliers, device producers and system integrators. Hence, the Connect RDI partnership includes two of the four key activities, SMS as a material supplier and EDM as a device producer. Furthermore, the role of tool suppliers is covered by the expertise and semiconductor manufacturing tools of RIB and EDM and the role of system integrators is represented to some extent by the electronic device manufacturing requirements introduced by EDM.

5.3.2 Previous inter-organisational relations among the Connect partners

All of the Connect partners had been involved in some type of inter-organisational relation prior to the start of Connect. Most notably through different arms-length relations and buyer-supplier agreements between EDM and SMS and SMS and RIB as well as through R&D and RDI partnerships including combinations of EDM, SMS and RIB as partners. However, it was not until 2013 in the SHAPE2 R&D partnership that the employees of EDM, SMS and RIB involved in Connect started to collaborate.

In 2010 EDM and RIB started the SHAPE1 R&D partnership with funds from EDM and the regional government. As with many other government funded partnerships, part of the work carried under SHAPE1 got disseminated in the public domain and attracted the attention of the R&D headquarters at SMS. Subsequently, staff at the R&D headquarters of SMS reached out to their colleagues Sarah and Sean which were based in the same location as RIB to get introduced to the partners and activities of SHAPE1.

After several meetings between employees at EDM, SMS and RIB, they came up with the idea to develop the SHAPE2 R&D partnership between 2013 and 2015 with funds from EDM, SMS and the regional government. In SHAPE2 SMS joined EDM and RIB to provide expertise and engineering time from their Business Director Sarah and Senior Process engineer Sean who was based at RIB. In addition, during the partnership SMS developed and provided novel materials so that RIB was able to manufacture different electronic components such as interconnects. Meanwhile, in SHAPE2 EDM provided specifications and electronics integration expertise through their R&D Director, Laura, and a Senior Process Support Engineer, Lucas, based in RIB. Furthermore, EDM analysed with their own characterization equipment the materials developed by SMS.

Finally, the contributions of RIB aimed to guide the development of future interconnect materials by providing a better understanding of the chemical processes that the novel materials developed by SMS underwent in the manufacturing of electronic components. This was done by comparing

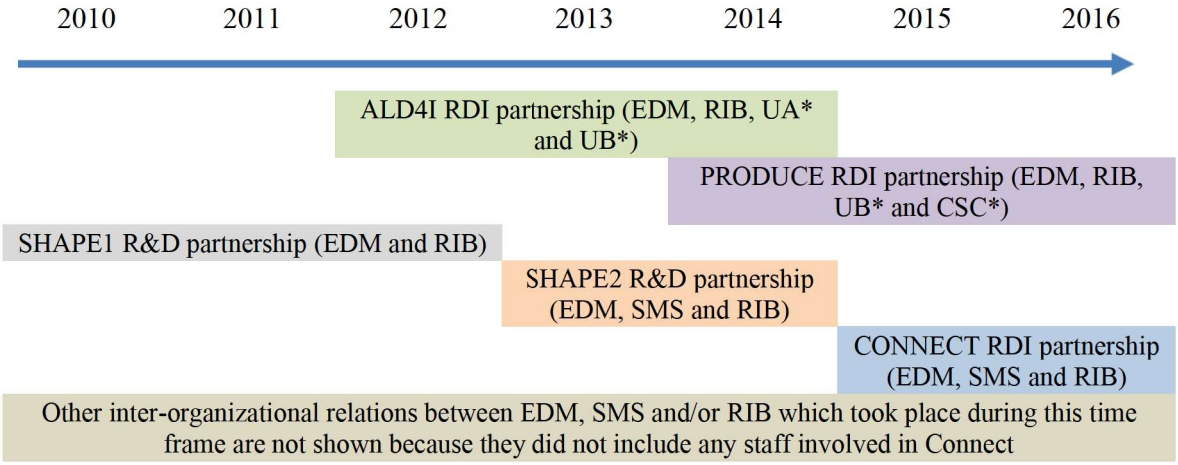
theoretical simulations with the different electronic components fabricated at RIB. For this, RIB involved a Senior Researcher, Rachel, and a postdoctoral researcher, Roger, from the Theoretical Modelling and Simulation research group as well as a Process Engineer, Ray, from their electronics and characterization laboratories.

Overlapping with the SHAPE1 and SHAPE2 R&D partnerships, EDM and RIB were also involved in two RDI partnerships, ALD4I and PRODUCE, under the government supported NanoAble nanotechnology program described in Section 5.1.3. The RDI partnership ALD4I started in 2012 to develop new materials that could reduce the number of steps in the fabrication of interconnects. This partnership ended in 2014 and involved not only EDM and RIB but also two universities, referred hereafter as UA and UB.

In addition, in 2014 EDM and RIB as well as UB and the large private organisation CSC, started collaborating for approximately 3 years in the RDI partnership PRODUCE. This partnership focused on finding new manufacturing processes to simplify the fabrication of interconnects. The existence of these two partnerships indicates that both EDM and RIB where familiar and interested in developing RDI partnerships within the interconnect topic and the NanoAble nanotechnology program.

Against this backdrop of inter-organisational relations, the Connect RDI partnership started in 2015. As a summary, the previously highlighted inter-organisational relations and Connect are shown in Table 23 chronologically.

Table 23 The Connect RDI partnership between EDM, SMS and RIB and their previous inter-organisational relations over time.



** Indicates organizations which are not involved in the Connect RDI partnership*

5.3.3 The formation of Connect

Before the end of the SHAPE2 R&D partnership in December 2014, the consortium wanted to build on the knowledge and results obtained to develop new products and services. With this in mind, towards the end of SHAPE2, EDM, SMS and RIB started to work on defining a new RDI partnership, Connect, while assessing and securing the funds it would require. EDM, SMS and RIB decided to focus the Connect RDI partnership in the area of interconnects because of the promising accumulated knowledge and results in SHAPE2 and the high market potential for all the partners.

As EDM, SMS and RIB started to discuss and prepare the Connect RDI partnership, they soon realised that it would be very costly and required a budget of around half a million euros. Consequently, EDM and RIB proposed applying for a grant from the regional government through the ongoing NanoAble nanotechnology RDI program. Both EDM and RIB were familiar with NanoAble since they had signed the NanoAble NDA and IP agreements and received grants and support to run the ALD4I and PRODUCE RDI partnerships.

Since SMS had no experience in running a partnership under the NanoAble nanotechnology RDI program (described in Section 5.1.3), in November 2014 Sarah from SMS decided to meet Peter, the Managing Director of NanoAble. She was especially interested in finding out more about the support grants it provided and the collaboration, confidentiality and IP agreements SMS would

have to sign if they received a grant from NanoAble. After meeting the Managing director of NanoAble, in December 2014 Sarah contacted SMS' legal team so they could also review the NanoAble collaboration, confidentiality and IP agreements. Understanding the implications of signing these agreements was key to the participation of SMS in NanoAble since their products and services rely on developing and protecting IP.

When the SHAPE2 partnership ended in December 2014, the partners focused on planning and preparing the Connect proposal in line with the NanoAble 2015 call for nanotechnology RDI partnerships proposals announced in NanoAble's web. RIB took the lead in writing the Connect proposal. In doing so, RIB contacted the partners individually and organised meetings among all the partners to request inputs and review different drafts of the Connect proposal. In parallel to these interactions between RIB and the Connect partners, the local team at SMS and EDM involved in the preparation of the Connect proposal reported back to their headquarters to obtain guidance and approval on key aspects such as the core objectives of Connect and the technical contributions and resources that would be made available by each partner. After several iterations and reviews of the Connect proposal, towards the end of March 2015 it was submitted in March to the NanoAble 2015 call for nanotechnology RDI partnerships proposals with deadline April 1st.

The proposal was then evaluated by three experts in the electronics industry. It was generally regarded positively by all evaluators, with clearly defined objectives, industry requirements, and very strong collaboration. Significant in-kind contributions in terms of the industry partners employees, mainly through the Senior Process Engineers based in RIB, materials for the deposition of interconnects and measurement equipment not available in RIB to analyse the deposited interconnects with novel materials. It was also highlighted that the expected Connect results in terms of know-how and understanding would be transferable immediately to SMS and EDM development teams given the close collaboration of the staff at RIB and the Senior Process Engineers based in RIB. Overall, the evaluators agreed that the Connect proposal was of a high quality and combined existing research and know-how derived from SHAPE2 to rapidly start technology development and scale up the production of novel interconnect materials with the

support of modelling and manufacturing process expertise. This is reflected in the high scores provided by the evaluators. Figure 20 shows the average scores of the evaluators to each criterion of the Connect proposal that was assessed (see Section 5.1.3 for more information on the NanoAble evaluation process).

Figure 20 Average evaluation scores of the Connect proposal

The evaluators also pointed out a number of weaknesses in the Connect proposal. First, it was not clarified in the proposal if and when the learnings and results derived from Connect could appear in a product of EDM and SMS or licensed by RIB. Second, the commercialisation of the results was regarded as "likely to be long" by one of the evaluator's report. Furthermore, another evaluation report indicated that the proposal could be considered as very ambitious and highlighted that the Connect proposal approach…

> *"is only one of a probably wide variety of possible solutions to the overall problem; its likelihood of being 'the one' to succeed is probably low."* (Connect Evaluation Report 1)

Finally, there was a significant risk to the partnership if the equipment required to deposit interconnects was unavailable. Hence, RIB was requested to commit making the equipment available prior to the approval of the Connect RDI partnership by the NanoAble Board. Following the receipt of this commitment by RIB and the signature of the NanoAble collaboration, confidentiality and IP agreements by SMS, NanoAble approved a grant of around € 125.000 to

support the Connect RDI partnership start in August 2015 in line with the details provided in the Connect proposal.

5.3.4 The execution of Connect

The goal of Connect was to develop and evaluate novel materials by improving the understanding of the factors affecting their deposition in scaled down interconnects of future integrated circuits. RIB, SMS and EDM aimed to achieve this goal by collaborating closely during 12 months on the following three key activities: novel material development for interconnects, the deposition of these novel materials and modelling the reactions and processes these materials undergo during deposition. In this way, the development of materials would be guided by both the theoretical modelling activities and the results of the deposited novel materials for interconnects. In addition, the resulting theoretical models would be improved by validating their assumptions and accuracy with the results of the deposited novel materials for interconnects.

To ensure alignment between these three key activities and coordinate the overall partnership, the partners were in contact regularly via email or phone and established monthly meetings between Sean, Ray, Rachel, Lucas and representatives from the R&D headquarters in SMS and EDM. In addition, since Sean, Ray, Rachel, Lucas were based in RIB, they agreed to organise additional face to face meetings among them as the partnership developed. These additional face to face meetings were particularly frequent between SMS and EDM employees. Sean at SMS highlights these meetings and the face to face interactions between SMS and EDM as follows.

> *"So we had a monthly call for everyone who was interested to call in and then myself and Lucas would deal with it more on a weekly basis… So we'd meet literally like every... sometimes twice a week."* (Sean at SMS)

In August 2015 Connect started with the implementation of hardware and software upgrades to the equipment in RIB which is responsible for the deposition of the interconnect materials developed by SMS. These upgrades were undertaken mainly by Ray at RIB under the supervision of Sean at

SMS and Lucas at EDM. To validate and qualify these upgrades, a number of materials well known to SMS were deposited by Ray at RIB. These deposited materials were sent to SMS' R&D headquarters laboratory so it could verify that, after the hardware and software upgrades, the materials' deposition process was running correctly. The upgrades, validation and qualification were planned to be finalised in the first month of the partnership but were finalised in the second month. This was due to minor delays such as obtaining health and safety approvals at RIB for the equipment upgrades and SMS' R&D headquarters requiring more time to undertake the analysis and verification in their laboratory.

In parallel to the equipment upgrade and from the beginning of the partnership until the end, the plan was to select novel sets of materials that would be developed by SMS and deposited by RIB following the advice of SMS and EDM. As the number of sets of materials to be developed is very broad, the partnership only considered those initially agreed by the partners in the deliverable "*D2.2 Report on initial list of materials sets of interest to be developed and deposited*" led by Lucas at EDM. Throughout the partnership, the selection of novel material sets and their deposition processes was guided and supported by EDM's insights and support since they were analysing all of the deposited materials using the characterization facilities at RIB and, if needed, at EDM's headquarters. Furthermore, the material and deposition processes selection was also planned to be guided by RIB's theoretical modelling activities.

However, the partners soon encountered more challenges than expected with the highlighted simulation work and experiments to deposit different novel material sets. During the first couple of months, the simulation team at RIB started to realise that leveraging the theoretical models to guide the material development and deposition experimental work was going to take longer than expected. This was highlighted by Rachel, the Head of the Theoretical Modelling and Simulation research group, in one of the interviews…

"we probably didn't have the productive feedback between theory and experiment where theory could help experiments… it was kind of two parallel activities… Maybe we were over ambitious in what we said in the proposal." (Rachel at RIB)

Apparently, establishing feedback loops between the experiments and simulations was not possible since the material development and deposition experiments were not producing enough quantitative data so the models could have the level of detail required to guide the experiments. It was not until the end of the partnership that the modelling group staff at RIB collected enough data to strengthen the accuracy of the theoretical models and be able to provide helpful simulations. Hence, the modelling results from Rachel and Roger at RIB presented, mainly during the monthly meetings, were not as helpful as expected to guide and interpret the material development and deposition activities carried by Sean at SMS, Ray at RIB and Lucas at EDM.

In addition, four months into the execution of the partnership all the work had to be halted from around November 2015 to February 2016 because the deposition equipment stopped working and had to be repaired unexpectedly. This meant that SMS and EDM could not perform any experiments and RIB could not use experimental data to perform modelling activities. According to the Connect documentation this was due to the…

"unexpected degradation of an equipment part… probably because of being defective and intensive equipment use over the first months [of Connect]". (Connect Change Request form submitted by Rachel at RIB)

Also, as the models developed by RIB became more accurate with the additional experimental data, the modelling calculations…

"reached a very demanding scale, where many weeks of high performance computing time is needed". (Connect Change Request form submitted by Rachel at RIB)

Hence, around July 2016 the modelling team at RIB were not able to provide feedback fast enough to support the experimental activities led by SMS and EDM. Because of this and the previous delay

related to the malfunction of the deposition equipment, the partners requested to extend four months the duration of the Connect RDI partnership by submitting a Change Request form in July 2016 to the NanoAble Managing Director. Taking in consideration the incurred delays, the Change request was considered justified and approved promptly to avoid further delays.

Furthermore, as the partnership was ending, SMS and EDM started to realise that none of the developed materials sets and deposition processes in line with the report "*D2.2 Report on initial list of materials sets of interest to be developed and deposited*" were getting close to the targeted performance due to undesired agglomeration of the deposited materials. Hence, SMS and EDM leveraged the achieved results together with the four month extension to reconsider their initial assumptions and come up with alternative materials sets and processes to experiment. These alternative materials and processes enabled them to come up with improved results. Unfortunately, while the results were of interest in guiding future research, the companies felt that they did not achieve the Connect goals since the results had no commercial applications. This situation was reflected in the following comments by Sean at SMS:

> *"So when we got to that point, we got to kind of improvise a bit. And just make up ideas, make up, make up experiments to lessen the agglomeration [which was an undesired result]… So I think the idea where we got with the buffer layer which is kind of a new mix of materials…mmm… that probably wasn't in the original plan but it was something that we had to try… But at the end of the day no matter what we did the materials we developed always agglomerated… I think at the end of the day we were fighting against a fundamental physical phenomena… But mmm you never know until you try it."* (Sean at SMS)

Nonetheless, the partners valued very positively the collaboration and work done in Connect. This was highlighted by the Connect stakeholders and documents as follows.

"So it was pretty good project actually cause we got to upgrade the [equipment] chamber with a lid, a new type of lid... mmm yeah we got to do some extra [materials XYZ] work." (Sean at SMS)

"…there was a desire for both [SMS and EDM] of us to continue collaborating. And is recognized internally [at SMS] that working with RIB is a good and efficient way to work with EDM and others in future projects…" (Sarah at SMS)

"[In relation to starting a new RDI partnership beyond Connect] They trusted that they could do it because they were working together." (Peter at NanoAble)

"This partly-negative outcome has nevertheless been of great importance to the semiconductor companies [SMS and EDM], as it has given a signal to reorient the roadmap for future technology…" (Connect Final Report)

As a result, during the last month of the Connect partnership the consortium agreed to extend their partnership beyond Connect. In this new partnership, they planned to try new ideas and approaches that had been developed during the execution of Connect by other research teams within and out of their organisations.

The partners' satisfaction with the work carried in Connect is also reflected in the fact that all the planned reports and milestones were completed despite the highlighted unexpected challenges and delays. Table 24 shows the list of reports and milestones included in the Connect proposal and when they were completed.

Table 24 Connect work plan along with the list of Work Package (WP), Reports (R) and Milestones (M) in order of delivery from the partnership start date (based on the Connect Final Report and the case study interviews).

	Description of work packages, reports, and milestones in Connect (leader)	Planned timing	Status at the end of Connect
WP1	**Equipment upgrade (Ray at RIB)**	**Month 1**	**Achieved in Month 2**
M1.1	Hardware installation complete (Ray at RIB)	Month 1	Achieved in month 1
M1.2	Software upgrade complete (Ray at RIB)	Month 1	Achieved in month 1
R1.1	System qualification and tests report (Sean at SMS)	Month 1	Delivered in month 2
WP2	**Material development and deposition (Lucas at EDM)**	**Month 1 to 12**	**Achieved in month 16**
R2.1	Material set #1 development and deposition process (Sean at SMS)	Month 2	Achieved in month 3
R2.1	Report on material set #1 development and deposition process (Sean at SMS)	Month 4	Delivered in month 4
R2.2	Report on initial list of materials sets of interest to be developed and deposited (Lucas at EDM)	Month 4	Delivered in month 4
R2.3	Material set #2 development and deposition process report (Sean at SMS)	Month 7	Delivered in month 11
R2.4	Material set #3 development and deposition process report (Sean at SMS)	Month 10	Delivered in month 14
R2.5	Report on factors dictating morphology of deposited materials sets (Sean at SMS)	Month 11	Delivered in month 15
R2.6	Material set #4 development and deposition process report (Sean at SMS)	Month 12	Delivered in month 16
WP3	**Reaction and deposition modelling (Rachel at RIB)**	**Month 4 to 12**	**Achieved in month 16**
M3.1	Validation of the deposited materials morphological model (Rachel at RIB)	Month 4	Achieved in month 4
M3.2	Proposal of material and deposition process improvements and alternatives (Rachel at RIB)	Month 10	Achieved in month 14
R3.1	Report on theoretical modelling of factors dictating the deposited material morphology (Rachel at RIB)	Month 7	Delivered in month 11
R3.2	Report on reactions of the materials deposited (Rachel at RIB)	Month 12	Delivered in month 16

5.3.5 The outcomes of Connect

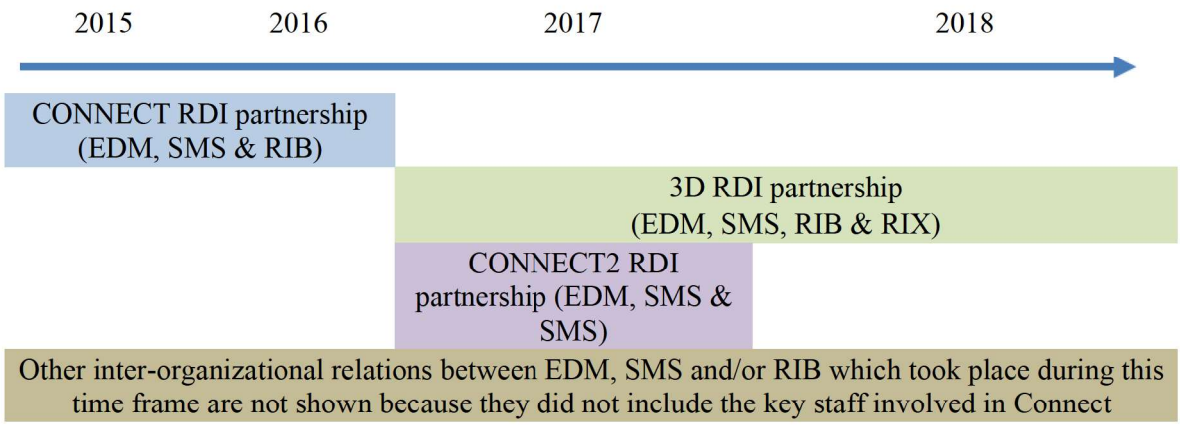
The main type of outcome delivered by the Connect RDI partnership was around the subsequent inter-organisational relations which the partners established for another two years in the area of interconnects. The Connect RDI partnership was succeeded by two RDI partnerships, one which included all the partners of Connect, 3D, and another which only included SMS and EDM, Connect2. As in Connect, the 3D RDI partnership was triggered by all the partners towards the end of Connect and was supported with a government grant through the NanoAble RDI nanotechnology program. Again, the focus was on developing novel materials sets for interconnects but using a different deposition method whereby even smaller interconnects than those targeted by Connect could be tested. Furthermore, the 3D RDI partnership included a new partner, the Research Institute X (RIX), which provided expertise and equipment to undertake a characterization technique that was not available at SMS, EDM or RIB.

Interestingly, the Connect2 RDI partnership was triggered by the interest of EDM to develop a product out of the material development trade secret that SMS had developed in Connect. The trade secret consisted of the development of a novel material set which had proven to be effective in the deposition of smaller interconnects than those available in the market. Hence, the RDI partnership between EDM and SMS focused on further developing the manufacturing and deposition process of this material. The success of this partnership would have allowed EDM to develop miniaturised interconnects within future integrated circuits and SMS to sell a new material set for the fabrication of interconnects.

However, right from the start both EDM and SMS run into different issues. On one hand, EDM realised that the time required to deposit this novel material could not be reduced and would never reach the deposition speed that generated the high volumes and low production costs required by the market. On the other hand, SMS was not able to scale up the production of the novel material set in line with the cost specifications provided by EDM. Because of these issues, both EDM and SMS decided to stop Connectv2 after working together for almost a year. Table 25 shows a

summary of the subsequent inter-organisational relations among EDM, SMS and RIB derived from the Connect RDI partnership

Table 25 The subsequent inter-organisational relations among EDM, SMS and/or RIB derived from the Connect RDI partnership



Other outcome types achieved in Connect revolved around new knowledge and learnings and new or improved technologies. However, the applicability of these outcome types in other areas is very challenging because Connect activities and objectives were too focused in the field of interconnects. In fact, both the Business Director at SMS and the Head of the Materials Modelling group at RIB highlighted this during the interview excerpts below.

> *"It [Connect] was very specific to the semiconductor industry. So I don't think anyone else could be interested."* (Sarah at SMS)

> *"I wouldn't say it [Connect] has hugely change the way we do things. We have worked on other activities related with the modelling of materials and processes related to Connect and they would have been more productive than this [in terms of translating RDI partnership results to other areas]"* (Rachel at RIB)

Furthermore, Connect delivered no innovations, publications, training, spill-overs or standards outcome types. As a summary, Table 26 presents the highlighted outcome types derived from Connect.

Table 26 Summary of outcomes derived from Connect

Outcome types	**Description of Connect outcomes by type**
New knowledge and learnings	Identified five learnings around material development and deposition for interconnect applications but its applicability is limited to interconnects and has no commercial interest.
IP	One trade secret for material development achieved but its applicability is limited to interconnects and has no commercial interest.
Innovation	None.
New or improved technologies	New materials and associated deposition processes where developed but their applicability is limited to interconnects and of no commercial interest.
Socio-economic	None.
Subsequent inter-organizational relations	Two RDI partnerships in the area of interconnects
Training	None.
Publications	None.
Standards development and adoption	None.
Spill-overs	None. Although RIB strengthened its theoretical modelling and infrastructure with new experimental data, learnings and hardware upgrades, its application is limited to the area of interconnects and no spill-overs were identified.

Overall, the Connect RDI partnership delivered a limited number of outcomes and, those that were delivered had a limited impact in the partners. In spite of this, the partners argued in the final RDI partnership report send to NanoAble that they have…

> *"…now developed the material development, analysis and modelling skills suited to understanding the interconnect material deposition issues and that these skills can be readily applied to future interconnect RDI partnerships"*

However, the subsequent RDI partnerships also delivered a very limited number of outcomes and did not lead to any new or improved product or service.

5.4 The NanoGlide RDI Partnership case study

Substantial innovations in technology and procedures over the past decades have resulted in decreased death rates during surgical operations. One of the key medical innovations contributing to this decrease is minimally invasive techniques for the treatment of different conditions such as cardiovascular diseases [17]. Compared to open surgical techniques, minimally invasive procedures have similar clinical efficacy with fewer side effects, shorter recovery time, and lower cost. Consequently, methods that have high risks of complications such as cardiopulmonary bypass, and large cardiothoracic incisions, are avoided.

With these significant advantages in mind, clinicians are developing methods to perform increasingly complex minimally invasive cardiovascular interventions. Catheters are one of the main medical devices used in this type of interventions because they provide a delivery system for disease diagnostic and treatment through the human circulatory system or small punctures. As an example, Figure 21 shows a catheter used in the diagnostics of different oesophageal conditions.

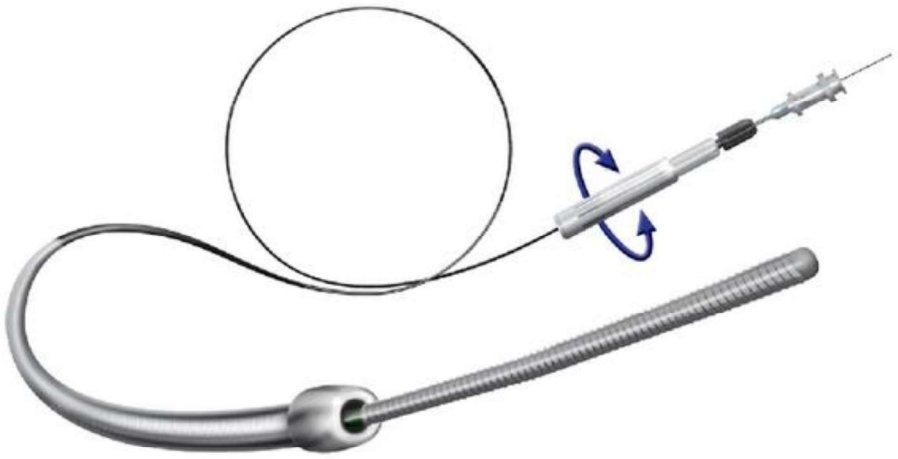


Figure 21 Illustrative example of a catheter for cardiovascular diseases (Galbraith, Del Rosario, & Niazi, 2011).

To decrease the risk of damaging small and critical blood vessels while facilitating the smooth insertion of catheters into the body, clinicians, medical device manufacturers and material suppliers

[17] See for example the EU Heart Network webpage at www.ehnheart.org, last accessed 14th March 2019.

are constantly searching for new solutions to develop catheters with lower friction and similar mechanical properties to those in use. One way of increasing the lubricity of catheters is through the introduction of additives to the polymers used in the fabrication of catheters.

In doing so, nanotechnology enables the development and introduction of a new range of additives, materials with dimensions of around 100 nanometres (nms) or less, which can potentially decrease the friction of catheters. Materials at this scale are referred to as nanomaterials and exhibit novel properties compared to the same materials in bulk form. Novel properties such as reduced friction, increased mechanical strength or large surface area are driving the introduction of nanomaterials across a range of products and industries[18].

5.4.1 Introduction to the partners of NanoGlide

The NanoGlide RDI partnership consisted of the inter-organisational collaboration between three partners, a research institute and two companies. First, the Research Institute C (RIC) is a non-for-profit research entity focused on developing novel research in the areas of nanoscience and advanced materials. The institute has over 200 employees across six areas one of which is nanocomposites for applications in areas such as the automotive, aerospace and medical devices industry. Inter-organisational collaborations undertaken by RIC aims to develop leading research and social and economic benefits to society.

RIC has a large infrastructure of equipment and extensive expertise for micro and nanoscale characterisation and advanced materials processing and modification. This includes an Advanced Materials laboratory with specialised equipment for the development and analysis of polymeric nanocomposites. Throughout the duration of the NanoGlide RDI partnership, the key employees involved are Sophia, an R&D Director responsible for the Advanced Materials lab at RIC, and John, an R&D engineer.

[18] US Department of Energy (2006, March). *Estimated energy savings and financial impacts of nanomaterials by design on selected applications in the chemical industry*. Retrieved from https://www1.eere.energy.gov

In addition, the NanoGlide consortium includes the large multinational Medical Device Supplier Co. (MDS) focused on the development and manufacturing of medical devices. With several decades of experience and over 15 000 thousand employees across different countries, MDS markets thousands of products which results in several billion euros in revenue. MDS has long-term experience in the application of knowhow and technology for medical devices such as catheters, stents and defibrillators. As a result, it has accumulated a wide experience in the validation and application of medical devices and cooperates closely with leading hospitals and academic institutes.

The MDS location involved in NanoGlide is within the same region as RIC and has a long history of developing and producing complex and innovative medical devices. This location was set-up in 1995 and at the start of NanoGlide employed over a thousand employees. Throughout the duration of the NanoGlide RDI partnership, the main MDS' employees involved are Emma, a Senior R&D Program Manager, Charlie, a Senior R&D Engineer, and Jacob, an R&D Engineer.

The third partner of NanoGlide is the Medical Polymer Supplier Co. (MPS) specialised in processing polymers to meet the needs of medical device manufacturers in the region. MPS is also located in the same region as the other partners and has over 30 years of experience in polymer processing. Through their state-of-the-art polymer processing facility MPS incorporates additives and modifiers to off-the-shelf polymers to provide the specific properties required by the medical device industry. MPS can for example adapt polymers' colour, texture and strength as well as provide them in small quantities as it is typically requested by medical device manufacturers. Furthermore, in this facility MPS also carries research and testing activities to develop novel medical polymers. MPS has a total of circa 15 employees and in NanoGlide involved Emily and Danile who hold the CEO and Engineering Director position respectively.

5.4.2 Previous inter-organisational relations among the NanoGlide partners

Prior to the NanoGlide RDI partnership all of the involved partners had recently collaborated in R&D and RDI partnerships. In 2013, Sophia at RIC started to interact independently with both industry partners and launched an R&D partnership named NanoStrength with MDS and a non-disclosed R&D partnership with MPS. Both partnerships were co-funded with a government grant, lasted approximately two years and were based around the idea of improving the performance of medical devices materials through the incorporation of novel nanomaterials.

Towards the end of these partnerships, Sophia started to develop a new collaboration idea and realised that the NanoAble program could help her to fund them. Since the NanoAble program favoured supporting RDI partnerships with more than one company that formed a supply chain, Sophia introduced for the first time MDS and MPS to plan the one year NanoPaque RDI partnership together with her and John at RIC. Ultimately, NanOpaque started in 2014 with financial support from MDS, MPS and NanoAble. According to Peter at NanoAble *"the NanoAble model drove MPS and MDS to work together"*.

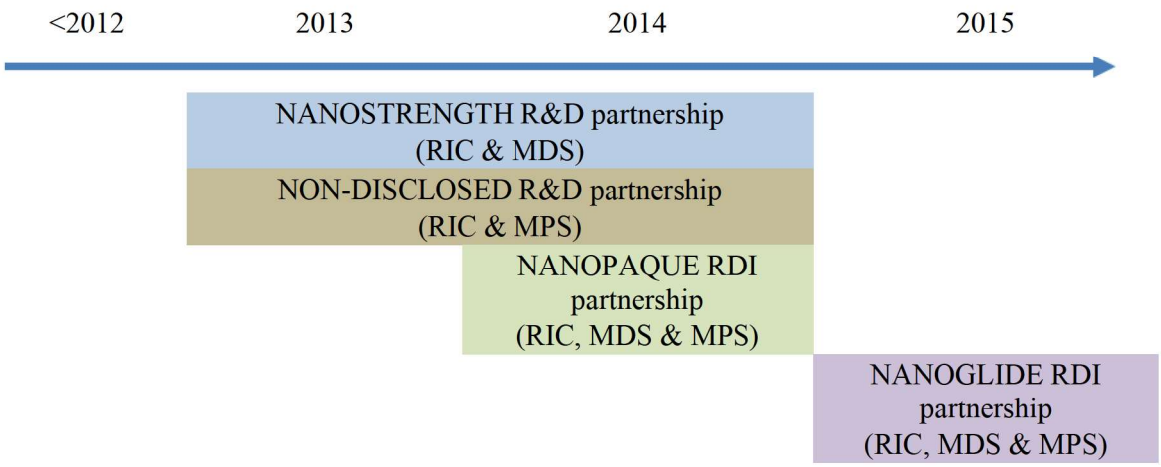
However, NanoOpaque *"started and then it went… and it took a fairly significant intervention to get the appropriate management attention and recover it" (Peter at NanoAble)*. This lack of management attention was both from RICs side as well as from MDS.

> *"…it was our first NanoAble project [RDI partnership]. So we didn't really know how to… you know… who is supposed to be the project manager or how is it supposed to work, how hard to push. You know. There's things to watch out for. We were learning."* (Emma at MDS)

Ultimately, NanoOpaque progressed adequately and delivered great results (see Section 5.4.5 for details) which led to RIC granting a license to MPS. Following the dissolution of NanOpaque in towards the end of 2014, NanoGlide started in 2015. As a graphical summary, the previously

highlighted inter-organisational relations among RIC, MDS and MPS along with the NanoGlide RDI partnership are shown in Table 27 chronologically.

Table 27 The NanoGlide RDI partnership between RIC, MDS and MPS and their previous inter-organisational relations over time.



5.4.3 The formation of NanoGlide

As the NanOpaque RDI partnership was getting closer to its end in 2014, MDS was interested in continuing the collaboration given the expertise of the academic institutions. With this in mind, at the beginning of the summer Emma at MDS started to inquiry what topic should be considered for a new RDI partnership with RIC and MPS and secured interest from the Cardiovascular disease Business Unit. Emma at MDS explains that:

> *"...we were involved in NanOpaque and then from my perspective I had come back to the business [units]... There's an opportunity to get access to some funding here.... [and] we didn't have to get approval [from headquarters]. It made it easier to get approved for... So I suppose we [MDS]... wanted to do some technology development projects. We knew the areas we wanted to investigate. So lubricity. We knew that there were... academic institutions that had experience.... NanoGlide really fitted within the more with... well its applicable to lots of different business units. [However] The direct need is in the Cardiovascular disease Business Unit..."* (Emma at MDS)

Working with RIC and MPS could allow the Business Unit to develop novel catheters and medical devices that can slide better through the body during clinical interventions due to the reduced friction coefficient of the novel polymers. The NanoSlide RDI partnership was triggered by MDS as highlighted by one of the interviewees.

> *"So it came through their [MDS] demand. Basically, they came to us with the problem."* (John at RIC)

However, it was also of interest for RIC and MPS as John recalls that NanoGlide:

> *"...was very much focused on his [Sophia's lab and group] expertise area which probably contributed to success... as far as I know MPS would have had a background need for this [improved lubricity novel nanocomposite] material anyway... So I think their own need drove the project."* (John at RIC)

In this way, once MDS communicated to RIC and MPS their topic of collaboration, they all agreed to work on it for six months and fund it through their internal resources and a grant from the NanoSlide program. Accordingly, Sophia took the lead and started to write a funding application to be submitted to the next NanoAble funding call with deadline end of September 2014. In preparing the funding application, Sophia consulted and received inputs from John at RIC, Emma at MDS and Joe and Henrik at MPS.

Once the NanoGlide RDI partnership proposal was submitted by Sophia to the NanoAble program call (see Section 5.1.3 for details), the proposal was evaluated in October 2014 by different independent experts. The proposal received high scores and positive comments from the evaluators.

> *"Very good. Builds on existing relationships developed during NanOpaque. New technology not previously supported within NanoAble."* (NanoGlide proposal evaluator)

Figure 24 shows an average of the scores provided by the different experts around each of the assessed criterion (see Section 5.1.3 for more information on the NanoAble evaluation process).

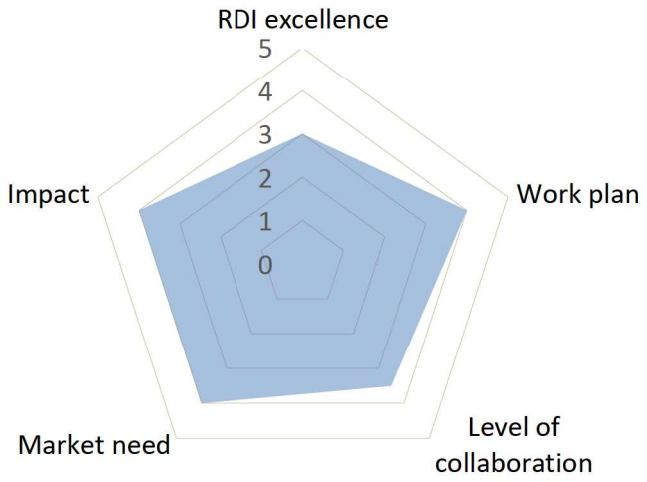


Figure 22 Average evaluation scores of the NanoGlide proposal

However, the proposal also received some minor negative comments such as the following:

"...under resourced for expected outputs" (NanoGlide proposal evaluator)

Nonetheless, in November 2014 the NanoAble Industry Board approved providing circa € 50 000 grant to support NanoGlide activities. Since the partners had already signed the NanoAble NDA and IP agreements for the NanOpaque RDI partnership, NanoGlide would also be covered under these agreements and the partners did not have to review and sign new NDA and IP agreements.

5.4.4 The execution of NanoGlide

In January 2014 the NanoGlide RDI partnership kicked off with the aim of combining a polymer used in building medical devices with different novel nanomaterials that increase its lubricity while maintaining the mechanical properties of the polymer. Increasing the lubricity of medical grade polymers enables the development of novel medical devices that can slide better and in smaller spaces through the body during clinical interventions.

Interestingly, right from the start MDS approached the NanoGlide partnership with a different perspective than the previous RDI partnership, NanOpaque, which was very similar in terms of the consortium composition, governance, resources. This was articulated as follows by Emma at MDS.

> *"These were small projects [NanOpaque and NanoGlide] from an academic perspective so it was hard to get priority… They could easily become an academic exercise rather than an exercise focused on achieving an outcome. So that was our perspective coming in to the NanoSlide project... was trying to make sure there was a focus on getting to a deliverable."* (Emma at MDS)

Therefore, MDS decided to put in place a new RDI partnership point of contact, Jacob, with different skills and *"effectively run it [NanoGlide] like a[n internal] project [at MDS]"* (Jacob at MDS).

> *So Adam was the point of contact for NanOpaque I think. And he'd be more a sort of a... he'd be less of a project manager and more of a technical guy... So Jacob [at NanoGlide] was much better at, you know, beating the drum and having the weekly calls...* (Emma at MDS)

Motivated by this new approach driven by MDS, throughout the duration of NanoGlide all the partners met over the phone and, if needed, in person every two weeks and were given very specific tasks to present at these meetings. *"I think that was one of the big drivers of the success"* (Jacob at MDS).

With this new approach and as indicated in the work plan included in the NanoGlide proposal, the partners started working in developing novel polymer composites at RIC's lab with a low friction coefficient. These composites consisted of an already agreed polymer used in building medical devices with different nanomaterial additives. In parallel to this, RIC and MDS also worked approximately four months in developing a novel testing environment to measure the friction of the developed polymer composites. The testing environment is of critical importance because it *"delivers a standard test environment for evaluation of the coefficient of friction of [polymer composites'] films while representing the end use conditions"* (Final NanoGlide Report).

As the development of the novel polymer composites task progressed, the partners considered a large number of nanomaterial additives that could be incorporated to the agreed polymer. After several discussion, RIC and MPS decided to combine more nanomaterial additives than were planned at the NanoGlide formation stage. So instead of combining the selected polymer with three different nanomaterial additives in three months as indicated in the NanoGlide proposal, the partnership ended up combining 14 nanomaterial additives in six months that resulted in 44 different composite combinations as shown in Table 28.

Table 28 Excerpt of the developed composites and friction results shared in NanoGlide

Novel composites prototypes	**Dynamic CoF – Dry**	**Dynamic CoF Wet**
Nanopolymer composite 1	0.54	0.22
Nanopolymer composite 2	0.35	0.19
Nanopolymer composite 3	0.67	0.16
Nanopolymer composite 4	0.32	0.17
….	…	…
Nanopolymer composite 44	0.63	0.13

This delayed the NanoGlide work plan and meant that MDS could not deliver a commercialization plan by March 2015 because they had to focus their available resources on tracking and benchmarking the new polymer and additives combinations. In addition, this created substantial tension between the partners because they seemed to be pursuing different outcomes.

> *"So RIC and MPS were sort of, happy to add more and more materials. Felt like their objective was to test as many materials as possible. While we felt that our objective was to figure out if [a nanomaterial was] actually good enough or not. So it was like two different motivations within the project."* (Emma at MDS)

Furthermore, the subsequent task of developing a new lab process to fabricate a new polymer with 2D layers nanomaterials had to be delayed. Hence, instead of ending in month four as planned during the formation stage, it finished in month six.

When the partnership was meant to finish, the partners received the results of the 42 new polymers, with 2D layered nanomaterials and nanomaterial additives, developed by RIC in consultation with MPDS and MDS. From these 42 new polymer composites, four were selected because they demonstrated considerable lower friction than the selected polymer on which they were based. Based on these promising results, around June 2015 the partners requested a four month extension to NanoAble to continue the work.

> *"I think because we were getting very successful initial results, it was the interest from MDS to maintain and keep going. So I think maybe at the 6 month stage we were only scratching the surface"* (Jacob at MDS)

This four month extension request had to be approved by NanoAble's Managing Director. Fortunately, as soon as this took place, the partners were able to continue with the next task in the work plan: producing the four selected polymer composites at MPS. This entailed transferring and adapting the polymer composite fabrication process developed at RIC's lab to a polymer composite manufacturing facility for medical device materials at MPS. This required a very close collaboration between Sophia and Jacob at RIC and Daniel at MPS which included several site visits from Sophia and Jacob to MPS. These visits allowed the partners to get a close insight to their polymer processing facilities and processes and trial at MPS different adaptations of the process developed at RIC's lab. Since the expertise of MPS and RIC staff in the area of polymer composites came from the production and academic perspectives, collaborating closely was very enriching.

> *We [RIC] had a lot of experience developing materials and testing materials… But probably we were a bit weaker in the scale up and commercial production which is where the MPS guys have their bread and butter. There was definitely a learning process between the two of us and that's one I found most useful. (John at RIC)*

Once the samples of the four selected polymer composites were produced at MPS in flat plates, the partners started to analyse them, particularly MDS given their key expertise on fabricating medical

devices. Unfortunately, MDS was not able to draw any solid conclusion on the polymer composites merit because medical devices are typically fabricated in the shape of tubes and MPS and RIC were only able to extrude samples in the shape of flat plates.

> *"…we don't use flat plates. We use tubes. I think may be at the start of the project maybe it wasn't scoped…"* (Jacob at MDS)

So MDS checked if they could extrude MPS' polymer composite samples into tubes at their headquarters. Since the waiting time to access MDS' extruder was very long, the partners agreed to subcontract Research Institute Subcontract (RIS) to extrude the polymer composites developed at MPS in the form of tubes. Being able to subcontract RIS towards the end of the partnership *"was a big plus"* according to Jacob because it was the only way to understand if there was merit in introducing these polymer composites in new medical device prototypes.

Hence, Sophia and John travelled abroad to RIS and spent almost a day in their facilities even though they wanted to stay longer to undertake more trials as highlighted by John and Jacob at RIC and MDS respectively.

> *"didn't get it [extruder] for as long as we [Sophia and John] would have liked ideally. We would have probably done another couple of trials and made some roughness [tests] and tables of the results."* (John at RIC)

> *"…we only did one run of the materials at RIS. We never really got to improve the process or investigate the process any further."* (Jacob at MDS)

Fortunately, the four selected polymer composites fabricated at MPS were extruded at RIS in the form of a tube successfully and sent to all the partners for analysis. These analyses were very positive and *"demonstrated that it is feasible to utilise nano[material] additives to reduce the coefficient of friction of [the selected polymer]"* (Final NanoGlide report). However, the extruded polymer composites tubes *"exhibited a decrease in the friction coefficient however this was not as large as observed in lab trials [where polymer composites were fabricated in the shape of flat*

plates." (Final NanoGlide report). These results influenced that, as explained below by Jacob, MDS did not extend their collaboration with MPS, RIC or both even though Emma at MDS explained that "*we understand more about materials as a result of the project.".*

> *"…we didn't see that same reduction in friction when we went to the tube [shape from flat plates]. And again there might be some process settings that you can tweak… The other one was, I think during the course of the partnership we did identified two or three polymer suppliers who were also claiming to have reduced the coefficient of friction by adding additives... So why would MDS invest heavily into something that we can buy off the shelf. And then also, you know, MDS aren't a multi-billion extrusion company. So we don't have the R&D resources to go chasing a project of this scale the same way an extrusion or a polymer company would. So we probably felt we weren't in a position to compete and that we would leave the polymer expertise to the polymer experts."* (Jacob at MDS)

Yet at the same time, these same results together with the highlighted limited time and trials towards the end of the partnership meant that MPS decided to extend their collaboration with RIC. Since the analysis of the polymer composites tubes took place at month 10, the partners could not send the tube samples to different potential customers and focused the last weeks of the partnership in writing the Final Report summarizing the work carried in NanoGlide. Table 29 shows a summary of the work plan included in the NanoGlide proposal and when it was actually completed according to the NanoGlide Final Report and the interviewees.

Table 29 NanoGlide work plan along with the list of Work Packages (WP), Reports (R) and Milestones (M) in order of delivery from the partnership start date

	Description of work packages, reports, and milestones in NanoGlide (leader)	Planned timing	Status at the end of NanoGlide
WP1	**Formulation and melting of selected polymer with nanomaterial additives (Sophia at RIC)**	**Months 1 to 3**	**90% achieved by month 6**
R1.1	Material and process recommendations (Sophia at RIC)	Month 1	Delivered in month 2
M1.1	Identity suitable nanomaterial additives to combine with the selected polymer (Sophia at RIC)	Month 1	Achieved in month 4
R1.2	Commercialization plan (Jacob at MDS)	Month 3	Partially by month 6
M1.2	New composites with nanomaterial additives developed and characterized (Jacob at MDS)	Month 3	Achieved in month 6
WP2	**Formulation and melting of selected polymer with 2D layered nanomaterials (Sophia at RIC)**	**Months 2 to 4**	**Completed in month 6**
M2.1	New composites with 2D layered nanomaterials developed and characterized (Sophia at RIC)	Month 4	Achieved in month 6
R2.2	Report on process development (Sophia at RIC)	Month 5	Delivered in month 6
WP3	**Optimization and pilot scale production of novel polymer composites (Daniel at MPS)**	**Months 3 to 6**	**70% completed in month 10**
M3.1	Samples developed and provided to MDS and MPS (Daniel at MPS)	Month 6	Achieved in month 10
R3.1	Samples delivered to customers (Jacob at MDS)	Month 6	Not delivered
R3.2	Final report (Sophia at RIC)	Month 6	Delivered in month 10

5.4.5 The outcomes of NanoGlide

The NanoGlide partnership delivered a large number of technical outcomes which enabled MPS to launch a new product to the medical devices industry which consisted of a polymer composite with increased lubricity. In addition, NanoGlide increased the knowledge and learnings of the partners around the areas of nanomaterials additives and processing polymer composites to increase lubricity of medical devices. RIC and MDS also developed new knowledge in how to measure the friction coefficient of polymer composites and resulted in a new method which allowed to analyse the fabricated samples towards the end of NanoGlide. Furthermore, it triggered a strong relation between RIC and MPS which resulted in different types of inter-organisational relationships such as a licence, new partnerships and RIC being subcontracted by MPS.

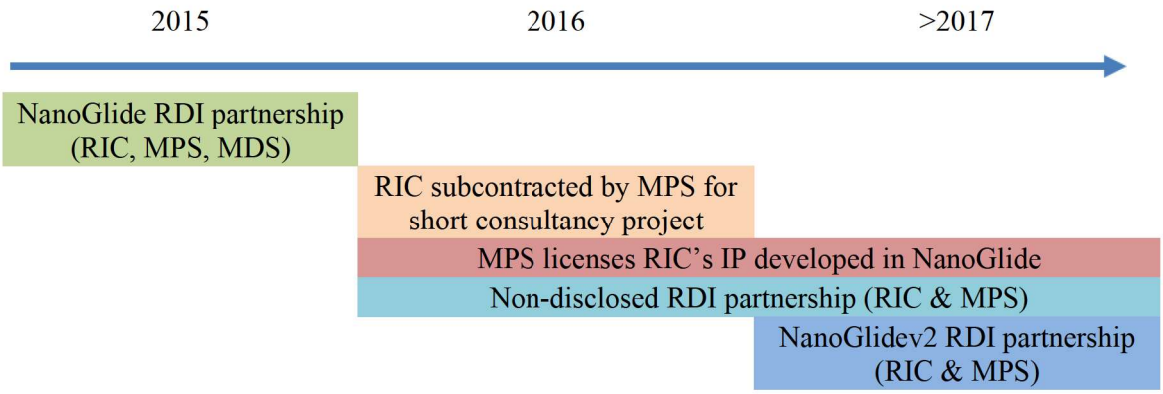
As MPS decided to launch a new polymer composite material based on the fabricated samples and work carried at NanoGlide, MPS entered in commercial discussions with RIC at the beginning of 2016. On one hand, MPS wanted to obtain a license on the polymer processing IP developed by RIC in NanoGlide and, on the other hand, subcontract RIC *"to test the material prior to [product] launch"* (John at RIC). The license and subcontracting agreement were signed around April 2016 and MPS was able to launch their new polymer composite product to the market in June 2016.

During the commercialisation phase of the new product several potential customers requested MPS harder versions of the polymer composite. Since MPS was not able to deliver a solution, they reached out to Sophia and John at RIC for help and agreed to establish a two year RDI partnership focused increasing the hardness of the polymer composite developed in NanoGlide. This partnership was named NanoGlide version 2 (NanoGlidev2) and started in 2017. Furthermore, RIC and MPS also strengthened their collaboration by starting a two year RDI partnership in a non-disclosed topic which was not related to NanoGlide. This was summarised by Peter at NanoAble as follows.

> *"They [MPS] had an idea that there are customers out there but they didn't have a customer… we gave them a license from NanoGlide so they could launch the product. They launched the product, customers trialed it. Then customers came back and said its very good but... can you do this. And they were like... back to RIC."* (Peter at NanoAble)

The highlighted inter-organisational relations subsequent to NanoGlide along with the entities involved are outlined chronologically in Table 30.

Table 30 The inter-organisational relations among MDS, MPS and/or RIC subsequent to the NanoGlide RDI partnership



As a summary, Table 31 summarizes the highlighted outcomes along with other outcomes types that were not delivered as a result of the NanoGlide RDI partnership.

Table 31 Summary of outcomes derived from NanoGlide

Outcome types	**Description of NanoGlide outcomes by type**
New knowledge and learnings	New learnings around nanomaterials additives and processing polymer composites to increase lubricity of medical devices. In addition, developed new learnings around measuring the friction coefficient of polymer composites.
IP	Three trade secrets developed by RIC around processing polymer composites with nanomaterials additives and new method developed by RIC and MDM to measure the friction coefficient of polymer composites.
Innovation	MPS launched a new polymer composite product with increased lubricity to the medical devices industry.
New or improved technologies	Novel process to blend nanomaterials and the selected polymer in a polymer composite with increased lubricity. In addition, a method to measure the friction coefficient of polymer composites was developed.
Socio-economic	MPS increased their internal investments to launch a new polymer composite product for medical devices.
Subsequent inter-organizational relations	Two RDI partnerships, a license and a subcontracting inter-organizational relation triggered as a result of NanoGlide.
Training	None.
Publications	None.
Standards development and adoption	None.
Spill-overs	RIC and MPS established two RDI inter-organizational relations, one in the area of NanoGlide and the other on a completely different topic related with the processing of polymer composites.

5.5 The NPMaterial RDI partnership case study

Within the fast emerging field of nanotechnology, a fast growing area is the nanomaterials market which involves the production of materials with dimensions of around 100 nanometres (nms) or less. At this scale nanomaterials exhibit novel properties compared to the same materials in bulk form and, thus, have been introduced across different markets very rapidly. Already in 2006 the US chemical industry produced nanomaterials which were found in more than 70,000 different products used in health, electronics, pharma and energy applications among others[19].

As an example of a nanomaterial, Figure 23 shows a nanoporous material with a pore size of around 15nms. As shown in the Figure, nanoporous materials typically present a sponge-like structure where the pores and interconnecting filaments are in the order of around 100nms or less. Interestingly, the purposeful engineering of specific nanoporous structures and materials can provide properties such as a high surface area and conductivity, resistance to corrosion and mechanical and thermal stability. In addition, adjusting the pore size allows to block certain substances while letting others pass through. These properties combined can be of great value in different applications such as chemical sensing because they improve the sensitivity, reliability and detection limits of sensors.

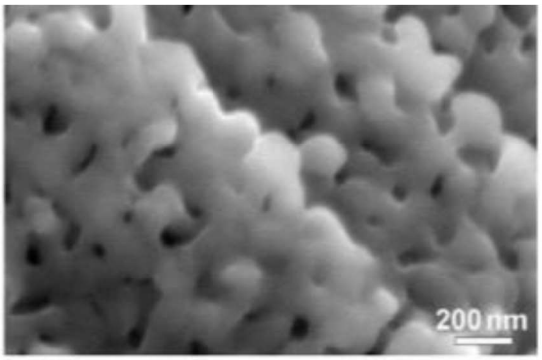


Figure 23 Illustrative examples of two nanoporous materials[20]

[19] US Department of Energy (2006, March). *Estimated energy savings and financial impacts of nanomaterials by design on selected applications in the chemical industry*. Retrieved from https://www1.eere.energy.gov

[20] Lu, L., Andela, P., De Hosson, J. T. M., & Pei, Y. T. (2018). Template-Free Synthesis of Nanoporous Nickel and Alloys as Binder- Free Current Collectors of Li Ion Batteries. ACS Applied Nano Materials, 1(5), 2206- 2218. https://doi.org/10.1021/acsanm.8b00284

As a result, there is significant and global interest in the development of nanoporous materials which address upcoming regulations and requirements on water monitoring. For example, in Europe the Water Framework Directive 2000/60/EC requires EU Member States to gradually control the concentration of 33 priority pollutants and other substances of national and local concern by 2027 in surface waters like rivers, lakes and groundwater. In addition, the key properties of nanoporous materials are expected to enable the development of portable water monitoring devices which can potentially replace the current costly and lengthy water measurement procedures performed typically in large and heavy analytical systems or specialized laboratories.

With this in mind, the NPMaterial RDI partnership aimed to optimise and evaluate a nanoporous material developed by one of the partners as a water sensor. The nanoporous material optimization and evaluation was done with a view to enable the development of a portable water analyser which had a measuring performance similar to that available in specialised laboratories or large and heavy analytical systems. In addition, a secondary goal of the partnership was to explore the feasibility of using the nanoporous material for medical and catalyst applications.

5.5.1 Introduction to the partners of NPMaterial

The NPMaterial RDI partnership consisted of the inter-organisational collaboration between three partners, a research institute and two companies. First, the partner Research Institute D (RID) is a major multisectoral and multidisciplinary public research organisation carrying RDI activities in areas such as advanced materials for the energy, pharmaceutical, medical and chemical industries among others. RID employs over one hundred researchers in the area of advanced materials and leverages unique research expertise and technological infrastructure to address upcoming scientific, industrial and societal challenges.

In the NPMaterial RDI partnership, RID involved their advanced materials research unit which has a long track record in the design and fabrication of nanomaterials. In doing so, RID's advanced materials research unit has access to advanced chemistry labs, characterization tools, theoretical modelling and simulation software and material testing facilities among other facilities. During the

execution of NPMaterial, RID mainly involved Lisa, a Principal Investigator in the advanced materials research unit. Lisa has a long track record in the research of nanoporous materials and, as a result, developed the nanoporous material used in the NPMaterial RDI partnership.

NPMaterial also involved the industry partner Nano Material Supplier Co. (NMS) which is focused on the development of nanomaterials and technologies and processes for their production. In addition, it provides materials science consultancy and analysis services. NMS customers include research organisation and blue-chip and Fortune 500 pharmaceutical, medical devices and biotechnology companies. Throughout its 15 years of history NMS has developed key expertise in the area of nanomaterials and developed and acquired a number of proprietary technologies to manufacture nanoparticles and nanoporous materials. As part of their growth plans, NMS is interested in collaborating with research and industry partners in the commercialisation and production scale-up of novel nanoparticles and nanoporous materials to the industries they serve and beyond. Throughout the duration of NPMaterial, NMS mainly involved their Chief Technical Officer, Ellie, who was at times supported by their Chief Commercial Officer, Chris.

The last partner of NPMaterial was the company Water Equipment Supplier Ltd. (WES) which is focused on providing liquid analysers for environmental and process monitoring in the chemical, water and pharmaceutical industries among others. WES was funded in 2000 and is recognised around the world for the reliability and robustness of their liquid analyser patented technologies. At the start of NPMaterial, the company had over 40 employees and over € 10M in sales across more than 30 countries. WES invests in excess of 10% of their annual turnover in research and development, around 20% of its employees are dedicated to R&D activities and runs a 1000 meters square R&D lab for the development of liquid analysing solutions. In the NPMaterial RDI partnership, NMS involved their R&D Director, Karen, and CEO, Gary.

With the combination of the nanomaterial research institute RID and the nanomaterial supplier NMS together with the liquid analyser provider WES, they aimed to innovate in the production of liquid analysers by introducing a nanoporous material with key properties for the analysis of

liquids. Furthermore, NMS and WES had the right expertise and capabilities to commercialise and manufacture not only the nanoporous material developed initially in a research environment by RID but a water analyser for different applications. Furthermore, NMS and RID were interested in exploring the use and production of the nanoporous material for medical and catalyst applications.

5.5.2 Previous inter-organisational relations among the NPMaterial partners

The NPMaterial RDI partnership was the first inter-organisational relation for the three partners. In the case of WES this is natural because they typically have very limited interactions in R&D and product development activities with other organisations.

> *"We normally do everything ourselves. Every single outside collaboration project we've ever done has never come to something."* (Karen at WES)

However, Ellie at NMS and Lisa at RID had known each other for a long time before the start of NPMaterial because, at some stage, Ellie had been a researcher on nanomaterials in a close academic collaborator of RID.

5.5.3 The formation of NPMaterial

The formation of the NPMaterial RDI partnership was driven by Lisa at RID for two main reasons. On one hand, she had been researching the area of nanoporous materials almost since the start of her career and was at point where part of the developed knowledge could be applied across different commercial applications. On the other hand, the funds for her contract at RID were ending and the most attractive source of funding available to continue her research was the NanoAble program which focused on supporting research organisations and companies to further develop and commercialise nanotechnology-based products.

Hence, during the summer of 2013 she met with different organisations to discuss how her research on nanoporous materials could be of use for their ongoing activities and how it could be supported financially with a grant from the NanoAble program. One of the organisations Lisa contacted was

WES because her research could improve their products in the area of water sensors. She had an initial face to face meeting with Gary at WES to introduce her research and later on Gary had a separate meeting with Peter, the Managing Director of the NanoAble program, to understand how could NanoAble support them financially to collaborate with Lisa.

After these meetings, Gary decided that the NPMaterial RDI partnership was of interest to WES even though he had not consult it with the R&D team or Karen, the R&D Director at WES.

> *"the thinking [to join NPMaterial] was fairly straightforward… We might get something out of it and we don't have to put [almost] anything in it. So let's give a chance we have nothing to lose."* (Karen at WES)

Following the meetings with WES, Lisa met with the Ellie and Chris at NMS to discuss their potential involvement in the NPMaterial RDI partnership. Despite the lack of previous collaboration between the NMS and Lisa, Ellie and Chris were interested in establishing this partnership because, if it was successful, they would commercialise a novel nanoporous material licensed by RID and start selling it to WES in a new market for NMS, the water industry.

> *"the [nanoporous]material [developed by Lisa at RID] was unique enough that there will be a lot of potential applications for it. So we knew WES presence in the partnership, and to be honest that helped us because if those guys are interested we may be able to make the material and supply it to WES and WES-like companies…"* (Ellie at NMS)

Furthermore, Lisa also contacted a small company and a research institute to support the partnership in the areas of commercialisation and R&D respectively. However, ultimately neither of them joined NPMaterial. During the development of the formation the small company decided to withdraw without providing any justification and after further assessment NMS and Lisa at RID decided that the research institute R&D capabilities would be of relevance only if NPMaterial was successful and further work was required to optimize the process development and manufacturing of the nanoporous material.

"Information from 'Voice of the Customer' by NMS will help to decipher what further characteristics of nanoporous material need to be determined by [the research institute] to satisfy the needs of... [highlighted by NMS]" (excerpt from NPMaterial document generated during the formation stage of NPMaterial)

Despite the involvement of WES and NMS, both parties never talked to each other during the formation of NPMaterial and had a very limited contribution to the writing of the NPMaterial proposal for the 2013 NanoAble call (see Section 5.1.3 for details). Hence, the NPMaterial proposal writing was done by Lisa with very little supervision from NMS and almost none from WES since Karen, the R&D Director at WES, was not involved until the execution of NPMaterial.

Once the NPMaterial RDI partnership proposal was submitted to the NanoAble call (see Section 5.1.3 for details) towards the end of October 2013, the proposal was evaluated by different independent experts. Figure 24 shows an average of the scores provided by the different experts around each of the assessed criterion (see Section 5.1.3 for more information on the NanoAble evaluation process).

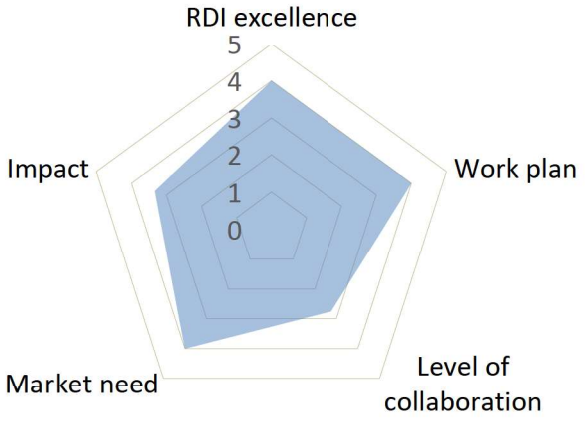


Figure 24 Average evaluation scores of the NPMaterial proposal

Given the low evaluation scores obtained, the NanoAble board hesitated to approve supporting the NPMaterial RDI partnership with funding. The NanoAble board members and evaluators

highlighted that the development of the nanoporous material was still at an early stage for an RDI partnership focused on developing a novel sensor for the water industry.

> *"This [NPMaterial] is certainly considered a high risk project. RID will have to ensure that the application space is validated early and… [by the end of NPMaterial] focused down onto specific applications with clear success criteria..."* (December 2013 Board Meeting minutes)

However, they also highlighted that the application of the nanoporous material could potentially be of great interest for other applications across different industries, there were funds available to support the NPMaterial RDI partnership and it was very well aligned with NanoAble's main goal: increase the competitiveness of companies by transferring nano-expertise from research institutes. Hence, the board ultimately approved to support it with a grant of around € 70 000 during the planned 10 month duration of the partnership. Following the board's approval, both WES and NMS reviewed and signed the NanoAble NDA and IP agreements in a short period of time and aligned with Lisa at RID to start the partnership.

5.5.4 The execution of NPMaterial

The NPMaterial RDI partnership started in February 2014 with the aim of optimising and evaluating RID's nanoporous material in water sensing applications with NMS's support in the area of manufacturing nanomaterials and WES' support in the development of water sensing equipment. Following the work plan included in the NPMaterial proposal, during the first three months Lisa at RID worked on optimizing and testing the nanoporous material as a water sensor for the volatile organic components specified by WES during the proposal preparation.

Most of this work was done independently by Lisa except when she engaged with Ellie at NMS to establish the specifications of the nanoporous material so it complied with environmental and health regulations as well as large scale production techniques in preparation for its potential commercialization. Hence, around the months of February and March Lisa sent different material

samples to Ellie at NMS so she could characterize them and provide her feedback. NMS was keen on coming up with the specifications as soon as possible to gauge commercial interest from potential clients which could apply the nanoporous material not only for water sensors like WES but also in medical, coating and filtration applications among others.

> *"Our main aim was to get a specification on the material from Lisa… We then took that spec[ification] sheet, stuck it up on our website and, as I said, went back to some of our client base that would be interested in such a material."* (Ellie at NMS)

Unfortunately, the material did not seem to be of use to any organization since neither the publication of its specifications on NMS' website around the middle of March or reaching out to several customers helped in attracting any interest. This lack of response from potential customers discouraged NMS from keeping actively engaged in the partnership after June or so.

According to Peter at NanoAble the lack of response was natural since, at this stage of the partnership, potential customers to NMS would not know what to expect from the nanoporous material.

> *"They [NMS] put the material [specification] on their website. But it never got any hits… but sure it wouldn't have because there was no evidence of any performance benefit. You know what I mean, they just said we have nanoporous gold available. So what like... it's just a new material"* (Peter at NanoAble)

Nonetheless, Lisa continued working independently on optimizing and testing the nanoporous material for sensing volatile organic components in the water. This activity was taking her longer than expected and despite she ended dedicating two extra months, May and June, it was never completed. For example, WES was never able to provide feedback because they never received from Lisa the planned volatile organic components water sensing prototype based on the nanoporous material.

In addition, in June Lisa requested to halt the NPMaterial partnership during the months of July and August by submitting a partnership Change Request form to NanoAble.

> *"For two months I have been asked to work on the EU project XYZ to exploit the [NPMaterial nanoporous material sensing capabilities]… for clinical diagnostics and food quality control applications. This will benefit NPMaterial partners WES and NMS by enabling the sensing capabilities of the nanoporous material… to be investigated in a sensor array [as opposed to a single sensor in NPMaterial]"* (NPMaterial Change Request From submitted by Lisa to NanoAble)

Peter, the Managing Director of NanoAble assessed this Change Request and approved it because it could bring added value to NPMaterial and without Lisa the partnership would not make any progress since she was the key driver of each activity in the agreed work plan.

Once Lisa was available in September to work on NPMaterial, she focused again on optimising and testing the nanoporous material but for sensing organic components in water. Again, this activity took longer than expected and had to be stopped by the end of October despite not being fully completed. For example, WES was never able to provide feedback because they never received from Lisa the planned organic components water sensing prototype based on the nanoporous material.

In addition, Lisa and NMS could not undertake the next planned activity because it required NMS to find potential customers to further tailor the nanoporous material according to their specific needs.

> *"…we would have gone down to this [activity or] work package if we would have got any request [from a potential customer to tailor the nanoporous material]. So we never really got our hands dirty and did anything."* (Ellie at WES)

Hence, Lisa skipped it and moved directly to the last planned activity included in the NPMaterial proposal. This activity focused on finding new applications for the nanoporous material in the areas

of medical devices, catalysis or both. Again Lisa was alone in conducting this task since NMS had already contacted their client base and potential customers of the nanoporous material did not show interest in any area.

> *"we put many materials up there [on our webpage] and invariably we get hits but the nanoporous material developed in NPMaterial didn't get any hit"* (Ellie at NMS)

Since Lisa started researching on nanoporous materials prior to the NPMaterial RDI partnership, she purchased a wide range of materials for her experiments. As a result, she build a number of contacts in different chemical providers which she decided to contact and discuss potential new applications for the nanoporous material under development in NPMaterial. Among all her contacts, she decided to start with the large multinational Specialty Chemical Provider (SCP) because she had work in the area of fuel cell catalysts and knew that SCP had a research program on fuel cells where the nanoporous material could be used.

From the start of their discussions, SCP got very interested on Lisa's research and the work carried at NPMaterial. Because of this SCP decided to invite her to their premises to present how the nanoporous material could be used as a catalyst in fuel cell applications. After the presentation, SCP encouraged Lisa to continue working in the area and was *"offered to act as an advisor"* according to the Final Report of NPMaterial. With their help and her own work, in November, December and January she started to develop future research ideas and a plan to enter the market of fuel cells by tailoring the nanoporous material developed in NPMaterial to behave as a catalyst. With this last activity and the writing of the NPMaterial Final Report by Lisa, the partnership ended at the end of January 2015. The Final Report was provided to NMS, WES and NanoAble. This was the first time Karen at WES got aware of the work done in NPMaterial because she indicated that no one at WES was actively following the NPMaterial partnership or collaborating with RID and NMS staff during the execution. Karen even highlighted that the NPMaterial partners *"…could have done all the work in a week from all that I know"*. Yet at the same time, the work carried was of value for WES and towards the end of the partnership it was interested in extending

their partnership with RID beyond NPMaterial. This is reflected in the NPmaterial Final Report as follows.

> *"While currently there is not sufficient information available to be able to commercialize such an application [of the developed novel nanomaterials], sufficient encouraging information was obtained from this report for WES to invest management and marketing time in looking at a number of possible products which may evolve from the current research carried out [at NPMaterial]"* (Final NPMaterial Report)

Throughout the highlighted activities of the NPMaterial RDI partnership, a number of reports and milestones planned at the proposal preparation were completed but others were not. Table 32 shows a summary of the work plan included in the NPMaterial proposal and what was completed according to the NPMaterial Final Report and the interviewees.

Table 32 NPMaterial work plan along with the list of Work Package (WP), Reports (R) and Milestones (M) in order of delivery from the partnership start date.

	Description of work packages, reports, and milestones in NPMaterial (leader)	Planned timing	Status at the end of NPMaterial
WP1	**Optimise nanoporous material for volatile organic components sensing in liquids (Lisa at RID)**	**Month 1 to 3**	**65% achieved in month 3**
M1.1	Establish specifications of nanoporous material for volatile organic components sensing (Lisa at RID)	Month 1	65% achieved by month 3
D1.1	Provide novel sensing platform for volatile organic components to WES (Lisa at RID)	Month 3	Completed 65% in month 5, not delivered
WP2	**Optimise nanoporous material for organic analytes sensing in liquids (Lisa at RID)**	**Month 4 to 5**	**60% achieved in month 9**
M2.1	Establish specifications of nanoporous gold for organic components sensing (Lisa at RID)	Month 5	60% achieved in month 8
D2.1	Provide novel sensing platform for organic analytes sensing to WES (Lisa at RID)	Month 5	Completed 60% in month 9, not delivered
WP3	**Custom synthesis of nanoporous material for potential customers of NMS (Lisa at RID)**	**Month 6 to 8**	**Not started**
M3.1	Identify porosity and composition of nanoporous metal required by NMS customer (Lisa at RID)	Month 8	Not started
M3.2	Provide bespoke nanoporous gold to NMS customer (Lisa at RID)	Month 8	Not started
WP4	**Scope out the potential uptake of the nanoporous material in medical and catalyst applications (Lisa at RID)**	**Month 9 to 10**	**Achieved in month 12**
M3.1	Identify market entry for the nanoporous material in medical and/or catalysis applications (Lisa at RID)	Month 10	65% achieved in month 12
M3.2	Develop link with new industry partner in either medical or catalysis applications (Lisa at RID)	Month 10	Achieved in month 12

5.5.5 The outcomes of NPMaterial

At the end of NPMaterial, both WES and NMS felt a very limited number and types of outcomes had been achieved. Ellie highlighted that the *"major thing [in NPMaterial] was that nothing happened. That we weren't inundated with lots of people saying can you do XYZ,or give us 10 grams or 1 gram or whatever"*. Even the developed new knowledge and learnings were not of much relevance for WES and NMS because its applicability and potential commercial impact was limited.

"I mean there was definitely a knowledge gain for us. We now know what the nanoporous material is and what the capabilities are. But as I said the biggest outcome was the lack of interest." (Ellie at NMS)

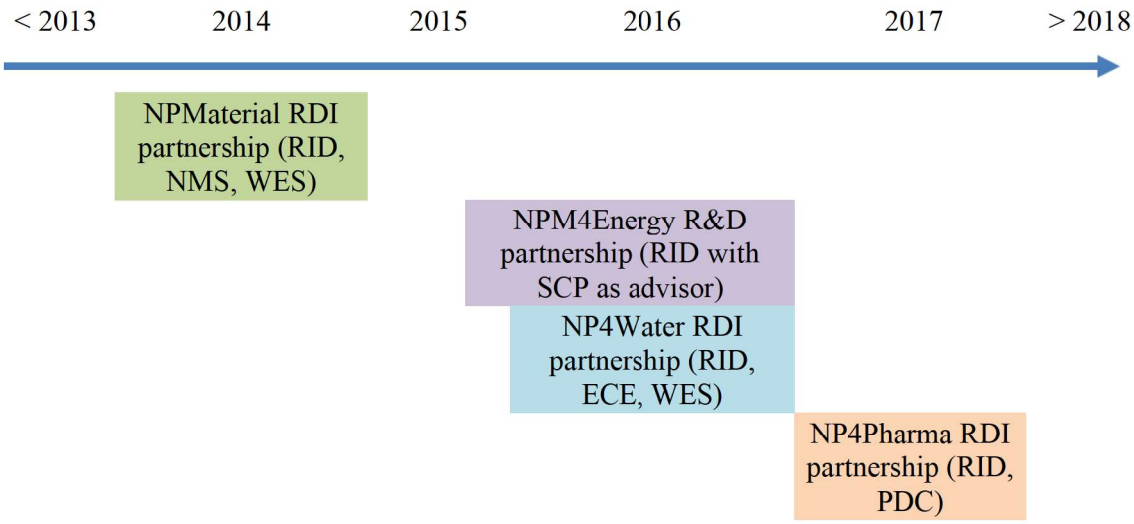
"I wouldn't put the nanoporous material water sensor in any dirty application. That's why we found a clean water niche market for the NP4Water [subsequent RDI partnership]" (Karen at WES)

Nonetheless, Lisa managed to leverage the outcomes from NPMaterial to trigger and lead three sub-sequent inter-organisational relations with different partners. First, Lisa secured a government grant to undertake a one year R&D project to explore the feasibility of using the nanoporous material developed at NPMaterial for fuel cells. This R&D project was named NPM4Energy and started in September 2015 with the large multinational Specialty Chemical Provider (SCP) as an advisor.

Second, Lisa and Karen at WES found a potential niche market application to leverage the capabilities of the nanoporous material developed in NPMaterial. To support this new RDI partnership idea, around 2016 Lisa and Karen secured another grant from NanoAble to start the NP4Water RDI partnership with the small sensor design company ECE as a new partner. NMS was also invited to participate in this RDI partnership but declined to participate. As with NPMaterial, the NP4Water RDI partnership delivered very limited outcomes and WES decided not to continue any inter-organisational relation focused on Lisa's nanoporous material.

This made Lisa focus on applying the nanoporous material in the pharma industry. For this, in 2017 Lisa secured a NanoABle grant to launch the NP4Pharma RDI partnership with PDC, a small pharma development company. PDC was interested in leveraging the nanoporous material for targeting the delivery of the drug they were developing in specific areas of the body. As a summary of the three subsequent inter-organisational relations derived from NPMaterial, Table 33 shows a chronological representation of them along with the entities involved.

Table 33 The subsequent inter-organisational relations among NMS, WES and/or RID derived from the NPMaterial RDI partnership



In 2017 Lisa also tried to establish another RDI partnership between RID, ECE and CAS, a medium size company focused on chemical analysis services. In this case, the focus was on developing a sensor for heavy metals detection based on Lisa's nanoporous material. However, they failed to secure a grant from NanoAble and, although the ideas and activities of each partners were planned, the partnership was never executed.

Furthermore, NPMaterial delivered a poster presentation at an international conference in 2012 and no IP, innovations, new or improved technologies, socio-economic, training or standards outcome types. As a summary, Table 34 presents the highlighted outcome types derived from NPMaterial.

Table 34 Summary of outcomes derived from NPMaterial

Outcome types	**Description of Connect outcomes by type**
New knowledge and learnings	New knowledge and learnings on how to tailor and fabricate a nanoporous material and its ability to sense nine components in water. However, its applicability is very limited since specific conditions in the water need to be maintained.
IP	None.
Innovation	None.
New or improved technologies	None.
Socio-economic	None.
Subsequent inter-organizational relations	Two RDI partnerships for specific applications in the water and pharma industry and one R&D project where RID was the only partner together with SCP acting as an advisor.
Training	None.
Publications	One poster presentation at an international conference.
Standards development and adoption	None.
Spill-overs	The developed nanoporous material can potentially be applied for catalysis in fuel cells.

Although NPMaterial delivered a very limited number of outcomes, a substantial amount of subsequent inter-organisational relations, two RDI partnerships and one R&D project, were derived. However, the subsequent RDI partnerships also delivered a very limited number of outcomes and the only partner that remained interested in these was RID. NMS and WES seemed to decrease their interest the more they got to know about the nanoporous material developed by Lisa.

> *"…I suppose the next major event was that after a year [working in NPMaterial] we decided… well we've given it a go, it hasn't worked."* (Ellie at NMS)

> *"[after NPMaterial and NPSense]… we knew it [nanoporous material] was not going to be a threat to our current technology."* (Karen at WES)

6 Case studies analysis

Chapter 6 focuses on the analysis of the collected data by building on the narratives of the previous chapter and implementing the two inference methods of critical realism, abduction, also known as theoretical re-description, and retroduction. In doing so, Section 6.1 describes how the conceptual structure and the demi-regularities of each case study are identified through directed content analysis. Then Section 6.2 presents how the collected data is theoretically redescribed to analyse, from a different frame of reference, the identified conceptual structure and demi-regularities. Finally, Section 6.3 details how the causal mechanisms are retroduced and their originating conditions and outcomes identified. This is followed by the validation of the identified conditions, mechanisms and outcomes through their corroboration across the four case studies and data collection sources.

6.1 The conceptual structure and demi-regularities of the case studies

In this Section the study leverages the detailed narratives developed in the previous chapter and implements a directed content analysis technique based on flexible deductive and pattern coding to unveil the structural components and demi-regularities of the case studies (Volkoff & Strong, 2013; Wynn & Williams, 2020). The definition of the conceptual structure of the case studies is based on identifying both the key physical and social components of the case studies (Bygstad & Munkvold, 2011). Due to the nature and activities involved in the case studies, the key physical components identified are related to the products and knowledge assets leveraged by each entity while the key social components are related to the actors involved by each entity and their interactions as the RDI partnership in each case unfolds over time. Moreover, the demi-regularities are identified by using the most frequently occurring codes as a starting point along with pattern coding to apprehend the underlying tendencies in each case study. For clarity, references to code names and demi-regularities are shown in italics throughout Section 6.1.

6.1.1 The conceptual structure and demi-regularities of PiezoPower

The PiezoPower RDI partnership continued with the collaborative structure established by RIA, EDP and MDM in the BioIntegrate R&D partnership which preceded PiezoPower. This collaborative structure enabled them to share and leverage their highly specialised knowledge and facilities around the areas of electronics and medical devices. However, at the start of the partnership, the established structure had to be modified by breaking the links between MDM and the other partners because MDM decided to exit the partnership. Hence, the new collaborative structure consisted of RIA and EDP and was focused on enabling RIA to develop new energy harvesting devices with the support of EDP which was interested in commercialising the results of PiezoPower.

The highlighted structure and interactions are illustrated in a simplified manner in Figure 25 by depicting for each entity, the key actors, the relations established and the direction of these relations as well as the infrastructure and knowledge relevant to the NanoGlide RDI partnership.

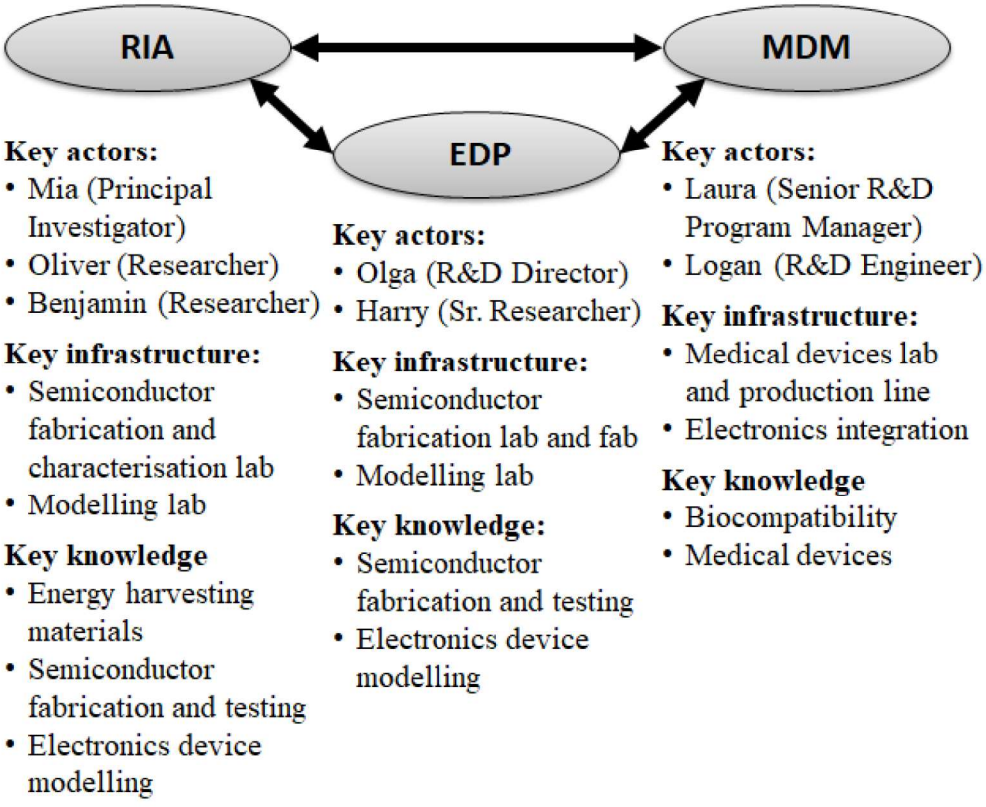


Figure 25 The key components and collaborative structure of the PiezoPower case study

The structure shown in Figure 25 enabled the formation of different demi-regularities throughout the execution of PiezoPower. In identifying these demi-regularities, the most frequently occurring codes were used as a starting point. Table 35 shows the coded conditions, processes and outcomes that accounted for at least 40% of all the codes in PiezoPower as well as the number of times they were found in the collected data.

Table 35 Most frequently occurring codes among the coded conditions, processes and outcomes in PiezoPower.

Coded Conditions		**Coded Processes**		**Coded Outcomes**	
Frequency	Code name	Frequency	Code name	Frequency	Code name
74	*Virtual and face to face meetings*	70	*Re-assessment of work plan*	22	*New knowledge*
73	*Management procedures*	62	*Establishing and strengthening relations*	17	*Personal satisfaction*
70	*Relational*			17	*Subsequent inter-organizational relations*
48	*Proximity*				

Given that Harry at EDP spent approximately two days a week in RIA working side by side with Oliver in the same office, it is not surprising that the first, third and fourth most coded conditions are *virtual and face to face meetings, relational,* and *proximity*. In addition, throughout the partnership there was a tendency to establish and deepen the personal and organizational relations of EDP and RIA due to the frequency of the highlighted conditions as well as the technical results, the employees positive view on the established relation and the shared and synergistic objectives.

This is reflected in the case narrative as well as in the most coded partnership outcomes identified, *sub-sequent inter-organizational relations*, *personal satisfaction* and *new knowledge*, and that the second most coded condition and process which are adherence to *management procedures* and *establishing and strengthening relations* respectively. From the most coded conditions, processes and outcomes and the interviews, it transpires that in PiezoPower there is a tendency to establish

and deepen personal and organizational relations between EDP and RIA. This is illustrated in interviews with Oliver at RIA and Olga at EDP as follows.

> *"Harry was always there to ask him a question but we also felt you know that ... the person made a difference. He was very good at... even just helping with other issues. I don't know... I grew up being a friend of Harry. I could go to his house and basketball matches. I always talked him about other stuff outside of work."* (Oliver at RIA)

> *"I suppose the important bit for us was that RIA was working on the materials deposition activity and optimizing the material. They had made good progress and were able to show good results which kept the interest of EDP. A lot of that was due to the fact that Harry was in place in RIA."* (Olga at EDP)

The highlighted codes, narrative and tendency to establish and deepen personal and organizational relations between EDP and RIA, led to the identification of the following causation pattern code which will hereafter be referred as a demi-regularity:

> *"The development and exchange of knowledge and technology grows inter-organizational relations when it is supportive of organizational strategies."*

The other tendency observed throughout the execution of PiezoPower were the numerous times EDP and RIA modified their planned RDI activities due to issues such as the lack of focus, unviable work plan and availability of resources. This typically resulted in numerous tense discussions between RIA and EDP as well as changes in the work plan and budget among others. This was reflected in the differences between the tasks accomplished and those included in the initial work plan, see Table 20 for details, as well as in the interviews with members of EDP and RIA. The following interview extracts illustrate this point:

> *"... actually we didn't do quite all the things that appear in the work plan... we did testing but initially we wanted to do a medic package and stuff but that was too much. It would take [pause] we still [2 years after] haven't done it."* (Oliver at RIA)

"...it was always a challenge to get enough people on the ground at the right time to get things going according to plan." (Olga at EDP)

"We run into some problems where the progress was very spotty. I kind of ... what is the best way of putting it. I had come to a Jesus meeting with them [RIA] to say I was very unhappy with how the progress was going in that you know... As we were coming to quarter reviews that you get a lot of progress that was dead I wanted a more even approach. We got to an agreement that from a RIA point of view the management of the project would have to be improved and [a new person] was brought into that." (Harry at EDP)

This tendency to continuously modify EDP's and RIA's plans can explain that the most coded process is *re-assessment of work plan*. Therefore, the following causation pattern code was identified which will hereafter be referred as a demi-regularity:

"Poor partnership management results in conflict and change"

As a summary, Table 36 shows the highlighted demi-regularities and codes in this Section together with other supportive codes and events found in the collected data during the execution of PiezoPower.

Table 36 Demi-regularities and supportive codes and events in the PiezoPower Case

Demi-regularities	Supportive code acronyms[21]	Supportive events
"The development and exchange of knowledge grows inter-organizational relations when it is supportive of organizational strategies."	VFFM, MP, Re, Pr, ESR, NK, PS, SIOR, GDA, CS, ECS, NIT.	1. Weekly meetings and open discussions between RIA and EDP 2. Publication submission 3. New partnership proposal agreed before the end of PiezoPower
"Poor partnership management results in conflict and change"	RAWP, IPP.	1. Fabrication delays at RIA due to poor planning 2. Assigned a project manager 3. Budget and work plan changes

6.1.2 The conceptual structure and demi-regularities of Connect

Prior to the start of Connect, EDM, SMS and RIB had been collaborating in an R&D partnership together and in bilateral inter-organisational relations, mainly, arms-length relations and buyer-supplier agreements between EDM and SMS or SMS and RIB. However, Connect was their first joint RDI partnership and enabled them to focus on a topic of key importance for the semiconductor industry, sustaining the miniaturization of the interconnections required by integrated circuits. Through Connect, EDM, SMS and RIB collaborated closely together to leverage key knowledge from their previous relations and in-house activities across the semiconductor value chain. In addition, the staff at EDM and SMS involved in the Connect partnership were also able to seek advice from colleagues in their respective headquarters and EDM was able to leverage additional characterisation facilities at their headquarters.

The highlighted collaborative structure and interactions in Connect are illustrated in a simplified manner in Figure 26 by depicting for each entity the key actors, the relations established and the direction of these relations as well as the infrastructure and knowledge relevant to the Connect RDI partnership.

[21] The full list of codes and acronyms may be found in Appendix D.

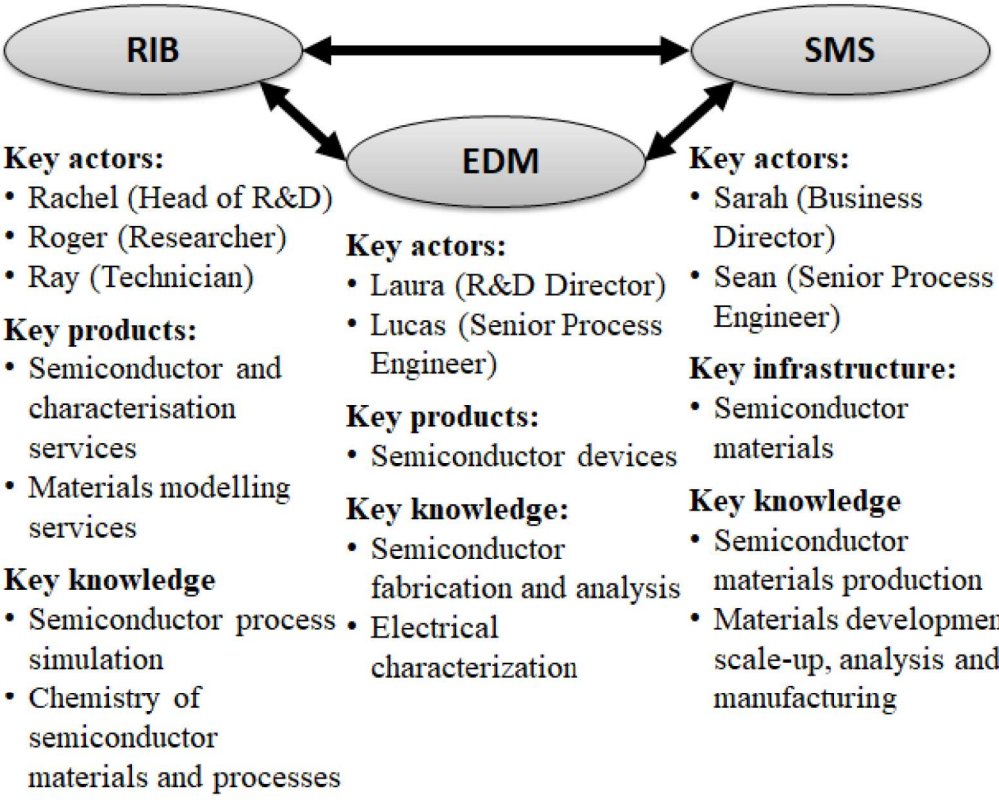


Figure 26 The key components and collaborative structure of the Connect case study

The structure shown in Figure 26 enabled the formation of different demi-regularities throughout the execution of Connect. In identifying these demi-regularities, the most frequently occurring codes were used as a starting point. Table 39 shows the conditions, processes and outcomes that accounted for at least 40% of all the codes identified in Connect.

Table 37 Most frequently occurring codes among the coded conditions, processes and outcomes in Connect

Coded conditions		**Coded processes**		**Coded outcomes**	
Frequency	Type	Frequency	Type	Frequency	Type
49	*Commitment and engagement*	14	*Re-assessment of work plan*	36	*New knowledge*
34	*Management procedures*	11	*Virtual and face to face meetings*	9	*New or improved technologies*
32	*Virtual and face to face meetings*				

Connect presented a strong collaboration among the partners as it is reflected not only in the narrative but also in the large number of *commitment and engagement*, and *virtual and face to face*

meetings coded conditions and the *virtual and face to face meetings* coded process. This strong collaboration and the frequent meetings, sometimes twice a week, was sustained by the exchange of knowledge and technological advances. Because of this, the most coded outcomes were *new knowledge* and *new or improved technologies*. This strong collaboration was highlighted by the partnership documentation and all the interviewees several times. The following are some illustrative examples from each interviewee:

> *"So we had a monthly call for everyone who was interested to call in [at EDM, SMS and RIB] and then myself and Lucas would deal with it more on a weekly basis… So we'd meet literally like every... some times twice a week."* (Sean at SMS)

> *"As I recall we did regular meetings with the central R&D teams [in the headquarters] and they were always really engaged in the technical context and how you move forward to the next step. So it was really hands-on management support."* (Rachel at RIB)

> *"…there was a desire for both [SMS and EDM] of us to continue collaborating. And is recognized internally [at SMS] that working with RIB is a good and efficient way to work with EDM and others in future projects…"* (Sarah at SMS)

> *"[In relation to starting a new RDI partnership beyond Connect] They trusted that they could do it because they were working together."* (Peter at NanoAble)

The highlighted codes, narrative and quotes, show a tendency to maintain and strengthen collaboration among the partners. As a result, the following demi-regularity was concluded:

> *"The development and exchange of knowledge and technology sustains and grows inter-organizational relations when it is supportive of organizational strategies."*

In spite of this, the Connect RDI partnership never achieved the agreed objectives and the planned activities had to be redefined as it evolved. The development of the Connect RDI partnership showed a tendency to be mediated by two types of unexpected events. On one hand, as time

evolved the partners identified several deficiencies in the planning and management of the partnership. Some illustrative examples of this are highlighted by the following interviewees:

> *"...[work plan delays in upgrading the equipment] was to do with getting precursors and precursors not being available."* (Peter at NanoAble)

> *"Probably we didn't have enough knowledge about the system at the start... there wasn't enough quantitative information for my strand [the theoretical component of Connect] to start... We probably didn't have the productive feedback between theory and experiment were theory could help experiments solve those problems... in a way it was sold in the proposal. And maybe we were over ambitious in what we said in the proposal..."* (Rachel at RIB)

On the other hand, the partners also faced a number of unexpected events which required them to change their plans to overcome delays and try to achieve the agreed goals. This was highlighted by the Connect partners and documentation as follows.

> *"... we got to a point when it started to look a little bit brown instead of metal coloured. So we started to investigate it and I thought perhaps there was a leak in the chamber or something. So we couldn't find a reason. So we asked for a new batch of the precursor and that fixed it straight away."* (Sean at SMS)

> *"...the calculations reached a very demanding scale, where many weeks of high performance computing time is needed".* (Connect Change Request form submitted by Rachel at RIB)

> *"...no matter what we did the materials we developed always agglomerated... I think at the end of the day we were fighting against a fundamental physical phenomena...* (Sean at SMS)

This tendency to change the Connect work plan in line with the partnership governance was captured by the dominant coded process *re-assessment of work plan* and coded condition adherence to *management procedures*. As a result, a pattern code was defined that led to the following demi-regularity:

"Poor partnership planning and unexpected events result in change."

As a summary of the described data, Table 38 shows the highlighted demi-regularities and codes together with other supportive codes and events found in the execution of Connect.

Table 38 Demi-regularities and supportive codes and events in the Connect case

Demi-regularities	Supportive codes (numbers)	"Supportive" events
"The development and exchange of knowledge sustain inter-organizational relations when it is supportive of organizational strategies."	CE,VFFM,M, NK, NIT,	1. Regular monthly and weekly meetings between the partners. 2. Leveraging guidance and facilities from the headquarters of SMS and EDM. 3. Subsequent partnership agreed before the end of Connect to try new ideas and approaches to reach their common goals.
"Poor partnership planning and unexpected events result in change."	RAWP, MP	1. Delays upgrading equipment due to precursor supply issues. 2. Unexpected degradation of precursors delayed the partnerships four months. 3. Theoretical modelling and simulation work at RIB did not provide relevant feedback to the activities of SMS and EDM.

6.1.3 The conceptual structure and demi-regularities of NanoGlide

In the NanoGlide case study the partners RIC, MDS and MPS established a collaborative structure where the key actors involved interacted to leverage and share key knowledge and infrastructure. The collaborative structure implemented in NanoGlide enabled RIC, MDS and MPS to develop a large number of RDI outcomes beyond what they could have achieved independently. In this way, with the expertise and support from MDS and MPS, RIC was able to scale up their new lab process to blend medical polymers with nanomaterials in the medical polymer processing plant at MPS.

It is also worth highlighting that the knowledge and infrastructure leveraged and shared in NanoGlide was typically not available in more than one partner. Furthermore, when the partners identified that a required piece of infrastructure was not accessible in their organisations, they were able to adapt their partnership and subcontracted RIS. By doing so, RIC, MDS and MPS were able to access RIS's polymer extrusion lab and further validate the increased lubricity of the developed medical polymer with nanomaterials.

The highlighted NanoGlide collaborative structure and interactions are illustrated in a simplified manner in Figure 27 by depicting for each entity the key actors, the relations established and the direction of these relations as well as the infrastructure and knowledge relevant to the NanoGlide RDI partnership.

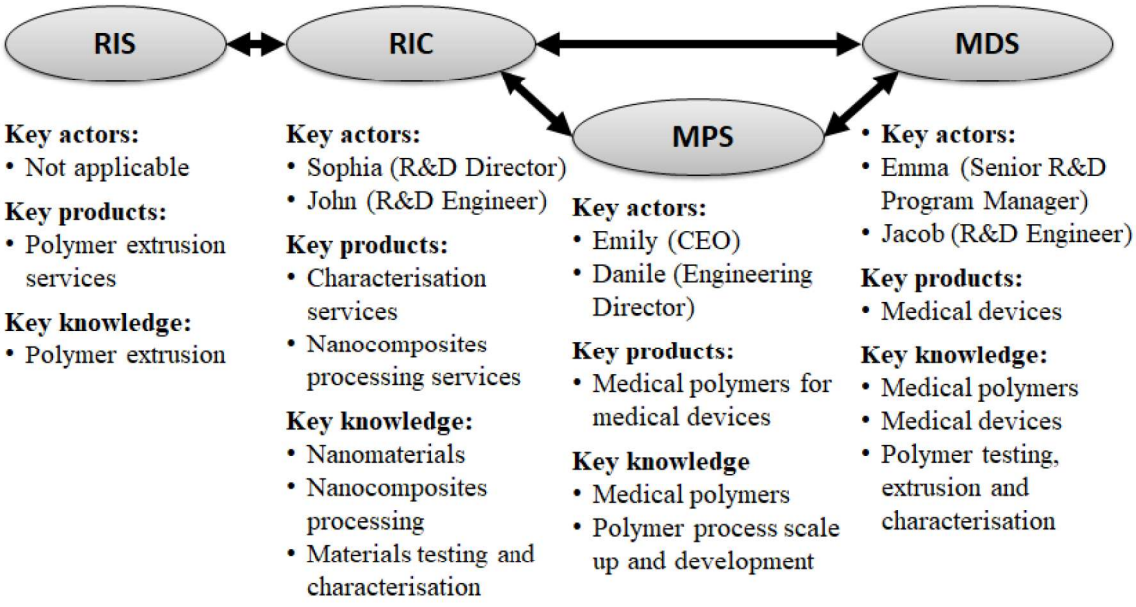


Figure 27 The key components and collaborative structure of the NanoGlide case study

The structure shown in Figure 27 enabled the formation of different demi-regularities throughout the execution of NanoGlide. In identifying these demi-regularities, the most frequently occurring codes were used as a starting point. In this way, Table 39 shows the conditions, processes and outcomes that accounted for at least 40% of all the codes identified in NanoGlide.

Table 39 Most frequently occurring codes among the coded conditions, processes and outcomes in NanoGlide.

Coded conditions		**Coded processes**		**Coded outcomes**	
Frequency	Type	Frequency	Type	Frequency	Type
18	*Goal definition inaccuracy*	14	*Re-assessment of work plan*	12	*New knowledge*
14	*Organisational assets*	11	*Establishing and strengthening relations*	8	*New or improved technologies*
11	*Management procedures*	9	*Knowledge transfer*		
10	*Flexibility*				

One important tendency highlighted in this table and already apparent in the narrative of the case study are the constant changes in the work plan and tasks of the different partners. This is reflected in Table 39 because the most common process is the *re-assessment of work plan*, the most common

condition is the *goal definition inaccuracy* and the two most common outcomes are *new knowledge* and *learning*. Moreover, as described in the case narrative in Section 5.4, NanoGlide went through many work plan changes which arose mainly from deficiencies in preparing a work plan at the formation of the RDI partnership and the exchange of knowledge and new findings that mediated the subsequent work of the partners.

The exchange and development of knowledge and learning as well as key resources from the partners is also found to be of key importance to explain that the second and third most common processes codes are *establishing and strengthening relations* and *knowledge transfer* and one of the most common conditions is *organisational assets*. As the NanoGlide RDI partnership unfolded over time, the partners established and strengthened different relations among each other while exchanging knowledge. For example, as described in the case narrative in Section 5.4, the relation between RIC, MPS and MDS was strengthened from around month 6 when RIC's lab results where shared among the partners. This was highlighted by Jacob at MDS as follows.

> *"I think because we were getting very successful initial results, it was the interest from MDS to maintain and keep going. So I think maybe at the 6 month stage we were only scratching the surface."* (Jacob at MDS)

Another example described in Section 5.4, would be that the relation between RIC and RIS was not established until around month 9 when MDS asked to extrude the new nanopolymer composites in tubes to carry additional testing. Hence, the inter-organisational relations in NanoGlide were mediated by the developed and exchanged knowledge throughout the execution. As a result, the following demi-regularity was identified:

> *"The development and exchange of knowledge and technology grows and sustains inter-organizational relations when it is supportive of organizational strategies."*

The last demi-regularity found in NanoGlide is the continuous conflict resolution activities to manage the aforementioned tendencies of modifying the work plan and establishing and

strengthening relations. This can explain why two of the most common coded conditions are adherence to *management procedures* and *flexibility*. Throughout the NanoGlide partnership, all the partners showed themselves open and willing to make concessions to maintain the partnership and adhered to the contractual and informal routines established by the partners to manage the partnership. For example, as described in Section 5.4, the selection of the different nanomaterials to be tested created a lot of tension in their communications and weekly meetings. On one hand, MDS was interested in checking the feasibility of combining nanomaterials and polymers for medical devices, and on the other hand, RIC and MPS were interested in trying as many possible combinations of nanomaterials and polymers.

Other examples described in Section 5.4 are related to the contract modifications and negotiations the partners dealt with to extend the duration of the partnership, mitigate the continuous work plan delays and modifying the partnership objectives to enable accessing the extruding facilities of RIS and developing new nanopolymer composites in the shape of a tube rather than in a flat plate. This tendency to change and, subsequently, conflict among the partners is related to poor partnership planning during the project and led to the identification of the following demi-regularity:

"Poor partnership planning results in conflict and change"

As a summary of the data described, Table 40 shows the highlighted demi-regularities and codes together with other supportive codes and events found in the collected data during the execution of NanoGlide.

Table 40 Demi-regularities and supportive codes and events in the NanoGlide Case

Demi-regularities	Supportive codes (numbers)	"Supportive" events
"The development and exchange of knowledge grows inter-organizational relations when it is supportive of organizational strategies."	OA, MP, F, ESR, KT, NK, NIT	1. NanoGlide duration extended four months due to promising results. 2. Increased collaboration between RIC, MPS and MDS. 3. RIC and MPS extend their partnership beyond NanoGlide.
"Poor partnership management results in conflict and change"	GDI, RAWP,	1. Increased number of nanomaterials for testing. 2. Extended the duration of NanoGlide. 3. Redesigned the nanopolymer extrusion format and subcontracted RIS.

6.1.4 The conceptual structure and demi-regularities of NPMaterial

The organisations RID, WES and NMS collaborated for the first time in the NPMaterial RDI partnership. The collaborative structure established through NPMaterial allowed the partners to leverage key knowledge and organisational assets which was typically not available within their organisations. In this way, these partners were able to develop, scale-up and demonstrate applications of novel nanomaterials for water applications and beyond. However, WES never ended up collaborating actively with the other partners because they were not informed regularly of the partnership development and never committed its technical team to follow and contribute to the partnership. In addition, a few months into the partnership, NMS decreased their engagement in NPMaterial because potential customers had shown no interest in the new nanomaterial developed by RID.

The highlighted NPMaterial collaborative structure and interactions are illustrated in a simplified manner in Figure 28 by depicting for each entity the key actors, the relations established and the direction of these relations as well as the infrastructure and knowledge relevant to the NPMaterial RDI partnership.

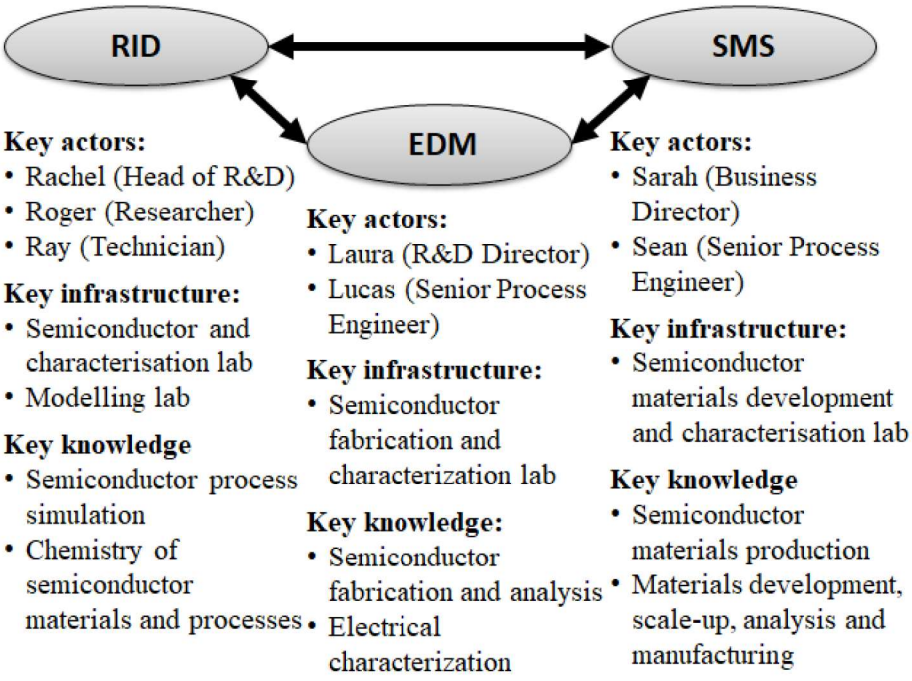


Figure 28 The key components and collaborative structure of the NPMaterial case study

The structure shown in Figure 28 enabled the formation of different demi-regularities throughout the execution of NPMaterial. In identifying these demi-regularities, the most frequently occurring codes were used as a starting point. Table 41 shows the conditions, processes and outcomes that accounted for at least 40% of all the codes identified in NPMaterial.

Table 41 Most frequently occurring codes among the coded conditions, processes and outcomes in NPMaterial.

Coded conditions		**Coded processes**		**Coded outcomes**	
Frequency	Type	Frequency	Processes	Frequency	Type
50	*Management procedures*	47	*Reducing the commitment and satisfaction*	22	*New knowledge*
29	*Commitment and engagement*	16	*Learning*	5	*Subsequent inter-organizational relations*

Despite the prevalence of the *new knowledge*, *learning* and *subsequent inter-organisational relations* codes throughout the NPMaterial duration, the most dominant code was a weak adherence to *management procedures* by all the partners. The different participating entities generally

expressed that the partnership was very poorly managed by RID and showed a lack of coordination between RID and WES throughout the partnership and eventually also between NMS and the rest of the partners. This was also supported by the lack of involvement by WES and, at times, by RID which was emphasized in the interviews and noted as the second most coded condition, lack of *commitment and engagement,* and the first most coded process, *reducing the commitment and satisfaction*. For example, NMS reduced their involvement and efforts in the partnership because they did not see any potential commercial interest in further improving the nanoporous material developed by RID. However, WES was not showing their interest in RID's novel nanoporous material because they were not aware of it until the end of the partnership.

> *"…with NPMaterial the project started off and 10 months later or whatever there was a report that came in and what happened in between we have no idea… we got the report okay and we looked at all the results and we tried to start NP4Water [, a subsequent partnership with RID based on the results of NPMaterial]* (Karen at WES)

> *"I mean we weren't getting physically our hand dirty because there wasn't a lot to do for us until there were customers involved. And we never had customers."* (Ellie at NMS)

In addition, inadequate management and work plan changes were often highlighted in the interviews and documentation from where the illustrative quotes that follow are found.

> *"The management [by the partnership coordinator, RID,] was extremely poor. While the research could be quite good. The management was unreal…"* (Karen at WES)

> *"A two month extension to the project end date is requested. For two months I [Lisa] have been asked to work on another partnership…".* (NPMaterial Alteration Form submitted by Lisa at RID without notifying the consortium partners)

> *"…it clearly under-delivered in terms of what it was expected to achieve. So I think a lot of that came from uncertainty on WES. But also frankly it wasn't very well managed. And the*

same problem arouse with [a subsequent RDI partnership involving Lisa at RID and Karen at WES] (Peter at NanoAble)

The highlighted codes, work plan deviations and lack of coordination between the NPMaterial partners led to identifying the following demi-regularity:

"Poor partnership management results in conflict and change"

In spite of this, the *new knowledge* and *learning* codes found in the data triggered a tendency among WES and RID to establish three subsequent partnerships which leveraged the results of NPMaterial. This is reflected in the interview extracts that follow and that the second most coded outcome was *subsequent inter-organizational relations*.

"I [Lisa] was invited by SCP to their Battery research centre in Europe to present on the nanoporous material as a catalyst in battery applications. They were interested in the prospect of using nanoporous catalysts in a tubular format in battery cells. They encouraged me to seek funding to investigate this further and offered to act as an advisor if such a project came to pass." (NPMaterial Final report)

"Yeah, we got the report [from RID]. Okay. And we looked at all the results and we tried to start [the subsequent partnership] NP4Water with something that would actually work. But it wasn't as easy as we thought. But we found one particular niche application." (Karen at WES)

"Nanoporous material [developed at NPMaterial] will be investigated as the sensing platform for NP4Pharma… It [NP4Pharma] builds on the output from current NP4Water project and forerunner NPMaterial…" (NP4Pharma Proposal)

Ellie and Chris at NSM never found that the knowledge developed at NPMaterial would be of interest for NMS and decided to stop any future work and inter-organisational relations on this topic.

"...after a year we decided... well we've given it a go, it hasn't worked. Move on like you know." (Ellie at NMS)

Hence, the tendency that sharing new knowledge triggers subsequent inter-organizational relations when it is aligned with organisational interests led to the following demi-regularity in NPMaterial:

"The development and exchange of knowledge grows inter-organizational relations when it is supportive of organizational strategies."

As a summary of the data described, Table 42 shows the highlighted demi-regularities and codes together with other supportive codes and events found in the execution of NPMaterial.

Table 42 Demi-regularities and supportive codes and events in the NPMaterial Case

Demi-regularities	Supportive code acronyms[22]	"Supportive" events
"The development and exchange of knowledge grows inter-organizational relations when it is supportive of organizational strategies."	NK, SIOR, Le, PI and PPD.	1. NMS and WES increase participation when samples and reports are shared. 2. Three subsequent RDI partnerships created.
"Poor partnership management results in conflict and change"	MP, CE, RCS, RAWP and GDI.	1. NMS stops active involvement. 2. Work plan changes.

6.1.5 Cross-case analysis

Across the data of all the cases and the identified demi-regularities there was a strong emphasis towards how the development and exchange of knowledge maintained the RDI partnership in spite of the different challenges they faced. Hence, the identified demi-regularities can be classified according to whether they are related to knowledge tendencies or not. In terms of those that are knowledge related, the same demi-regularity was found in the PiezoPower, NpMaterial and

[22] The full list of codes and acronyms may be found in Appendix D

NanoGlide cases and the demi-regularity identified in the Connect case was almost identical. Because of this, as shown in Table 43, all the demi-regularities identified present a causal pattern whereby inter-organisational relations in the Connect case are sustained and in the other cases are grown if the knowledge developed and exchanged is supportive of the individual organisational strategies of the partners. These similarities allowed to elaborate the cross-case demi-regularity shown in Table 43 along with the demi-regularities found in all the case studies.

Table 43 Knowledge related demi-regularities identified

	Knowledge related demi-regularities identified
PiezoPower	*"The development and exchange of knowledge grows inter-organizational relations when it is supportive of organizational strategies."*
Connect	*"The development and exchange of knowledge sustains inter-organizational relations when it is supportive of organizational strategies."*
NanoGlide	*"The development and exchange of knowledge grows inter-organizational relations when it is supportive of organizational strategies."*
NpMaterial	*"The development and exchange of knowledge grows inter-organizational relations when it is supportive of organizational strategies."*
Cross-case	***"The development and exchange of knowledge sustains or grows inter-organizational relations when it is supportive of organizational strategies."***

However, among those that are non-knowledge related there is no clear consistency throughout the identified demi-regularities. As shown in Table 44, while the PiezoPower and NpMaterial case share the same demi-regularity, the NanoGlide and Connect cases have similar, yet different demi-regularity. Hence, not only there is no common demi-regularity across the cases but also no common demi-regularity among the successful RDI partnerships, PiezoPower and NanoGlide, and the unsuccessful RDI partnerships, NPMateiral and Connect

Table 44 Non-knowledge related demi-regularities identified

	Non-knowledge related demi-regularities identified
PiezoPower	*"Poor partnership management results in conflict and change"*
Connect	*"Poor partnership planning and unexpected events result in change."*
NanoGlide	*"Poor partnership planning results in conflict and change"*
NpMaterial	*"Poor partnership management results in conflict and change"*
Cross-case	***No dominant cross-case demi-regularity***

As a result, in the next step of the selected research method, the theoretical re-description of the data, builds on the following cross-case demi-regularity identified:

> *"The development and exchange of knowledge sustains or grows inter-organizational relations when it is supportive of organizational strategies."*

6.2 Theoretical re-description

The identified demi-regularity across all the cases points towards the development and exchange of knowledge in mediating RDI partnership development. It is thus possible to explain RDI partnership development as simple knowledge efficiency choices undertaken by the identified components of the inter-organisational relations established in the four RDI partnerships selected (see Figure 25, Figure 28, Figure 28 and Figure 26). However, doing so would be against the ontology of critical realism which considers that entities are irreducible to their independent components because new properties emerge from the synergies of the components in the entity's structure under study (Easton, 2010; Sayer, 2000; Wynn & Williams, 2012, 2020).

This emergence of properties characterizes the critical realism view of the world (Sayer, 2000). In critical realism, properties from the components and structures can be identified in the empirical data through abduction, also known as theoretical re-description (Danermark et al., 2002; Hoddy,

2019; Lennox & Jurdi-Hage, 2017; Wynn & Williams, 2020). In doing so, the theoretical perspectives on partnerships and RDI partnerships highlighted in Sections 2.4 and 3.3 were considered along with others such as the Dynamic Capabilities View (Teece, 2007; Teece, Pisano, & Shuen, 1997), Structuration Theory (Giddens, 1979) and the Chaos theories (Levy, 2007; M Alshammari, 2016; Stacey, 1993). However, none of these theories fitted completely with the empirical data collected. The most plausible interpretation of the empirical data was provided by the knowledge-based view as it is argued in what follows.

Even though the transaction cost economics, resource dependency, resource-based view and social network relation theories can provide valuable insights into particular subsets of the collected data, they fail to explicate how and why the RDI partnerships under this study develop. This is because the organisations and RDI partnerships in the case studies are mainly mediated by the development and exchange of knowledge rather than other aspects related to their resources, social networks or relational efficiency. For example, as shown in Figure 25, despite EDP's resources being similar and more comprehensive than those of RIA, EDP is interested in working with RIA and vice versa due to the development and exchange of knowledge as highlighted by staff at EDP and RIA.

> *"I told Mia I'll work on it [PiezoPower] until they find a replacement. Ended up they never found a replacement and… then I realised this is actually something interesting and I decided to stay on it [PiezoPower] and this is actually what led me to be a staff researcher and write these other proposals and follow-up projects. Because you know, in the past I never did any work on the [area of PiezoPower] This was a new area for us, RIA, and also EDP."* (Oliver at RIA)

> *"So, from EDP's perspective… it [PiezoPower and the subsequent relations with RIA] was basically exposing EDP to a material, technology we didn't know anything about."* (Olga at EDP)

Following with the same RDI partnership as an example, it is also evident from the numerous incomplete tasks in the work plan (see Table 20) and the interviews that the relationship between

EDP and RIA was not focused on minimising costs but focused on fostering the development of knowledge and exchange.

> *"...right from the beginning from Piezopower we knew okay we are going to work on piezoelectric, we are going to look at developing the materials... Now we didn't think it take as long as it did."* (Oliver at RIA)

As a result, a theoretical re-description based on a knowledge-based approach is selected to allow going beyond efficiency discussions of the analysed RDI partnerships in each case study. Moreover, the knowledge-based approach re-description is contextualised by leveraging the knowledge-accessing theory of strategic alliances (R. M. Grant & Baden-Fuller, 1995, 2004) which is developed for exploitative strategic alliances such as the RDI partnership case studies selected in this research (see Section 4.3.2 for the selection criteria of case studies).

The knowledge-access theory indicates that RDI partnership structures main advantage lies on knowledge exploitation, through the partners' knowledge base sharing and access, rather than explorative alliances where knowledge is transferred and acquired among the partners (R. M. Grant & Baden-Fuller, 1995, 2004). In this way, RDI partnerships' main advantage is that organisations can access and share each other's knowledge to develop new products. Hence, from a knowledge-access theory perspective, RDI partnerships can be considered as structures where there is a fit between the knowledge and product domains of the partners and agency is shaped by the knowledge access needs of the partners to develop new products.

Taking a knowledge-access view of RDI partnerships is distinctive from dominant approaches in the literature; Transaction Cost Economics, Resource Based View, Knowledge-Based View, Social Network Theory and Resource Dependence Theory (He et al., 2020). In addition, doing so from the stance of critical realism, provides a novel approach where the mechanisms in the real domain revolve around causal explanations on how the RDI partnerships need to share their knowledge to develop new products. This re-conceptualization of the phenomena provides a contrasting view to

previous work in the literature which is typically based on describing, predicting and understanding RDI partnerships and alliance development on the basis of

- efficiency (Dyer, 1997; J. E. Oxley, 1997),
- acquiring resources or knowledge (Barney, 1995; Eisenhardt & Schoonhoven, 1996; Parker, 2012; Patthareeya & Lorsuwannarat, 2012),
- social capital (Gulati, 1995), and
- dependencies (Rice & Galvin, 2006; Vincent & O'Mahoney, 2018).

Such explanations are typically based on TCE, RBV, KBV, SNT and RDT and would fail to explain the patterns shown in the data. For example, despite the inefficiencies and lack of knowledge acquisition, social connectedness and dependencies in the NPMaterial case, RID and WES partnership resulted in a subsequent RDI partnership while NMS stopped collaborating with RID and WES. In this way, the collected data is redescribed to be seen from a different frame of reference and given a new meaning (Danermark et al., 2002).

As a result, critical realism and a knowledge-access view of the collected data, allows to apprehend the deeper causal mechanisms which shape agency throughout the four selected case studies. However, if these causal mechanisms are activated in other contexts, agency would be shaped differently. Because of this, the undertaken theoretical re-description makes possible to avoid near-sighted perspectives from the analysis of the collected data.

6.3 Retroduction and empirical corroboration

Retroduction infers causal mechanisms from the collected data by building on prior knowledge, theories and the undertaken theoretical re-description. In doing so, the conditions which activate these causal mechanisms along with their outcomes are also identified. Hence, in this Section the data and identified demi-regularity are retroduced to identify the causal mechanisms which explain how the characteristics of nanotechnology RDI partnerships mediate their development. For this

RDI partnerships are taken as a starting point and, for clarity, throughout this Section the identified causal mechanisms are shown in **bold** and their conditions and outcomes are shown in *italics*.

Building on the knowledge access perspective identified in the theoretical re-description and the identified cross-case demi-regularity, the analysis of the collected data reveals that all of the cases and interviewees point towards the existence of key knowledge within the partners that, when shared, can accelerate the organisational innovation strategies of each partner. By collaborating in an RDI partnership, the partners created a *space of possibilities* (Bygstad & Munkvold, 2011) where their distinctive and complementary knowledge could be accessed. For example, in the NanoGlide RDI partnership it is possible to develop novel combinations of nanomaterials and polymers for improved medical devices because a *space of possibilities* is created when unique knowledge from the partners can be shared to further develop it collaboratively. In this way, NanoGlide allows to integrate RIC's novel low friction nanomaterials expertise with MPS' materials fabrication and MDM's medical devices knowledge.

> *"…[NanoGlide] was very much focused on his [Sophia's lab and group] expertise area which probably contributed to success… as far as I know MPS would have had a background need for this [improved lubricity novel nanocomposite] material anyway… So I think their own need drove the project."* (John at RIC)

> *"So I suppose we [MDS]... wanted to do some technology development projects. We knew the areas we wanted to investigate. So lubricity. We knew that there were… academic institutions that had experience…. NanoGlide really fitted within the more with... well its applicable to lots of different business units. [However] The direct need is in the heart procedures business unit…"* (Emma at MDS)

Building on the created *space of possibilities*, then the organisations in the analysed RDI partnerships had to agree to purposively develop and exchange knowledge which accelerates their organisational innovation strategies. For this, each partner had to manage access to their knowledge components by considering whether they allow other organisations to access to their knowledge,

access other organisation's knowledge or both as in the open innovation model described by (Chesbrough, 2003, p. 45). Following on the NanoGlide example, RIC, MPS and MDM selected what novel composites could be developed and tested from the available combinations of nanomaterials and polymers. This was highlighted as follows in the interviews by John at MPS and Emma at MDM and in the co-owned IP by RIC and MDM shown in Table 31.

> *"...depending on where we were at [in NanoGlide development], MPS would have a practical research role as well... We [RIC] had a lot of experience developing materials and testing materials because of that characterisation. But probably we were a bit weaker in the scale up and commercial production which is where the IPC guys have their bread and butter. There was definitely learning process between the two of us and that's one I found most useful."* (John at RIC)

> *"So RIC and MPS were sort of, happy to add more and more materials. Felt like their objective was to test as many materials as possible. While we felt that our objective was to figure out if actually good enough or not. So it was like two different motivations within the project. We had to try to keep sort of... keep the lid on adding more and more and more materials."* (Emma at MDM)

These events in NanoGlide resemble open innovation which is defined by Chesbrough, Vanhaverbeke, and West (2014, p. 24) *"as a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with each organization's business model"*. Hence, it is plausible that RDI partnerships can be causally explained through the **open innovation** mechanism. The outcome of this mechanism is *new knowledge* which is shared among the partners in the RDI partnership. Again, in NanoGlide this is exemplified with the new composite prototypes developed by RIC and shared among all the partners as indicated in the NanoGlide documentation (see Table 28 for an excerpt).

Moreover, the **open innovation** causal mechanism along with the associated conditions and outcomes can be observed in three different consecutive periods of time throughout the NanoGlide execution. The first period was from approximately month 1 to 6, the second from month 6 to 8 and the third from 8 to 10 as shown in Table 45. Interestingly, the **open innovation** outcomes, *new knowledge*, modified the contextual conditions of the phenomenon by increasing the *space of possibilities* among the partners. This contributes to triggering again the activation of the causal mechanism in a self-reinforcing dynamic. The open innovation mechanism along with its contextual conditions and outcomes resemble the view of learning as an interactive process at the inter-organisational level where partners share, interpret and integrate knowledge (Rajala, 2018; Seo, 2020).

Table 45 Observations of the open innovation mechanism, conditions and outcomes throughout the NanoGlide duration.

Empirical evidence at NanoGlide	**Conditions**	**Mechanism**	**Outcomes**
	Space of possibilities	**Open innovation**	**New knowledge**
First observation (months 1 to 6 approx.)	RIC's new materials expertise can be integrated with MPS' materials fabrication and MDM's medical devices knowledge	Novel composites developed and tested in a lab by RIC with inputs from MPS and MDM.	Novel composites developed in a lab and tested.
Second observation (months 6 to 8 approx.)	Novel composites developed in a lab available for further refinement and tests.	Selected composites are improved and fabricated in an industrial plant by MPS with inputs from RIC and MDM. Tests are done by RIC and MDM.	Novel composites and tests.
Third observation (months 8 to 10 approx.)	Novel composites developed in an industrial fabrication plant available for further refinement and tests.	Selected composites are improved further by RIC and MPS, fabricated by MPS and extruded in tube format at RIS with inputs from MDM.	Novel composites further improved, extruded in tube format and tested.

As a summary, Figure 29 shows a representation of the self-reinforcing dynamic of the identified condition, causal mechanism and outcome in the NanoGlide RDI partnership.

Figure 29 Representation of the identified condition, causal mechanism and outcome in the NanoGlide RDI partnership

Although the **open innovation** mechanism can explain why the *space of possibilities* among the partners is increased each time is enacted, it does not account for how the partners create a *space of possibilities* with specific components of their knowledge bases and not others. This poses the following question in the NanoGlide case study:

> *How did the NanoGlide partners share specific components of their knowledge bases to create a space of possibilities which, in turn, results in the open innovation causal mechanism?*

This question can be reformulated to any RDI partnership as follows.

> *How do the elements of structure in RDI partnerships interact to create the contextual conditions which, in turn, enact the open innovation causal mechanism?*

Given the open systems perspective of critical realism, this question can be answered by searching for other mechanisms which influence the identified contextual conditions of **open innovation** (Bygstad & Munkvold, 2011; Mingers et al., 2013). In doing so, the starting point to search for this

causal mechanism is the organisational level because each organisation in NanoGlide is ultimately responsible to share or not specific components of their knowledge bases.

Hence, the data is analysed at the organisational level to identify a plausible causal mechanism that explains how the *space of possibilities* is renewed throughout the duration of NanoGlide. The first time it is observed that the *space of possibilities* is modified is around month 6 when, individually, all the partners conclude that the shared knowledge is of interest to accelerate their organisational innovation strategies and more time is required to undertake further work jointly. This interest was reflected in the four month extension noted in the NanoGlide documentation and articulated during the interviews with staff at MDM and RIC as follows.

> *"I remember talking with Peter that we could extend it. And I think because we were getting very successful initial results, it was the interest from MDM to maintain and keep going. So I think maybe at the 6 month stage we were only scratching the surface."* (Jacob at MDM)

> *"With an extra few months we can push this a lot further and so that it sort of naturally came out of it [NanoGlide] rather than breaking I [NanoGlide] t and going into a ... full [different contractual project]... just continue on. It was basically just the results... with an extra few months we were able to say this is feasible and here it is."* (John at RIC)

Subsequently, a new *space of possibilities* is created when MDM shares more knowledge on medical devices, for example around performance requirements, and their specific needs. This was articulated by Peter and Jacob at NanoAble and MDM respectively.

> *"...it was fine to be able to produce flat plates [with the novel composites] in the lab in RIC... But... we don't use flat plates. We use tubes.... I think maybe at the start of the project maybe it wasn't scoped... And maybe we changed the go post like in that... well look we actually want a tube... because the dispersion [of nanomaterials in composites] might be different at a flat plate as opposed to a tube."* (Jacob at MDS)

"There were some changes around the performance level that MDS required. Or the performance enhancement. So... there was a meeting in the north of the country where MDM were trying to shift the performance enhancement that was required." (Peter at NanoAble)

Finally, another *space of possibilities* is created at the end of NanoGlide when the development and test results of novel composites extruded in tube format were shared among the partners. Interestingly, the partners' assessment and view on the potential opportunities which could derive from these results were very different. While MDM just viewed the results as extending their materials knowledge without any potential commercial value, RIC and MPS assessed these results as very promising for future inter-organisational relations and commercial opportunities. These views are clearly reflected in the numerous and different types of inter-organisational relations established between RIC and MPS after the end of NanoGlide (see Table 30 for details) as well as in the interview quotes with MDM and NanoAble staff that follow.

"...we didn't see that same reduction in friction when we went to the tube... The other one was...I think during the course of the project we did identify two or three polymer suppliers who were also claiming to have reduced the coefficient of friction by adding additives. So why would MDS invest heavily into something that we can buy off the shelf. And then also, you know, MDS aren't a multi-billion extrusion company... So we don't have the R&D resources to go chasing a project of this scale the same way an extrusion or a polymer company would. So we probably felt we weren't in a position to compete and that we would leave the polymer expertise to the polymer experts." (Jacob at MDS)

"...we understand more about materials as a result of the project." (Emma at MDS)

"They [MPS] had an idea that there are customers out there but they didn't have a customer... we gave them a license from NanoGlide so they could launch the product. They launched the product, customers trialed it. Then customers came back and said its very good but... can you do this. And they were like... back to RIC." (Peter at NanoAble)

As highlighted, at three different occasions the partners created different *spaces of possibilities* which *"involves gathering and filtering technological, market, and competitive information from both inside and outside the enterprise, making sense of it, and figuring out implications for action"* (Teece, 2007, p. 1326). Hence, it is plausible to pose the existence of a **sensing** mechanism as described by Teece (2007) at the organisational level. This mechanism is observed to be activated under the contextual conditions of *increased knowledge access* and results in *actions to shape developments*. The sensing mechanism along with its contextual conditions and outcomes resemble the view of learning as a capability where the absorptive capacity of the organisations plays a key role in how they learn, which is part of the sensing mechanism according to Teece (2007), and that learning takes place at the organisational level (Rajala, 2018; Seo, 2020). As a summary Figure 30 shows a representation of the identified **sensing** mechanism along with the associated condition and outcome identified.

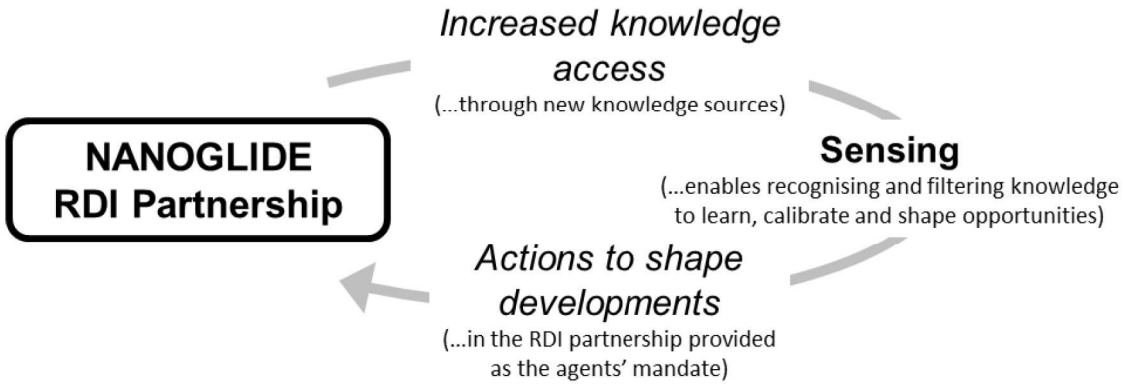


Figure 30 Representation of the sensing mechanism along with the associated contextual condition and resulting outcome identified in the NanoGlide RDI partnership

In addition, Table 46 provides a brief description of the identified *increased knowledge access* condition, **sensing** causal mechanism and *actions to shape developments* outcome over three observations during the NanoGlide execution.

Table 46 Observations of the sensing mechanism, contextual conditions and outcomes throughout the NanoGlide duration.

NanoGlide	Contextual conditions	Mechanism	Outcomes
	Increased knowledge access	**Sensing**	**Actions to shape developments**
First observation (month ~ 6)	Novel composites developed in a lab and tests shared.	All partners review positively the tests carried by RIC and see potential commercial opportunities.	All partners interested in extending the duration of NanoGlide. MPS is available to share fabrication knowledge.
Second observation (month ~ 8)	Novel improved composites and tests shared.	All partners review positively the tests carried by RIC and MDM and see potential commercial opportunities.	MPS and RIC want to continue sharing process and fabrication knowledge. MDM willing to share more medical devices knowledge and extrude composites in tube format.
Third observation (month ~ 10)	Novel composites available for further refinement and tests.	RIC and MPS view the results very positively and plan to exploit them commercially. MDM extend their knowledge base but do not see any application for their products.	RIC and MPS motivated to license the IP and create new partnerships. MDM interested in exploring other composites.

The identified *actions to shape developments* outcome from the **sensing** mechanism at the organisational level mediates the inter-organisational conditions by modifying the *space of possibilities* in the NanoGlide RDI partnership. At the same time, the *increased knowledge access* condition of the sensing mechanism is mediated by the *new knowledge* outcome of the open innovation mechanism at the inter-organisational level. Hence, it is concluded that these mechanisms are co-evolutionary and synergistic despite they operate at different levels.

Figure 31 shows a representation of the highlighted co-evolutionary synergistic multi-level mechanisms in NanoGlide, contextual conditions and outcomes.

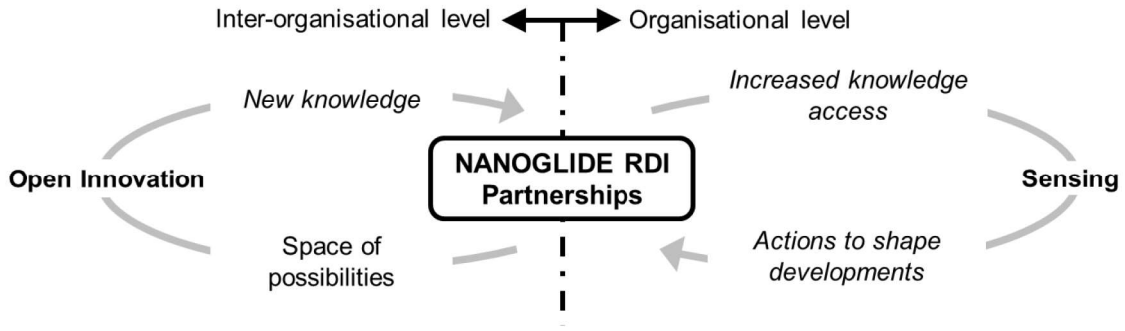


Figure 31 The co-evolutionary synergistic multi-level mechanisms of NanoGlide and their conditions and outcomes

Following Wynn and Williams (2012, 2020), the identified co-evolutionary synergistic multi-level mechanisms, conditions and outcomes in NanoGlide were validated across the other three cases studies (see Table 47 for more details). Similarly to how it was described in NanoGlide, *"the temporal unfolding of events and longitudinal data"* (Wynn & Williams, 2012, p. 802) from primary and secondary sources was examined to validate that the identified mechanisms, conditions and outcomes in NanoGlide are empirically corroborated across the other three cases, Piezopower, NPMaterial and Connect. In doing so, it was observed that the **open innovation** and **sensing** mechanisms were enacted three times in the successful RDI partnerships, NanoGlide and Piezopower, and only twice in those that were considered unsuccessful, NPMaterial and Connect, as per the case selection process in 4.3.2. Moreover, at the inter-organisational level the **open innovation** mechanism of successful partnerships required the participation of a larger number of partners than in the unsuccessful ones. Likewise, at the organisational level the **sensing** mechanism of successful partnerships was enacted in more partners than in the unsuccessful ones. Table 47 shows illustrative examples of the observations in the collected longitudinal empirical data which validates the identified conditions, mechanisms, and outcomes across the four cases in this study.

Table 47 Illustrative examples of the observations in the collected data which validates the identified conditions, mechanisms and outcomes across all the cases.

	PiezoPower	**Connect**	**NanoGlide**	**NPMaterial**
Space of possibilities	Potential to combine the semiconductor materials, modelling, process development and device fabrication knowledge at RIA and EDP.	RIB's modelling and process knowledge can support the integration of the materials and device fabrication knowledge at SMS and EDM.	RIC's new materials expertise can be integrated with MPS' materials fabrication and MDM's medical devices knowledge.	RID's new nanomaterial can be integrated in WES' water sensing and NMS's materials fabrication expertise
Open innovation	RIA and EDP select materials to be deposited and RIA starts depositing them.	SMS and EDM agree to deposit new materials with RIB's support.	Novel composites developed and tested in a lab by RIC with inputs from MPS and MDM.	RID and NMS share knowledge to improve and scale-up the fabrication of the new nanomaterial.
New knowledge	Initial materials deposited and tested by RIA.	Joint developments on depositing, characterising and simulating new materials reactions are shared.	Novel composites developed in a lab and tested.	RID develops and characterises an improved version of the new nanomaterial.
Increased knowledge access	Initial materials deposited and tested by RIA are shared with EDP.	Simulations, process and characterisation data on the deposition of new materials	Novel composites developed in a lab and tests shared.	RID shares the new nanomaterial and tests with NMS
Sensing	RIA and EDP view the progress as slow. It is, thus, not possible to assess their commercial value.	All partners review the results and do not see commercial opportunities.	All partners review positively the tests carried by RIC and see potential commercial opportunities.	RID and NMS review the tests and NMS undertakes further characterisation. NMS sees no commercial value in the new nanomaterial while RID expects it can benefit many industries.
Actions to shape developments	EDP requests RIA to appoint a project manager to avoid future delays.	All partners interested in extending the duration of Connect to deposit new materials and carry more simulations.	All partners interested in extending the duration of NanoGlide. MPS is available to share fabrication knowledge.	NMS stops contributing actively to NPMaterial. RID plans to continue working on improving the new nanomaterial for different applications.

As a result, it is concluded that the identified co-evolutionary synergistic multi-level mechanisms and their conditions and outcomes provide a causal explanation to how the characteristics of nanotechnology RDI partnerships mediate their development. Figure 32 shows a graphical representation of these synergistic multi-level mechanisms in nanotechnology RDI partnerships along with their associated conditions and outcomes.

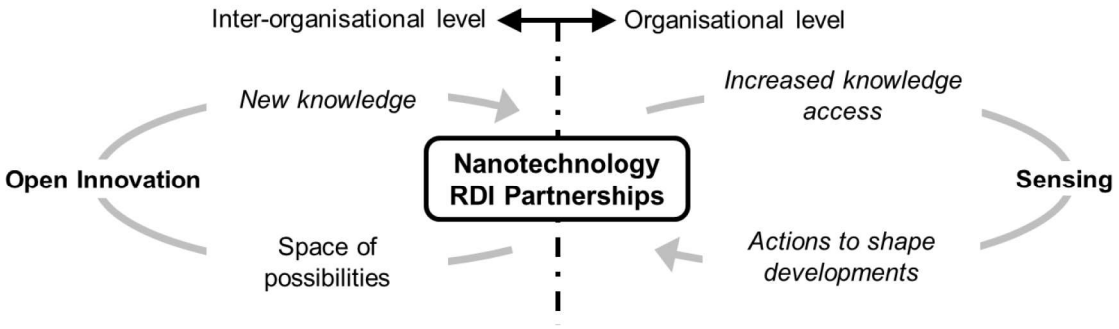


Figure 32 The co-evolutionary synergistic multi-level mechanisms of nanotechnology RDI partnerships and their conditions and outcomes.

7 Discussion, contributions and implications

This Chapter discusses and summarizes the findings and contributions of this study to answer the following research question identified in Section 1.4:

> ***How can the characteristics of nanotechnology RDI partnerships mediate their development?***

In answering this question, this study provides a multi-level explanation of how the retroduced key characteristics – conditions, mechanisms and outcomes – of nanotechnology RDI partnerships can mediate their development. By developing an explanation which identifies how these key characteristics co-evolve and are enacted at the organisational and inter-organisational level, this study sheds light into the "black-box" of RDI partnership development and guides the management of RDI partnerships. At the inter-organisational level, it was shown that RDI partnerships can be causally explained through the open innovation mechanism which is triggered when the partnering organisations create a space of possibilities where their distinctive and complementary knowledge can be accessed. The resulting characteristic of the open innovation mechanism is the new knowledge outcome which is shared among the partners in the RDI partnership.

At the organisational level, this new knowledge creates a new characteristic which is the condition of increased knowledge access by the partners. In turn, the increased knowledge access triggers the sensing mechanism identified in the Dynamic Capabilities View theory (Teece, 2007) which results in the outcome of actions to shape the RDI partnership development at the inter-organisational level. Hence, the highlighted co-evolutionary and synergistic key characteristics –conditions, mechanisms and outcomes can mediate re co-evolutionary and synergistic despite they operate at different levels of RDI partnership development. As a result, the highlighted key characteristics in terms of conditions, mechanisms and outcomes provide a plausible explanation of how they can co-evolutionary and synergistically mediate RDI partnership development by operating at the organisational and inter-organisational level.

In what follows, Section 7.1 presents a discussion of these findings and their comparison with the extant literature while Section 7.2 presents the different research contributions of this study. In this way, Section 7.2.1 focuses on the theoretical contributions, Section 7.2.2 on the empirical contribution, Section 7.2.3 on the methodological contributions and Section 7.2.4 on the policy and practice contributions. Then the chapter concludes with Section 7.3 by describing the limitations of this study and implications for future research.

7.1 Discussion

In this Section the findings are discussed with a twofold objective. Initially, in Section 7.1.1 the findings are discussed with a view towards developing and substantiating a critical realist theory of RDI partnerships by showing how it is built on critical realism. Then in Section 7.1.2 the findings are discussed with a view to describe how they extend or confirm previous studies by comparing them with the extant literature.

7.1.1 Towards a critical realist theory of RDI partnerships

The focus thus far in this study has been on the identified contextual conditions, mechanisms and outcomes (see e.g. Table 45, Table 46, Table 47). Nonetheless, in this study RDI partnerships are seen as structures which, in line with critical realism, are part of an open system. Therefore, this perspective of social systems implies that even though the identified mechanisms activated in an RDI partnership structure and nanotechnology context generated the observed outcomes, they may not take place in the future. As RDI partnerships are part of complex and open social systems such as competing RDI partnerships, alliance portfolios and industrial networks, the identified mechanisms are contingent on extrinsic conditions. Epistemic relativism implies that the identified conditions, mechanisms and outcomes shown in Figure 33 are provided as plausible explanations of the activated mechanisms in the given RDI partnership structures and nanotechnology context of this study.

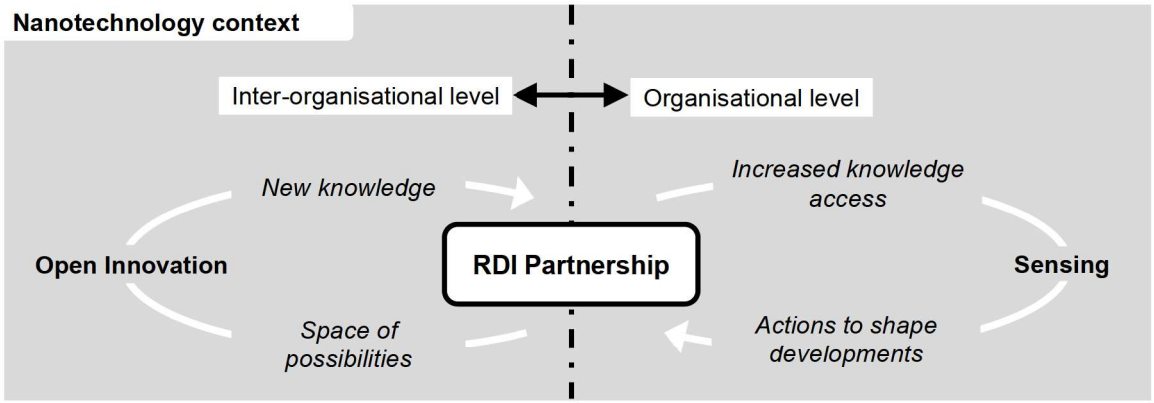


Figure 33 The contextual conditions, mechanisms and outcomes of RDI partnership structures in a nanotechnology environment.

The identified mechanisms in this study, open innovation at the inter-organizational level and sensing at the organizational level, are in line with the types of mechanisms[23] that, according to Delanda (2006), should be searched for in critical realism studies. On one hand, open innovation falls within the micro-macro mechanism since the interactions of the partnering organizations generates new knowledge for the RDI partnership. On the other hand, sensing falls within the macro-micro mechanism since the shared knowledge in the RDI partnership facilitates and limits the behavior of partnering organizations. In this way, the interplay of the micro-macro and macro-micro mechanisms mediates the multi-level RDI partnership structure as time unfolds in a cyclical and synergistic manner.

Even though this interplay of mechanisms could be thought to have a mutual reinforcement dynamic, it was not always the case. For example, the observation of the mechanisms in the NPMaterial case, summarized in Table 47, shows that mutual reinforcement is not warranted. In this case study, the new knowledge outcome resulting from the open innovation mechanism yielded different outcomes in the sensing mechanism of the NPMaterial partners. While the new knowledge did not reinforce the sensing mechanism and made NMS stop their activity in

[23] The types of mechanisms defined by Delanda (2006) are as follows.

- Micro-macro mechanisms which explain how the interplay of different components generate an outcome at a higher level.
- Macro-micro mechanisms which explain how the higher level facilitates and limit the different components.

NPMaterial, the same new knowledge reinforced the sensing mechanism of RID which, at the same time, reinforced the open innovation mechanism and developed more new knowledge. It is therefore concluded that RDI partnerships can be seen as multi-level structures where synergistic mechanisms at the inter-organizational and organizational levels can be reinforced and constrained by the same or different contextual conditions. This supports and extends the literature which had suggested the dual behaviour of conditions in the formation of RDI partnerships (Sakakibara, 2002). From a critical realist view of causation, the highlighted dual behaviour of conditions can be illustrated as follows in Figure 34.

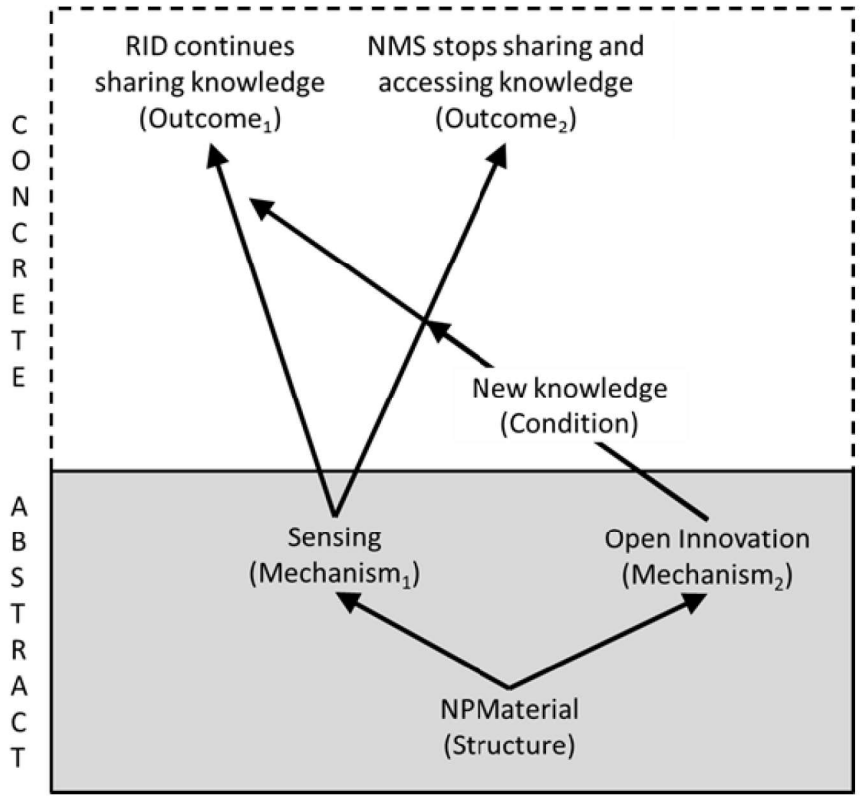


Figure 34 The dual behaviour of conditions from a critical realist view of causation

The NPMaterial observation of the open innovation mechanism also illustrates how the RDI partnership structure allowed its agents – the researchers and managers of RID and NMS – to develop new knowledge by integrating knowledge from RID and NMS. However, at the same time, these agents have the ability to transform RDI partnership structures through agency. In the NPMaterial example, the RDI partnership structure was transformed when, through the sensing

mechanism, NMS disengaged from the partnership by not sharing or accessing knowledge. This confirms that the proposed theorization of RDI partnerships follows the critical realist transformation model of social research where structure and agency are distinct and their interaction leads to transformation following the intentions of agents (Danermark et al., 2002).

Finally, in line with critical realism, the analysed multi-level RDI partnership structures presented emerging properties inferred from the interplay of the interconnected organizations in the RDI partnership structures. This reflects the concept of emergence in critical realism which states that the emergent properties of structures cannot be explained by its components or the aggregation of its components. For example, in the PiezoPower case the development of new knowledge in the form of a piezoelectric material cannot be reduced to its partners. This is reflected as follows in the interviews when Mia at RIA highlights that EDP had not been able to develop independently the same outcomes as they did together and Olga and Harry EDP highlight how the PiezoPower structure lead to a range of new outcomes at EDP.

> *"It sounds like it's very easy just to make the piezoelectric material... oh yeah you just sputter X, put Y and you get XY... Well they [EDP] knew it wasn't simple because they'd tried it in the past before the PiezoPower RDI partnership."* (Mia at RIA)

> *"...we consider that the main thing we got out of the PiezoPower project was knowledge about the piezoelectric material and the understanding of our work and its possibilities which is being used in an application and it would go into commercial products in that space. We have no doubt about that."* (Olga at EDP)

> *"So it [PiezoPower] became a platform technology for many different initiatives that you know spread across a large range of applications."* (Harry at EDP)

In this way, the structural development and properties of RDI partnerships is not predefined and are constructed via the emerging interactions between the sensing mechanism at each partner and the open innovation mechanism at the inter-organizational level. Such a constructive approach embeds

a high degree of uncertainty in RDI partnership development and can disrupt previous assumptions and pre-established development paths (Van de Ven & Poole, 1995). This indicates that RDI partnerships development involves emergent developmental processes in line with the concept of emergence in critical realism and its open future view of the world (Sayer, 2000, pp. 13-15). At the same time, the explanation provided for nanotechnology RDI partnerships indicates that the different levels within RDI partnerships – individuals, groups and organizations as shown in Figure 5 – are nested levels which conflate in the RDI partnership structure via the open innovation mechanism. As a result, the RDI partnerships process theory provided falls within the teleological type because it has a constructive and nested developmental view of change for the entity under study, RDI partnerships (Van de Ven & Poole, 1995).

Given the discussed dynamics, openness and micro-macro and micro-macro aspects of the identified mechanisms along with the structural emergence of RDI partnerships and importance of agency, it can be concluded that the identified mechanisms are consistent with the metatheory of critical realism and its transformational model of society. As such, these mechanisms must be recognised as plausible explanations of RDI partnerships in the nanotechnology context which, even though they are fallible reflections of reality, provide a knowledge base to continue refining our understanding of reality.

7.1.2 Comparing the findings to the extant literature

While research on RDI partnerships and encompassing bodies of research focused on alliances and inter-organizational relations rarely take a philosophical position (Beamish & Lupton, 2016), this study takes a critical realism stance. This contrasts with the RDI partnerships, alliances and inter-organizational relations studies which typically reflect a positivistic approach since they are dominantly based on quantitative research designs drawing from secondary sources of data (Gomes et al., 2016; Lahiri et al., 2021; A. L. Oliver & Ebers, 1998). In fact, only a few studies in the area of inter-organizational relations (see e.g.Easton, 2010; Easton et al., 2000; Ryan et al., 2012;

Vincent, 2008) were found to adopt a critical realism approach and none in the alliances, partnerships or RDI partnerships bodies of literature.

Because of this, the undertaken critical realist theorizing complements previous studies by emphasizing the role of agency and going beyond variance theory development. In addition, the use of critical realism enabled the re-description of the collected data with the knowledge-access theory which, in Section 6.2, was shown to provide superior understanding and departed from the dominant theoretical approaches used in the literature, TCE, RBV, KBV, SNT and RDT (Barringer & Harrison, 2000; Beamish & Lupton, 2016; Parmigiani & Rivera-Santos, 2011). It can, thus, be concluded that the use of both critical realism and knowledge-access theory enables a new approach to the study of RDI partnerships, and potentially to other types of alliances, which complements the extant literature.

As a result of the critical realist approach and leveraging a knowledge-access theory re-description, it is shown how the identified sensing and open innovation synergistic mechanisms, based on the Dynamic Capabilities View (DCV) and open innovation paradigm respectively, interact along with the contextual conditions and outcomes. This responds to calls from scholars and wider strategic issues in relation to capturing the links between the DCV and open innovation literature strands (Randhawa, Wilden, & Hohberger, 2016; Teece, 2007; Vanhaverbeke & Cloodt, 2014). For example, Hutton, Demir, and Eldridge (2021, p. 3), highlight that *"...theoretical insight into the process-level mechanisms by which OI [Open Innovation] can contribute to a firm's DC [Dynamic Capabilities] has not yet been extensively developed."*.

As the identified open innovation mechanism is at the inter-organisational level and the sensing mechanism is at the organisational level, the reviewed literature in the field of partnerships and adjacent bodies is enriched in several ways. First, it accounts for hitherto unobserved links between RDI partnership relations and new knowledge outcomes with the partners' organisational innovation strategies and vice versa (Kohtamäki et al., 2018). In this way, the identified open innovation and sensing mechanisms explain how new knowledge is developed through inter-

partner relations and the partners' organizational innovation strategy drive the new knowledge access and sensing to shape the RDI partnership. Secondly, the multi-level approach is complementary because according to Nippa and Reuer (2019, p. 571) the *"great majority of past research papers puts organizations, i.e., the IJV or the parent firms, in the center of their analyses"*.

It is important to highlight that this was possible by leveraging the novel RDI partnership development model in Figure 5 as a sensitizing device and through the use of a case study research approach which departs from *"most [of the] empirical studies on R&D partnerships and other forms of inter-firm collaboration [which] are based on survey–research and, therefore, usually of a cross-sectional nature."* (Hagedoorn, 2002, p. 477). For this, the case study approach was longitudinal, included successful and failed RDI partnerships, and was underpinned by different data sources from at least two partnering organisations and multi-level data such as interviews at the inter-organizational level, organizational level, and individual level – as described in Section 4 and, particularly, Section 4.3.3. According to Dyer et al. (2007), this data collection strategy differs from previous studies and enables the researcher to *"...assess empirically whether companies participating in the same alliance have similar assessments of alliance performance"* (p. 18). In line with Dyer et al. (2007), the analysed case studies show that the partners can have different views on the performance of RDI partnerships.

This case study design and data collection strategy along with the novel model in Figure 5 have therefore provided a vantage point to overcome major blind spots – single-party, single-level and single time conceptualization – in the literature as well as other limitations highlighted in this Chapter (Lumineau & Oliveira, 2018; Martínez-Noya & Narula, 2018; Steinmo & Rasmussen, 2016). In this way, the study acknowledges the multi-level, multi-party and co-evolutionary elements of RDI partnerships to account for the perceptions each partner may have towards the RDI partnership, the interactions among levels and the conceptualization of time which is intrinsic to the involved partners and the RDI partnership created (Lumineau & Oliveira, 2018; Martínez-Noya & Narula, 2018; Steinmo & Rasmussen, 2016).

Within the alliance performance literature, the dominant view is that performance is determined by inter-organisational or organisational contextual conditions such as knowledge, capabilities, absorptive capacity, location and more (Gomes et al., 2016). However, this study shows that alliance performance is determined by the contextual conditions, outcomes and agency at the inter-organisational and organisational level. In addition, this study found that the literature typically views contextual conditions and outcomes as static to alliances such as RDI partnerships. However, the undertaken analysis concludes that contextual conditions and outcomes are shaped by the interactions at the inter-organisational and organisational level resulting from the synergistic interactions of the sensing and open innovation mechanism.

In addition, this study shows that the mediating effect of contextual conditions and RDI partnership outcomes fluctuates along with the evolution of the partners' sensing mechanism and the inter-organisational open innovation approach to knowledge sharing – inside-out, outside-in and both inside-out and outside-in from an organisation. In this way, this study responds to the call for a co-evolutionary perspective in strategic alliances by Koza and Lewin (1998) and their view that *"...the absence of co-evolutionary modeling and empirical studies is indicative of new directions that research on alliances might take"* (p. 261). Despite this early call, this study found that co-evolutionary perspectives are still lacking even if they have the potential to open new perspectives and avenues for research (Bidault, 2020; Das & Teng, 2002). Das and Teng (2002) highlights that *"Alliance co-evolution is of research interest because, after all, strategic alliances [such as RDI partnerships] uniquely represent a system consisting of multiple elements, i.e., the partners and the alliance per se… The literature has been unclear about the elements of an alliance co-evolutionary system."* (p. 738). Hence, the findings of this study advance research in the area of RDI partnerships and adjacent bodies like alliances because it identifies the co-evolutionary elements, contextual conditions, mechanisms and outcomes, and explains how these elements interact and are interconnected over time at the organisational and inter-organizational level.

Furthermore, the findings of this study are in line with and confirm previous key studies as follows. First, the organisational and inter-organisational contextual conditions, mechanisms and outcomes

found are supported by the literature review in Section 2 which concluded that the development of RDI partnerships consists of multiple organisations collaborating through co-evolutionary, multi-level conditions, processes and outcomes (see e.g. Aldrich & Sasaki, 1995; Delbufalo, 2012; Ekanayake, Childerhouse, & Sun, 2017; He et al., 2020; Lumineau & Oliveira, 2018; Q. Xu & Renyong, 2009; Zaheer et al., 2010). Second, the dynamics of the identified sensing and open innovation mechanisms is cyclical in line with the dominant view in the inter-organizational relations, alliances and partnerships literature (see e.g. Das & Teng, 2002; Doz, 1996; Lahiri et al., 2021; Majchrzak et al., 2015; Ring & Van de Ven, 1994).

Third, the underexplored area of inter-organisational literature on strategic alliances, including R&D alliances, and networks development present co-evolutionary, cyclical and multi-level types of development (Das & Teng, 2002; Doz, 1996; He et al., 2020; Martínez-Noya & Narula, 2018; Todeva, 2006; Yang et al., 2021) similar to those found in this study of RDI partnerships. However, the multi-partner vertical exploitative nanotechnology RDI partnerships under study also showed higher complexity due to the increasing multiplicity and co-existence of heterogenous interactions and a prominent and leading industrial role in RDI partnership development to accelerate the uptake and exploitation of nanotechnology-enabled outcomes.

Fourth, the common governance framework of the RDI partnerships under study as well as the literature on strategic alliances, including R&D alliances, and networks show how the governance framework predisposes inter-organisational relations towards positive outcomes (Martínez-Noya & Narula, 2018). Finally, the collected data and theorizing in Section 7.1.1 has shown how the contextual condition of knowledge in the NPMaterial case can have a dual role of reinforcing and constraining the sensing and open innovation mechanisms. This confirms the dual behaviour of the conditions identified in the literature review of this study (see Section 3.4.1.1) and is in line with Sakakibara (2002) study which described how *"...the same factor can play both roles [of inducements and opportunities in the formation of alliances]."* (p. 1045).

7.2 Research Contribution

This Section summarizes the theoretical, empirical, methodological, policy and practice contributions of this study. Section 7.2.1 presents and describes how the theoretical contribution of this study to inter-organizational relations theory in the area of nanotechnology RDI partnerships focused on Research, Development and Innovation (RDI) overcomes major blind spots in the literature. In contributing to this area, this study also contributes to the innovation and strategy literature in three ways. First by linking through a causal explanation how open innovation and the dynamic capability of sensing mediate knowledge access in RDI partnership development. Second by complementing the available literature on strategic alliances with insights on RDI partnership development which consist of more than two partners. Third by providing explanations on partnership management suited for a novel multidisciplinary context of rapid technological change focused on Gibbons et al. (1994, p. 3) mode 2 knowledge development.

Then, Section 7.2.2 presents the empirical contributions of the study which are based on the narratives of four case studies underpinned by the original longitudinal and contextualised collected data. The novelty of the data stems from collecting data on polar cases with more than two partners during the execution stage and accounting for the view of different organisations and levels within the RDI partnership in each case. Moreover, this data is of special novelty because it provides evidence in the emerging area of nanotechnology as well as the dynamics of RDI partnerships where private organisations are the predominant partners.

Thereafter, Section 7.2.3 presents the methodological contributions which revolve around the development of a novel and comprehensive research framework which integrates and extends previous guidance in a coherent and detailed process of eight steps which draws from the bodies of literature on research design (Miles et al., 2014; Singleton & Straits, 2005; Yin, 2009), critical realism (Bhaskar, 2016; Danermark et al., 2002; Eco, 1984) and case study research (Bygstad & Munkvold, 2011; Easton, 2010; Fletcher, 2017; Pan & Tan, 2011; Wynn & Williams, 2012, 2020). Doing so, contributes to the conduct of qualitative research in the performance of inter-

organisational relations and critical realism research and process inquiry in inter-organisational relations. Given the highlighted methodological contributions and their novel demonstration in the area of inter-organisational relations, this study complements and *"...contributes to an emerging discussion about how CR can be applied, responding to the general problem of a lack of methodological guidance... particularly in respect to choices around data collection, coding and analysis"* (Hoddy, 2019, p. 111).

Finally, Section 7.2.4 presents how the causal explanation and the underlying conditions, mechanisms and outcomes can aid policy and practice to increase the success rate and management of nanotechnology RDI partnerships as well as foster and facilitate their socio-economic impact.

7.2.1 Theoretical contribution

This empirical research study contributes to inter-organizational relations theory in the area of partnerships focused on Research, Development and Innovation (RDI) within a nanotechnology context. The theoretical contribution lies in the co-evolutionary, multi-level mechanism-based explanation of how the characteristics of nanotechnology RDI partnerships can mediate their development. This contribution is based on a teleological process theory on how the *"...underlying mechanisms which drive the processes"* (Pettigrew, 1997, p. 339) of RDI partnerships can be emergent and disrupt previous assumptions and pre-established development paths (Van de Ven & Poole, 1995). Providing a co-evolutionary, multi-level, teleological view accounts for a wider range of dynamics and contingencies that can take place in RDI partnership development at the inter-organisational and organisational level. Such a view shows and explains for example the hitherto unobserved link between with the partners' organisational innovation strategies and vice versa (Kohtamäki et al., 2018). In this way, the theoretical contribution shows the driving mechanisms of how new knowledge is developed through inter-partner relations and the partners' organizational innovation strategy drive the new knowledge access and sensing to shape the RDI partnership.

This advances our understanding of the phenomena by explaining how the interactions of complex, contextual, multi-level and heterogenous characteristics over time mediate RDI partnership

development. This goes beyond and departs from the extant literature on inter-organizational relations, alliances and RDI partnerships which is built on major blind spots – single-party, single-level and single time conceptualization studies – offering contributions based on variance approaches and theory (Doz et al., 2000; Gomes et al., 2016; He et al., 2020; Lahiri et al., 2021; Lumineau & Oliveira, 2018; Martínez-Noya & Narula, 2018; Nippa & Reuer, 2019; Salk, 2005; Todeva & Knoke, 2005). This was achieved by analysing and explaining the sequence of events RDI partnerships and its multiple organisations undergo during the partnership execution in terms of open innovation and sensing mechanisms and their co-evolution and interplay at the inter-organisational and organisational levels respectively. Doing so responds to long standing and continuous calls across different areas in the literature of inter-organizational relations. Some illustrative examples of these calls spanning the past three decades are as follows.

> *"Relatively little scholarly attention has been devoted to studying developmental processes of IORs [Inter-Organisational Relations]. Instead, most of the research to date has been focused either on the antecedent conditions or the structural properties of interorganizational relationships in comparison with other governance forms."* (Ring & Van de Ven, 1994, p. 91)

> *"...most [inter-organizational and network theoretical contribution] have explained outcomes by referring to the structural antecedents that condition the different contexts which actors behave within."* (Vincent, 2008, p. 875)

> *"...although alliances are known to be highly evolutionary and unstable [5], it is still unclear about how and why changes take place in alliances and how alliances develop."* (Wilson & Hynes, 2009, p. 620)

> *"The relationship of dynamics to IOC [Inter-organizational Collaboration] outcomes suggests the need for rigorous research specifically focused on identifying key descriptive elements of the dynamics and the different conditions under which these dynamic descriptive elements are likely to occur"* (Majchrzak et al., 2015, p. 1357)

> *"... there remains a constant need to focus on theory advancement which plays a crucial role in sowing the seeds for the subject [of strategic alliances] to develop further."* (Gomes et al., 2016, p. 25)

By providing a co-evolutionary, multi-level view on RDI partnership development which explains and links the underlying open innovation mechanism at the RDI partnership level and the sensing mechanism at the organisational level, this study also responds to calls from scholars over time to provide co-evolutionary perspective in the development of inter-organizational relations. Some examples of such calls are as follows.

> *"the absence of co-evolutionary modelling and empirical studies is indicative of new directions that research on alliances might take"* (Koza & Lewin, 1998, p. 261).

> *"Alliance co-evolution is of research interest because, after all, strategic alliances [such as RDI partnerships] uniquely represent a system consisting of multiple elements, i.e., the partners and the alliance per se… The literature has been unclear about the elements of an alliance co-evolutionary system."* (Das & Teng, 2002, p. 738)

> *"future research may examine how sub-processes [such as management] evolve and how individual evolution relates to the evolution of entire IFC [inter-firm collaboration]… , it is possible that the evolution sub-process may not progress as planned with the collaborating partners."* (Lahiri et al., 2021, p. 9)

Hence, the theoretical contribution of this study, a co-evolutionary, multi-level mechanism-based explanation of RDI partnership development, responds to the calls of scholars spanning three decades and provides fresh insights in the area of inter-organizational relations by combining a multi-level and processual analysis of the phenomena from a co-evolutionary perspective. In this way, it sheds light into the "black-box" of RDI partnership development through empirical research which theorises in terms of mechanisms by building on the observed sequence of activities which RDI partnerships and its partners undergo during their execution. Moreover, the cyclical and

synergistic sensing and open innovation micro-macro-micro mechanisms identified are in line with the mechanisms[24] that, according to Delanda (2006), should be unveiled in critical realism studies and previous inter-organizational studies which show that development processes are not sequential but of a cyclical nature (Das & Teng, 2002; Lahiri et al., 2021; Ring & Van de Ven, 1994).

Explaining how the sensing and open innovation mechanisms are interrelated along with the contextual conditions and outcomes also responds to calls from scholars and wider strategy issues in relation to linking the DCV and open innovation literature strands (Hutton et al., 2021; Randhawa et al., 2016; Teece, 2007; Vanhaverbeke & Cloodt, 2014). In this way this study captures how the relationship between the organisational-level sensing mechanism drives the inter-organisational-level open innovation mechanism and vice-versa. Consequently, it extends the literature on open innovation and DCV and deviates from the inter-organizational literature which is typically based on describing, predicting and understanding RDI partnerships and alliance development on the basis of

- efficiency (Dyer, 1997; J. E. Oxley, 1997),
- acquiring resources or knowledge (Barney, 1995; Eisenhardt & Schoonhoven, 1996; Parker, 2012; Patthareeya & Lorsuwannarat, 2012),
- social capital (Gulati, 1995), and
- dependencies (Rice & Galvin, 2006; Vincent & O'Mahoney, 2018).

However, such explanations are typically based on the dominant theoretical approaches in the literature, TCE, RBV, KBV, SNT and RDT (He et al., 2020), and as shown in Section 6.2, are insufficient to account for the patterns observed in the collected data of this study.

[24] The types of mechanisms defined by Delanda (2006) are as follows.

- Micro-macro mechanisms which explain how the interplay of different components generate an outcome at a higher level.
- Macro-micro mechanisms which explain how the higher level facilitates and limit the different components.

The significance of the main theoretical contribution is also emphasized by the novelty and precise focus, scope and context of this study. First, the research is focused on a specific type of inter-organizational collaboration, RDI partnerships, which has been provided scant attention. It emerges from the reviewed literature (see e.g. Figure 8), that a focus on a specific type of inter-organisational relations is of critical importance (Prange et al., 2015). Dyer et al. (2007) stresses that *"Though many research studies combine R&D alliances and other types of alliances as a single subject for analysis, we conclude that R&D alliances should be treated as a separate and independent type of collaborative activity."* (p. 10). Moreover, *"...what we know about IORs [Inter-Organizational Relations] in general is likely to be overly influenced by characteristics of the most studied forms, such as joint ventures, and may not actually apply broadly to all IORs."* (Parmigiani & Rivera-Santos, 2011, p. 1120).

Second, the scope of the theoretical contribution is centred on the execution of IORs given the findings from the literature reviews carried in Chapter 2 and 3, and the observations of Todeva and Knoke (2005, p. 142) *"The period after an alliance announcement, from implementation to termination, is less thoroughly investigated."* and Dyer et al. (2007, p. 3) *"benefits from alliance participation differ significantly across firms in the same alliance and that alliance execution factors are more important than initial conditions of alliance formation."*. Third, the novelty and nascent state of the chosen context, nanotechnology (Petricevic & Verbeke, 2019; Rampersad et al., 2010), substantiates the distinctive theoretical contribution of this study (He et al., 2020).

In contributing to inter-organizational relations theory in the area of RDI partnerships within a nanotechnology context, this study also contributes to the innovation and strategy literature in three ways. First, the literature on innovation and strategy typically refers to the critical role and benefits that open innovation and dynamic capabilities have for the competitiveness of organisations (Chesbrough et al., 2014; Teece, 2007). However, there is cursory analysis devoted to detailed understanding of the interplay of open innovation and dynamic capabilities in the building of

knowledge (Costello, 2019; K. Lee & Yoo, 2019). This study extends research in the innovation and strategy literature by linking through a causal explanation how open innovation and the sensing dynamic capability mediate knowledge access in RDI partnership development. In this way, the innovation and strategy literature are enriched by showing how these mechanisms facilitate and impinge organisations to build knowledge in RDI partnerships. Second, this study complements the available literature on strategic alliances because the highlighted contributions have been drawn from nanotechnology RDI partnerships with more than two partners and, according to (He et al., 2020), the available *"...substantive theories in SA [Strategic Alliances] are largely limited to supporting the management of bilateral linear interfirm relationships"* (p. 18). Doing so is of great relevance because alliances of more than two partners can account to up to 50% of all the established alliances and are particularly common in technology-intensive industries (S. Xu et al., 2014).

Finally, the theoretical contribution of this study on understanding nanotechnology RDI partnership development extends existing strategic theory on partnership management because it is applicable to a novel multidisciplinary context of rapid technological change focused on Gibbons et al. (1994, p. 3) mode 2 knowledge development. However, existing strategic theory on partnership management is based on classical theories of competitive strategy such as the resource-based view, resource dependence theory and the knowledge based view which are not suited for the continuous and rapid technological and market changes organisations experience (Teece et al., 1997). Moreover, studies dealing with how teams from within and across disciplines collaborate (see e.g. Battard, 2012; Bellotti et al., 2016; Porac et al., 2004; Zuo & Zhao, 2018) are typically based on collaborations which juxtapose different disciplines and focus on mode 1 knowledge development (Gibbons et al., 1994)[25]. Hence, there is limited understanding on how multidisciplinary collaborations focused on mode 2 knowledge development use and integrate different efforts and

[25] Gibbons et al. (1994, p. 3) describes *that knowledge development "in mode 1 problems are set and solved in a context governed by the, largely academic, interests of a specific community. By contrast, mode 2 knowledge is carried out in a context of application. Mode 1 is disciplinary while mode 2 is transdisciplinary. Mode 1 is characterized by homogeneity, mode 2 by heterogeneity".*

results from different disciplines (Battard, 2012; Pennington, 2015) as in the nanotechnology RDI partnerships analysed (Islam & Miyazaki, 2009; Dovev; Lavie & Drori, 2012).

The highlighted contributions show how critical realism allows to theorise from case studies by providing a contextualised explanation in the form of causal mechanisms (Welch et al., 2011). In this way, this study identified two causal mechanisms along with the contextual conditions under which they operate and the derived effects in the form of outcomes. Such an approach goes beyond the dominant tendency in the literature – positivistic research designs (Gomes et al., 2016; Lahiri et al., 2021; A. L. Oliver & Ebers, 1998) – focused on finding and describing patterns of relations between causes and effects and limited to induction and, thus, the empirical domain (Lennox & Jurdi-Hage, 2017). Not being tied to these positivistic constraints, allowed this study to integrate context in the explanations and go beyond what is observed by means of abduction and retroduction. For example, by integrating context in the search for explanations rather than generalisable patterns, this study unveiled and demonstrated, as shown in Figure 34, that RDI partnership development can be reinforced and constrained by the same condition. This supports and extends to the development stage the literature suggesting the dual behaviour of conditions in the formation of RDI partnerships (Sakakibara, 2002). Moreover, contributes to the emerging discussion on the dynamic nature and multiple roles that specific conditions can play in inter-organizational relations as they develop (Bidault, 2020; Bruyaka et al., 2018; Gupta & Rosenkopf, 2019).

7.2.2 Empirical Contribution

The four case studies enrich the literature in inter-organisational relations by providing longitudinal and contextualised data. Empirical evidence of this nature is rare as highlighted by Hagedoorn (2002, p. 477) – *"so far most empirical studies on R&D partnerships and other forms of inter-firm collaboration are based on survey–research and, therefore, usually of a cross-sectional nature"* – and echoed by subsequent studies (Bakker, 2010; Gomes et al., 2016; He et al., 2020; E. Niesten & Jolink, 2015). The selected context in which this data has been collected enriches the literature not

only by providing evidence on the emerging area of nanotechnology but also the dynamics of RDI partnerships where private organisations are the predominant partners. As Youtie and Kay (2014) highlights, the limited available "*Nanotechnology studies have focused on scientific publications and patents, with a heavy emphasis given to university research. Fewer works have sought to understand dynamics by looking at the enterprise level."* (p. 2).

Moreover, the originality of the collected data is underpinned by the laborious efforts dedicated to gain access and carefully select a diverse and complementary pool of empirical evidence to what is available. First, it is from the execution stage of RDI partnerships (Todeva & Knoke, 2005). Second it relies on *"short-term contractual IJVs (or non-equity JVs) [which] remain a relatively understudied phenomenon, in part due to the difficulty involved in their observation"* (Beamish & Lupton, 2016, p. 173; Martínez-Noya & Narula, 2018). Third, in contrast to the literature which, according to Hagedoorn et al. (2000, p. 580), *"suffer[s] from selection bias; the partnerships studied often tend to be some of the most successful, and hence those with high returns."*, this study includes two case studies where the RDI partnerships delivered ample RDI outcomes and another two which delivered limited RDI outcomes. Doing so answers recent calls in the literature from scholars such as Steinmo and Rasmussen (2016) who state that *"because R&D collaborations frequently fail.... Future studies should therefore… include both successful and unsuccessful collaborations"* (p. 1258). As a result, this study provides a rare pool of data for the limited number of scholars which focus on the negative aspects of inter-organizational relations (Zaheer et al., 2010) and, in particular, those beyond buyer-supplier inter-organizational relations (Oliveira & Lumineau, 2019).

Moreover, the data was drawn to account for multiple views and levels of the RDI partnership phenomena by including primary and secondary data across different organisations involved in the four selected case studies. Based on the literature review of this study, this addresses a gap in the extant literature of RDI partnerships and inter-organizational relations (Davis & Eisenhardt, 2011; Dyer et al., 2007; Rampersad et al., 2010; Smith, 2012; Yin, 2009, p. 41). Finally, the data collected is from RDI partnerships which include three partnering organisations rather than dyads

on which the extant empirical evidence is typically based on (see e.g. Eisner et al., 2009; Gulati, 1998; Vonortas & Okamura, 2009; S. Xu et al., 2014). This helps to better understand the potential differences between RDI partnerships based on two or more partners (J. E. Oxley, 1997).

7.2.3 Methodological Contribution

The literature on inter-organisational relations has shown little attention to qualitative studies and processes as reflected in the literature reviews in Chapter 2 and 3 as well as many others (Bergenholtz & Waldstrøm, 2011; Gomes et al., 2016; A. L. Oliver & Ebers, 1998). According to Smith (2012, p. 43), *"research on inter-organizational R&D is… based on snapshot studies at the management or firm level of analysis that leave open questions regarding the actual inter-organizational innovation practices"*.

At the same time, *"Critical Realism is proving to be particularly apposite in the study of such processes"* (Ryan et al., 2012, p. 300). However, *"researchers have not yet identified a standard formula for conducting retroductive analyses"* (Wynn & Williams, 2020, p. 60) and *"the existing gap between the philosophical foundation, methodological recipes and hands-on practices of applied critical realism must be bridged"* (Frederiksen & Kringelum, 2021, p. 18). Moreover, to the best knowledge of the author of this study, it has never been implemented in the study of RDI partnerships. Accordingly, for the first time in the area of RDI partnerships, this study offers a structured and comprehensive research framework that details in eight clear steps the process of conducting critical realism based case study research. It also demonstrates the value of carrying a critical realist study in the area of RDI partnerships while contributing to fill the highlighted methodological gap of qualitative studies with a process perspective in the area of inter-organisational relations.

The framework developed integrates and extends previous research in a coherent and detailed step by step basis by drawing from the bodies of literature on research design (Miles et al., 2014; Singleton & Straits, 2005; Yin, 2009), critical realism (Bhaskar, 2016; Danermark et al., 2002; Eco,

1984) and case study research (Bygstad & Munkvold, 2011; Easton, 2010; Fletcher, 2017; Pan & Tan, 2011; Wynn & Williams, 2012, 2020)

As a result, the research framework advances the application of critical realism research by leveraging flexible deductive coding and data analysis in a structured approach which embeds the key principles of critical realism (Wynn & Williams, 2012, 2020). This contribution is of great significance not only because it helps to reverse that *"the application of critical realism to case studies remains 'underdeveloped'"* (Welch et al., 2011, p. 749) but also because critical realism is predominantly conducted through grounded theory techniques (Hoddy, 2019). Hence, the research framework also overcomes criticism on grounded theory techniques reflecting an empiricist approach due to its inductive nature and, thus, based on the available data (Fletcher, 2017).

A detailed and structured research framework is of great value as it adds to the *"few examples of applied CR in which the researchers clearly explain how critical realist philosophy informed their choice and use of methods."* (Lennox & Jurdi-Hage, 2017, p. 28). In this vein, this study also contributes to critical realism by illustrating how the research framework was conducted in four case studies focused on RDI partnership development. Doing so with a focus on process inquiry, the research illustrates how to extend the current rare focus on processes in inter-organisational relations which has already proven of benefit in the area of marketing (Bizzi & Langley, 2012).

The study also makes a methodological contribution to the conduct of qualitative research in the performance of inter-organisational relations. The combination of qualitative and quantitative data from different organisations and the RDI partnerships together with a multi-level analysis at the organisational and inter-organisational levels is novel and provides in-depth insights and finer-grained details on performance. Using this approach is of great value since, as highlighted by Dyer et al. (2007, p. 3), the *"... benefits from alliance participation differ significantly across firms in the same alliance and that alliance execution factors are more important than initial conditions of alliance formation."*. Such claims have also been emphasized over time by many others such as (Doz, 1996), Ariño (2003), Rampersad et al. (2010) and Lumineau and Oliveira (2018). Hence, this

approach to conducting research provides ample opportunities to determine how the different concepts which influence performance, such as proximity (Knoben & Oerlemans, 2006), may differ depending on the specific individual characteristics of each organisation involved in an inter-organisational relation. It can also progress research for measuring outcome and process performance of inter-organisational relations by overcoming the inherent barriers of methodological approaches which rely on the analysis and view of one organisation (Ariño, 2003; Lumineau & Oliveira, 2018).

Given the highlighted methodological contributions and their novel demonstration in the area of inter-organisational relations, this study complements and *"contributes to an emerging discussion about how CR can be applied, responding to the general problem of a lack of methodological guidance… particularly in respect to choices around data collection, coding and analysis"* (Hoddy, 2019, p. 111). There is a wide range of prospects for further theoretical and empirical contributions enabled by the methodological contributions of this study.

7.2.4 Contributions to Policy and Practice

Contrary to the general belief in industry that knowledge access should be restricted as much as possible, the findings show the opposite. Moreover, this study sheds light into the "black-box" of nanotechnology RDI partnership development and how knowledge access and new knowledge sustains inter-organisational relations even beyond their duration. These insights highlight the importance of fostering knowledge creation and exchange beyond supporting the creation of nanotechnology competencies and research institutes in public organisations or government supported collaborations. Policy makers can leverage these insights to develop and optimize IP framework agreements, support measures that raise awareness towards the value of exchanging IP and open access to the knowledge developed in government supported collaborative research programs. Such measures can increase the success rate of nanotechnology RDI partnerships and the relations they trigger.

As a result, the findings of this study can guide policy to increase knowledge-based results derived from nanotechnology RDI partnerships. These are of key value for policy makers because inter-organisational relations exhibit high failure rates of up to 70% across emerging contexts similar to nanotechnology and established industries such as biotechnology and the pharmaceutical and electronics industries (Campart & Pfister, 2007; Duysters & Kok, 1999; Lahiri et al., 2021; Park & Ungson, 2001; M. E. Porter, 1987). Increasing the success rate of nanotechnology RDI partnerships can save hundreds of millions of euros per year to public and private organisations given that governments have invested billions of euros in policy actions such as the Taiwanese National Nanoscience & Nanotechnology Program with a total budget in excess of € 1B from 2003 to 2014 and the US National Nanotechnology Initiative which is expected to account for a total investment of around $30 billion between 2006 and 2021[26]. Moreover fostering and facilitating the results of RDI partnerships is of critical importance because of the positive impacts of nanotechnology to the economy and society (A. L. Porter et al., 2019; Roco et al., 2011).

The developed co-evolutionary, multi-level mechanism-based explanation of RDI partnership development is also of key interest to practice because it shows the interplay and links between the conditions, mechanisms and outcomes of RDI partnerships from a co-evolutionary perspective. As a result, the multi-level and processual analysis as well as the mechanism-based explanation of the phenomena are tools for strategy and research managers to guide and manage the execution of RDI partnerships as well as knowledge building and exchange in RDI partnerships. This goes beyond existing studies which tend to focus on a myriad of conditions disregarding the importance of processes and a co-evolutionary perspective (Das & Teng, 2002; Koza & Lewin, 1998; Lahiri et al., 2021; Salk, 2005).

In this way, practitioners can understand the importance of co-evolution in RDI partnerships and, therefore, dedicate different managers and efforts to follow RDI partnerships at the inter-organisational and organisational levels. These contributions are of critical importance for

[26] A breakdown of US National Nanotechnology Initiative budget per year may be found at the following US government webpage: https://www.nano.gov/nanodashboard

practitioners because not only the number of RDI inter-organisational relations increased continuously over the last four decades at rates of up to around 40% year over year but also the rate of joint ventures versus other inter-organisational relations such as RDI partnerships has decreased (Hagedoorn, 2002). Furthermore, due to the continuous and rapid changes organisations experience in high technology environments, the contributions of this study on understanding nanotechnology RDI partnership development are of strategic interest to organisations that to remain competitive need to establish and manage RDI partnerships (Nippa & Reuer, 2019; Petricevic & Verbeke, 2019; Teece et al., 1997; Wilson & Hynes, 2009).

7.3 Limitations of this study and implications for future research

This study is based on the co-evolutionary, multi-level analysis of RDI partnerships by focusing on the organisational and inter-organisational levels. Hence, the theoretical and methodological contributions of this study can be extended by incorporating an industrial and individual level of analysis. This will allow the linking of industry evolution and individual factors to the findings of this study.

In addition, the generalizability of the findings of this study can be extended by focusing on six directions for future research (Shapira et al., 2010). First the research carried draws from a specific type of inter-organizational relation and, thus, caution must be observed when the findings of this study are applied to other types of inter-organizational relations. This opens new avenues to investigate the transferability of the research to relations such as joint ventures and licensing agreements. Second, this study is focused on the execution stage of RDI partnerships and future research can build on it and link it with the extant research on the formation stage to cover the full life cycle of RDI partnerships from formation to dissolution.

Third, the collected data showed how the outcomes of different RDI partnerships included the formation of new RDI partnerships. Hence, future studies can focus on how RDI partnership cascade over time and contribute to the limited findings available (Hagedoorn et al., 2001; Marion

et al., 2015). Fourth, the context of the case studies, nanotechnology, and including organisations from different industries also implies that further work can focus on how the uniqueness of specific industries mediate nanotechnology RDI partnerships development. Fifth, although there is no evidence that the phenomena under study is affected by government grants (Hagedoorn, 2002), caution must be observed and further research can be undertaken to compare cases studies from government supported RDI partnerships, such as the ones in this study, and non-government supported RDI partnerships. Finally, while the retrospective selection of the case studies provides many benefits such as studying diverse and rich cases (Bizzi & Langley, 2012), future research on real time research designs can bring more empirical data through direct observations.

Overall, future research should continue in this direction by focusing on "messy" research which is contextualised, multi-level and beyond the predominant variance approaches. As shown in this study, there are ample benefits from undertaking further research which pushes the boundaries of research on the dynamics of RDI partnerships or other inter-organisational relations and from different philosophical positions such as critical realism.

Bibliography

Aaboen, L., Dubois, A., & Lind, F. (2012). Capturing processes in longitudinal multiple case studies. *Industrial Marketing Management, 41*(2), 235-246. doi:http://dx.doi.org/10.1016/j.indmarman.2012.01.009

Aarseth, W., Andersen, B., Ahola, T., & Jergeas, G. (2012). Practical difficulties encountered in attempting to implement a partnering approach. *International Journal of Managing Projects in Business, 5*(2), 266-284.

Agarwal, S., & Ramaswami, S. N. (1992). Choice of Foreign Market Entry Mode: Impact of Ownership, Location and Internalization Factors. *Journal of International Business Studies, 23*(1), 1.

Ahuja, G. (2000). The duality of collaboration: inducements and opportunities in the formation of interfirm linkages. *Strategic Management Journal, 21*(3), 317-343.

Albors-Garrigós, J., Rincon-Diaz, C. A., & Igartua-Lopez, J. I. (2013). Research technology organisations as leaders of R&D collaboration with SMEs: role, barriers and facilitators. *Technology Analysis & Strategic Management*, 1-17. doi:10.1080/09537325.2013.850159

Aldrich, H. E., & Sasaki, T. (1995). R&D consortia in the United States and Japan. *Research Policy, 24*(2), 301-316. doi:http://dx.doi.org/10.1016/0048-7333(93)00768-O

AlliedMarketResearch. (2018). *Global Nanotechnology Market*. Retrieved from https://www.alliedmarketresearch.com/nanotechnology-market

Alwadain, A., Fielt, E., Korthaus, A., & Rosemann, M. (2014). A CRITICAL REALIST PERSPECTIVE OF ENTERPRISE ARCHITECTURE EVOLUTION: CONDITIONING AND OUTCOMES. *Australasian Journal of Information Systems, 18*(3), 213-226. doi:10.3127/ajis.v18i3.1102

Ariño, A. (2003). Measures of strategic alliance performance: An analysis of construct validity. *Journal of International Business Studies, 34*(1), 66-79.

Ariño, A., & de la Torre, J. (1998). Learning from Failure: Towards an Evolutionary Model of Collaborative Ventures. *Organization Science, 9*(3), 306-325.

Arranz, N., & de Arroyabe, J. C. F. (2006). Joint R&D projects: Experiences in the context of European technology policy. *Technological Forecasting and Social Change, 73*(7), 860-885. doi:10.1016/j.techfore.2005.11.003

Arranz, N., & de Arroyabe, J. C. F. (2008). The choice of partners in R&D cooperation: An empirical analysis of Spanish firms. *Technovation, 28*(1-2), 88-100. doi:10.1016/j.technovation.2007.07.006

Avgerou, C. (2019). Contextual explanation: alternative approaches and persistent challenges. *MIS Q., 43*(3), 977–1006. doi:10.25300/misq/2019/13990

Bäck, I., & Kohtamäki, M. (2015). Boundaries of R&D collaboration. [Thereisaneedtodevelopagreater understandingofthecharacteristicsandmanagementofR&Dwork that rossesorganizationalboundaries(Johnsen, 2009; Davisand Eisenhardt,2011). -]. *Technovation, 45/46*, 15.

Baker, T., & Welter, F. (2018). Contextual Entrepreneurship: An Interdisciplinary Perspective. *Foundations and Trends® in Entrepreneurship, 14*, 357-426. doi:10.1561/0300000078

Bakker, R. M. (2010). Taking Stock of Temporary Organizational Forms: A Systematic Review and Research Agenda R.M. Bakker Temporary Organizational Forms. *International Journal of Management Reviews, 12*(4), 466-486. doi:10.1111/j.1468-2370.2010.00281.x

Barmeyer, C., & Davoine, E. (2019). Facilitating intercultural negotiated practices in joint ventures: The case of a French–German railway organization. *International Business Review, 28*(1), 1-11. doi:10.1016/j.ibusrev.2018.06.001

Barney, J. B. (1991). Firm Resources and Sustained Competitive Advantage. *Journal of Management, 17*(1), 99-120.

Barney, J. B. (1995). *Looking Inside for Competitive Advantage* (Vol. 9).

Barringer, B. R., & Harrison, J. S. (2000). Walking a tightrope: creating value through interorganizational relationships. *Journal of Management, 26*(3), 367-403. doi:https://doi.org/10.1016/S0149-2063(00)00046-5

Battard, N. (2012). Convergence and multidisciplinarity in nanotechnology: Laboratories as technological hubs. *Technovation, 32*(3/4), 234-244. doi:10.1016/j.technovation.2011.09.001

Beamish, P. W., & Lupton, N. C. (2016). Cooperative strategies in international business and management: Reflections on the past 50 years and future directions. *Journal of World Business, 51*(1), 163-175. doi:https://doi.org/10.1016/j.jwb.2015.08.013

Bellotti, E., Kronegger, L., & Guadalupi, L. (2016). The evolution of research collaboration within and across disciplines in Italian Academia. *Scientometrics, 109*. doi:10.1007/s11192-016-2068-1

Bergenholtz, C., & Bjerregaard, T. (2013). How institutional conditions impact university–industry search strategies and networks. *Technology Analysis & Strategic Management*, 1-14. doi:10.1080/09537325.2013.850473

Bergenholtz, C., & Waldstrøm, C. (2011). Inter-Organizational Network Studies - A Literature Review. *Industry and Innovation, 18*(6), 539.

Bergin, M., Wells, J. S., & Owen, S. (2008). Critical realism: a philosophical framework for the study of gender and mental health. *Nurs Philos, 9*(3), 169-179. doi:10.1111/j.1466-769X.2008.00358.x

Bhaskar, R. (1975). *A realist theory of science* (2nd ed.). London, United Kingdom: Verso.

Bhaskar, R. (2008). *A realist theory of science*. Abingdon, United Kingdom: Routeledge.

Bhaskar, R. (2016). *Enlightened Common Sense: The Philosophy of Critical Realism* (M. Hartwig Ed. 1st ed.). London, United Kingdom: Routledge.

Bidault, F. (2020). The evolution of relational quality in strategic alliances: A multiple case study analysis. *Recherches en Sciences de Gestion*(138), 69-100.

Bidault, F., & Cummings, T. (1994). Innovating through alliances: Expectations and limitations. *R & D Management, 24*(1), 33.

Bizzi, L., & Langley, A. (2012). Studying processes in and around networks. *Industrial Marketing Management, 41*(2), 224-234. doi:http://dx.doi.org/10.1016/j.indmarman.2012.01.007

Boddy, D., Macbeth, D., & Wagner, B. (2000). Implementing collaboration between organizations: an empricial study of supply chain partnering. *Journal of Management Studies, 37*(7), 1003-1017.

Bogers, M., Chesbrough, H., Heaton, S., & Teece, D. J. (2019). Strategic Management of Open Innovation: A Dynamic Capabilities Perspective. *California Management Review, 62*(1), 77-94. doi:http://dx.doi.org/10.1177/0008125619885150

Brooks, H. (1967). *Applied Research, Definitions, concepts, Themes*. Retrieved from

Bruyaka, O., Philippe, D., & Castañer, X. (2018). Run Away or Stick Together? The Impact of Organization-Specific Adverse Events on Alliance Partner Defection. *Academy of Management Review, 43*(3), 445-469. doi:10.5465/amr.2014.0323

Bryman, A., & Bell, E. (2011). *Business Research Methods* (3rd ed.): Oxford University Press.

Bstieler, L., & Hemmert, M. (2008). Developing trust in vertical product development partnerships: A comparison of South Korea and Austria. *Journal of World Business, 43*(1), 35.

Buckley, P. J., & Park, B. I. (2013). Realised absorptive capacity, technology acquisition and performance in international collaborative formations: an empirical examination in the Korean context. *Asia Pacific Business Review, 20*(1), 109-135. doi:10.1080/13602381.2013.779126

Burrell, G., & Morgan, G. (1979). *Sociological Paradigms and Organisational Allalysis* (14 ed.). Hants: Ashgate Publishing Limited.

Bygstad, B., & Munkvold, B. (2011). *In Search of Mechanisms. Conducting a Critical Realist Data Analysis* (Vol. 3).

Caloghirou, Y., Vonortas, N. S., & Ioannides, S. (2004). *European collaboration in research and development : business strategy and public policy*. Cheltenham, UK: Edward Elgar.

Campart, S., & Pfister, E. (2007). Technology, cooperation and stock market value: An event study of new partnership announcements in the biotechnology and pharmaceutical industries *Economics of Innovation and New Technology, 16*(1), 31.
Cannavale, C., Esempio, A., & Ferretti, M. (2021). Up- and down- alliances: A systematic literature review. *International Business Review*, 101813. doi:https://doi.org/10.1016/j.ibusrev.2021.101813
Cappelli, P., & Sherer, P. (1991). The missing role of context in OB: The need for a meso-level approach. *Research in organizational behavior*, 55-110.
Carayannis, E. G., Alexander, J., & Ioannidis, A. (2000). Leveraging knowledge, learning, and innovation in forming strategic government-university-industry (GUI) R&D partnerships in the US, Germany and France. *Technovation, 20*(9), 477-488.
Carayannis, E. G., & Campbell, D. F. J. (2012). Mode 3 Knowledge Production in Quadruple Helix Innovation Systems. 1-63. doi:10.1007/978-1-4614-2062-0_1
Casson, M., & Mol, M. J. (2006). *Strategic Alliances: A Survey of Issues from an Entrepreneurial Perspective. Handbook of Strategic Alliances. SAGE Publications, Inc*. Thousand Oaks, CA: SAGE Publications, Inc.
Castañer, X., & Oliveira, N. (2020). Collaboration, Coordination, and Cooperation Among Organizations: Establishing the Distinctive Meanings of These Terms Through a Systematic Literature Review. *Journal of Management, 46*(6), 965-1001. doi:10.1177/0149206320901565
Chesbrough, H. W. (2003). *Open Innovation: The New Imperative for Creating and Profiting From Technology* (Vol. 21).
Chesbrough, H. W., Vanhaverbeke, W., & West, J. (2014). *New Frontiers in Open Innovation*: Oxford University Press.
Choi, J., & Contractor, F. J. (2019). Improving the Progress of Research & Development (R&D) Projects by Selecting an Optimal Alliance Structure and Partner Type. *British Journal of Management, 30*(4), 791-809. doi:http://dx.doi.org/10.1111/1467-8551.12267
Coghlan, D., & Coughlan, P. (2011). Transforming Networks through Network Action Learning. *OD Practitioner, 43*(2), 2-6.
Coghlan, D., & Coughlan, P. (2015). Effecting Change and Learning in Networks Through Network Action Learning. *Journal of Applied Behavioral Science, 51*(3), 375-400. doi:10.1177/0021886314540210
Cohen, W. M., & Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly, 35*(1), 128-152. doi:10.2307/2393553
Colombelli, A., Krafft, J., & Quatraro, F. (2014). The emergence of new technology-based sectors in European regions: A proximity-based analysis of nanotechnology. *Research Policy, 43*(10), 1681-1696. doi:10.1016/j.respol.2014.07.008
Constantelou, A., Tsakanikas, A., & Caloghirou, Y. (2004). Inter-country technological linkages in European Framework Programmes: a spur to European integration? *International Journal of Technology Management, 27*(8), 773-790.
Contractor, F. J., & Lorange, P. (1988). Competition vs. cooperation: A benefit-cost framework for choosing between fully-owned investments and cooperative relationships. *Management International Review, 28*, 5+.
Contractor, F. J., & Lorange, P. (2002). The growth of alliances in the knowledge-based economy. *International Business Review, 11*(4), 485-502.
Contractor, N. S., Wasserman, S., & Faust, K. (2006). Testing multitheoretical, multilevel hypothesis about organizational networks: An analytic framework and empirical example. *Academy of Management Review, 31*(3), 681-703. doi:10.5465/AMR.2006.21318925
Cooper, B., & Wallace, C. (2000). The evolution of partnerships. *Sociological Methods & Research, 28*(3), 365-381.
Costello, G. J. (2019). Proposing an innovation-based view of the firm. *The Irish Journal of Management, 37*(1), 65. doi:https://doi.org/10.2478/ijm-2018-0006
Coughlan, P., Coghlan, D., Rigg, C., & O'Leary, D. (2021). Exploring and Exploiting the Dynamics of Networks in Complex Applied Research Projects: A Reflection on Learning

in Action. *British Journal of Management, n/a*(n/a). doi:https://doi.org/10.1111/1467-8551.12482
Cui, A. S., Calantone, R. J., & Griffith, D. A. (2011). Strategic change and termination of interfirm partnerships. *Strategic Management Journal, 32*(4), 402.
D'Este, P., Guy, F., & Iammarino, S. (2013). Shaping the formation of university-industry research collaborations: what type of proximity does really matter? *Journal of Economic Geography, 13*(4), 537.
D'Este, P., & Perkmann, M. (2011). Why do academics engage with industry? The entrepreneurial university and individual motivations. *Journal of Technology Transfer, 36*(3), 316-339. doi:http://dx.doi.org/10.1007/s10961-010-9153-z
Daellenbach, U. S., & Davenport, S. J. (2004). Establishing Trust during the Formation of Technology Alliances. *Journal of Technology Transfer, 29*(2), 187-202.
Danermark, B., Ekström, M., & Karlsson, J. C. (2002). *Explaining Society. Critical Realism in the Social Science*. 11 New Fetter Lane, London EC4P 4EE: Routledge.
Das, T. K., & Kumar, R. (2011). Regulatory Focus and Opportunism in the Alliance Development Process. *Journal of Management, 37*(3), 682-708.
Das, T. K., & Teng, B.-S. (2002). The dynamics of alliance conditions in the alliance development process. *Journal of Management Studies, 39*(5), 725-746.
Davis, J. P., & Eisenhardt, K. M. (2011). Rotating Leadership and Collaborative Innovation: Recombination Processes in Symbiotic Relationships. *Administrative Science Quarterly, 56*(2), 159-201. doi:10.1177/0001839211428131
de Rond, M., & Bouchikhi, H. (2004). On the Dialectics of Strategic Alliances. *Organization Science, 15*(1), 56-69.
Delanda, M. (2006). *A New Philosophy of Society: Assemblage Theory and Social Complexity*. London- Ncw York: Continuum.
Delbufalo, E. (2012). Outcomes of inter-organizational trust in supply chain relationships: a systematic literature review and a meta-analysis of the empirical evidence. *Supply Chain Management, 17*(4), 377-402. doi:http://dx.doi.org/10.1108/13598541211246549
Dill, B. (2010). Public-public partnerships in Urban water provision: The case of Dar es Salaam. *Journal of International Development, 22*(5), 611.
Dooley, L., & Kirk, D. (2007). University-industry collaboration: Grafting the entrepreneurial paradigm onto academic structures. *European Journal of Innovation Management, 10*(3), 316. doi:http://dx.doi.org/10.1108/14601060710776734
Doz, Y. L. (1996). The evolution of cooperation in strategic alliances: initial conditions or learning processes? *Strategic Management Journal, 17*, 55-83.
Doz, Y. L., Olk, P. M., & Ring, P. S. (2000). Formation processes of R&D consortia: which path to take? Where does it lead? *Strategic Management Journal, 21*(3), 239.
Duysters, G., & Kok, G. (1999). Crafting successful strategic technology partnerships. *R&D Management, 29*(4), 343.
Dyer, J. H. (1997). Effective interfirm collaboration: how firms minimize transaction costs and maximize transaction value. *Strategic Management Journal, 18*(7), 535-556.
Dyer, J. H., Powell, B. C., Sakakibara, M., & Wang, A. J. (2007). The determinants of success in R&D alliances. 1-6. doi:10.5465/AMBPP.2007.26508253
Dyer, J. H., & Singh, H. (1998). The relational view: cooperative strategy and sources of interorganizational competitive advantage. *Academy of Management Review, 23*(4), 660-679.
Easterby-Smith, M., Lyles, M. A., & Tsang, E. W. K. (2008). Inter-Organizational Knowledge Transfer: Current Themes and Future Prospects. *Journal of Management Studies, 45*(4), 677-690. doi:10.1111/j.1467-6486.2008.00773.x
Easton, G. (2010). Critical realism in case study research. *Industrial Marketing Management, 39*(1), 118-128. doi:https://doi.org/10.1016/j.indmarman.2008.06.004
Easton, G., Ackroyd, S., & Fleetwood, S. (2000). Part II: Substantive contributions: Chapter 10: Case research as a method for industrial networks. *Realist Perspectives on Management & Organisations*, 205-219.
Eco, U. (1984). *Semiotics and the Philosophy of Language*. London: Macmillan.

Edmondson, A. C., & McManus, S. E. (2007). Methodological fit in management field research. *Academy of Management Review, 32*(4), 1155-1179.
Eichler, H.-g., Kong, S. X., & Grégoire, J.-p. (2006). Outcomes research collaborations between third-party payers, academia, and pharmaceutical manufacturers. *The European Journal of Health Economics : HEPAC, 7*(2), 129-135. doi:http://dx.doi.org/10.1007/s10198-006-0345-2
Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *The Academy of Management Review, 14*(4), 532-550. doi:10.2307/258557
Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal, 50*(1), 25-32.
Eisenhardt, K. M., & Schoonhoven, C. B. (1996). Resource-based View of Strategic Alliance Formation: Strategic and Social Effects in Entrepreneurial Firms. *Organization Science, 7*(2), 136-150.
Eisner, A. B., Rahman, N., & Korn, H. J. (2009). Formation conditions, innovation, and learning in R&D consortia. *Management Decision, 47*(6), 851-871.
Ekanayake, S., Childerhouse, P., & Sun, P. (2017). The symbiotic existence of interorganizational and interpersonal ties in supply chain collaboration. *International Journal of Logistics Management, 28*(3), 723-754. doi:http://dx.doi.org/10.1108/IJLM-12-2014-0198
Emerson, R. M. (1962). Power-Dependence Relations. *American Sociological Review, 27*(1), 31-41. doi:10.2307/2089716
Eriksson, P., & Kovalainen, A. (2008). *Qualitative Methods in Business Research* Retrieved from http://methods.sagepub.com/book/qualitative-methods-in-business-research doi:10.4135/9780857028044
Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From National Systems and "mode 2" to a Triple Helix of university-industry-government relations. *Research Policy, 29*(2), 109-123.
Faems, D., Janssens, M., & Bart van, L. (2007). The Initiation and Evolution of Interfirm Knowledge Transfer in R&D Relationships. *Organization Studies, 28*(11), 1699-1728.
Fearne, A. (1998). The evolution of partnerships in the meat supply chain: insights from the British beef industry. *Supply Chain Management: An International Journal, 3*(4), 214-231. doi:doi:10.1108/13598549810244296
Fletcher, A. J. (2017). Applying critical realism in qualitative research: methodology meets method. *International Journal of Social Research Methodology, 20*(2), 181-194. doi:10.1080/13645579.2016.1144401
Flynn, H., Hwang, D., & Holman, M. (2014). Nanotechnology Update: Corporations Up Their Spending as Revenues for Nano-enabled Products Increase. Retrieved from https://portal.luxresearchinc.com/research/report_excerpt/16215
Forfas. (2010). *Ireland's Nanotechnology Commercialisation Framework 2010 – 2014*. Ireland Retrieved from http://www.forfas.ie/media/forfas310810-nanotech_commercialisation_framework_2010-2014.pdf.
Frederiksen, D. J., & Kringelum, L. B. (2021). Five potentials of critical realism in management and organization studies. *Journal of Critical Realism, 20*(1), 18-38. doi:10.1080/14767430.2020.1846153
Funk, R. J. (2014). Making the Most of Where You Are: Geography, Networks, and Innovation in Organizations. *Academy of Management Journal, vol. 57*(no. 1).
Galbraith, E. M., Del Rosario, M., & Niazi, K. (2011). Use of the Stingray Re-Entry System in Two Complex Cases of Occluded Superficial Femoral Arteries. *Case Reports in Vascular Medicine, 2011*, 3. doi:10.1155/2011/976312
García-Terán, J., & Skoglund, A. (2019). A Processual Approach for the Quadruple Helix Model: the Case of a Regional Project in Uppsala. *Journal of the Knowledge Economy, 10*(3), 1272-1296. doi:http://dx.doi.org/10.1007/s13132-018-0521-5
Gebre-Mariam, M., & Bygstad, B. (2019). Digitalization mechanisms of health management information systems in developing countries. *Information & Organization, 29*(1), 1-22. doi:10.1016/j.infoandorg.2018.12.002

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The new production of knowledge: the dynamics of science and research in contemporary societies.* London: Sage.
Giddens, A. (1979). *Central problems in social theory: action, structure, and contradiction in social analysis*: University of California Press.
Gilley, J. W., & Gilley, A. (2017). *Organizational Change and Innovation*: Springer.
Godin, B. (2004). *Measurement and Statistics on Science and Technology: 1930 to the Present*: Routledge.
Gomes, E., Barnes, B. R., & Mahmood, T. (2016). A 22 year review of strategic alliance research in the leading management journals. *International Business Review, 25*(1, Part A), 15-27. doi:https://doi.org/10.1016/j.ibusrev.2014.03.005
Granovetter, M. (1985). Economic Action and Social Structure: The Problem of Embeddedness. *American Journal of Sociology, 91*(3), 481-510.
Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Info Libr J, 26*(2), 91-108. doi:10.1111/j.1471-1842.2009.00848.x
Grant, R. M., & Baden-Fuller, C. (1995). *A Knowledge-Based Theory of Inter-Firm Collaboration* (Vol. 1995).
Grant, R. M., & Baden-Fuller, C. (2002). *The knowledge-based view of strategic alliance formation: knowledge accessing versus organizational learning.*
Grant, R. M., & Baden-Fuller, C. (2004). A Knowledge Accessing Theory of Strategic Alliances. *Journal of Management Studies, 41*(1), 61-84. doi:10.1111/j.1467-6486.2004.00421.x
Greasley, K., Watson, P. J., & Patel, S. (2008). The formation of public-public partnerships. *The International Journal of Public Sector Management, 21*(3), 305-313. doi:http://dx.doi.org/10.1108/09513550810863204
Greenlee, P. (2005). ENDOGENOUS FORMATION OF COMPETITIVE RESEARCH SHARING JOINT VENTURES. *The Journal of Industrial Economics, 53*(3), 355.
Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. In D. N. K. & L. Y. S. (Eds.), *Handbook of qualitative research.* (pp. pp. 105-117). Thousand Oaks, California: Sage.
Gulati, R. (1995). Social Structure and Alliance Formation Patterns: A Longitudinal Analysis. *Administrative Science Quarterly, 40*(4), 619-652.
Gulati, R. (1998). Alliances and networks. *Strategic Management Journal, 19*(4), 293-317.
Gulati, R., & Gargiulo, M. (1999). Where do interorganizational networks come from? *The American Journal of Sociology, 104*(5), 1439-1493.
Gupta, A., & Rosenkopf, L. (2019). All Ties are not Equal: Personal Ties and Alliance Formation. *Applied Management Journal, 20*, 1-18.
Guzmán, A., Brown, F., & Acatitla, E. (2020). Conditional factors Pushing catch-up across developed and emerging countries in the nanotechnology sector, 2000–2010. *Economics of Innovation and New Technology*, 1-19. doi:10.1080/10438599.2020.1715059
Hagedoorn, J. (1993). Understanding the rationale of strategic technology partnering: Interorganizational modes of cooperation and sectoral differences. *Strategic Management Journal (1986-1998), 14*(5), 371.
Hagedoorn, J. (2002). Inter-firm R&D partnerships: An overview of major trends and patterns since 1960. *Research Policy, 31*(4), 477-492.
Hagedoorn, J., Carayannis, E., & Alexander, J. (2001). Strange bedfellows in the personal computer industry: technology alliances between IBM and Apple. *Research Policy, 30*(5), 837.
Hagedoorn, J., & Duysters, G. (2002). External sources of innovative capabilities: the preference for strategic alliances or mergers and acquisitions. *Journal of Management Studies, 39*(2), 167-188.
Hagedoorn, J., Link, A. N., & Vonortas, N. S. (2000). Research partnerships. *Research Policy, 29*(4/5), 567.

Hagedoorn, J., Roijakkers, N., & Kranenburg, H. V. (2006). Inter-Firm R&D Networks: the Importance of Strategic Network Capabilities for High-Tech Partnership Formation. *British Journal of Management, 17*(1), 39-53.

Hagedoorn, J., Roijakkers, N., & Kranenburg, H. V. (2008). The formation of subsequent inter-firm R&D partnerships between large pharmaceutical companies and small, entrepreneurial biotechnology firms - how important is inter-organisational trust? *International Journal of Technology Management, 44*(1/2), 81.

Halinen, A., & Törnroos, J.-Å. (2005). Using case methods in the study of contemporary business networks. *Journal of Business Research, 58*(9), 1285-1297. doi:http://dx.doi.org/10.1016/j.jbusres.2004.02.001

Hall, R. (1992). The Strategic Analysis of Intangible Resources. *Strategic Management Journal, 13*(2), 135-144.

Harrigan, K. R., & Newman, W. H. (1990). Bases of interorganization co-operation: Propensity, power, persistence. *Journal of Management Studies, 27*(4), 417-434.

Hart, A., New, C., & Freeman, M. (2004). Health visitors and "disadvantaged" parent-clients. In B. C. C. N. (Eds.) (Ed.), *Making realism work: Realist social theory and empirical research* (pp. pp. 151–170). London: Routledge.

Harzing, A. W. (2014). The Journal Quality List. Retrieved from http://www.harzing.com/jql.htm

He, Q., Meadows, M., Angwin, D., Gomes, E., & Child, J. (2020). Strategic Alliance Research in the Era of Digital Transformation: Perspectives on Future Research. *British Journal of Management, n/a*(n/a). doi:10.1111/1467-8551.12406

Hemmert, M., Bstieler, L., & Okamuro, H. (2014). Bridging the cultural divide: Trust formation in university-industry research collaborations in the US, Japan, and South Korea. [Where as trust has been extensively studied in the context of innovation collaboration among industrial and proccssccs. - Spccifically, this rcscarch advanccs our undcrstanding of UICs by(1) amining how trust develops in UICs inthreedifferentcountries,(2) exploring how initial trust formation mechanisms are mediated by champion behavior; and (3) identifying whether different institutional settings between countries moderate the importance of trust formation mechanisms.]. *Technovation, 34*(10), 605.

Hennart, J.-F. (2006). Alliance Research: Less is More*. *The Journal of Management Studies, 43*(7), 1621.

Hertzfeld, H. R., Link, A. N., & Vonortas, N. S. (2006). Intellectual property protection mechanisms in research partnerships. *Research Policy, 35*(6), 825.

Hoddy, E. T. (2019). Critical realism in empirical research: employing techniques from grounded theory methodology. *International Journal of Social Research Methodology, 22*(1), 111-124. doi:10.1080/13645579.2018.1503400

Holmes, S., & Moir, L. (2007). Developing a conceptual framework to identify corporate innovations through engagement with non-profit stakeholders. *Corporate Governance, 7*(4), 414-422. doi:http://dx.doi.org/10.1108/14720700710820498

Hsieh, H.-F., & Shannon, S. E. (2005). Three Approaches to Qualitative Content Analysis. *Qualitative Health Research, 15*(9), 1277-1288. doi:10.1177/1049732305276687

Hutton, S., Demir, R., & Eldridge, S. (2021). How does open innovation contribute to the firm's dynamic capabilities? *Technovation, 106*, 102288. doi:10.1016/j.technovation.2021.102288

Inzelt, A. (2004). The evolution of university–industry–government relationships during transition. *Research Policy, 33*(6/7), 975-995. doi:10.1016/j.respol.2004.03.002

Islam, N., & Miyazaki, K. (2009). Nanotechnology innovation system: Understanding hidden dynamics of nanoscience fusion trajectories. *Technological Forecasting and Social Change, 76*(1), 128-140. doi:https://doi.org/10.1016/j.techfore.2008.03.021

Jenssen, J. I., & Nybakk, E. (2013). Inter-organizational networks and innovation in small, knowledge-intensive firms: a literature review. *International Journal of Innovation Management, 17*(2), 1.

Johanne Rønnow, O., Harmsen, H., & Friis, A. (2008). Product development alliances: factors influencing formation and success. *British Food Journal, 110*(4/5), 430-443. doi:http://dx.doi.org/10.1108/00070700810868942

Joshi, A. M., & Nerkar, A. (2011). When do strategic alliances inhibit innovation by firms? Evidence from patent pools in the global optical disc industry. *Strategic Management Journal, 32*(11), 1139.
Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy, 26*(1), 1-18.
Kay, N. M. (1992). Markets, false hierarchies and the evolution of the modern corporation. *Journal of Economic Behavior & Organization, 17*(3), 315-333. doi:https://doi.org/10.1016/S0167-2681(95)90011-X
Keith Goffin, & Mitchell, R. (2010). *Innovation Management*. Houndmills, Basingstoke, Hampshire, RG21 6XS, England Palgrave Macmillan.
Knoben, J., & Oerlemans, L. A. G. (2006). Proximity and inter-organizational collaboration: A literature review. *International Journal of Management Reviews, 8*(2), 71.
Kogut, B. (1988). Joint Ventures: Theoretical And Empirical Perspectives. *Strategic Management Journal, 9*(4), 319.
Kogut, B., & Zander, U. (1992). Knowledge of the firm, combinative capabilities, and the replication of technology.". *Organization Science, 3*(3), 383.
Kohtamäki, M., Rabetino, R., & Möller, K. (2018). Alliance capabilities: A systematic review and future research directions. *Industrial Marketing Management, 68*, 188-201. doi:https://doi.org/10.1016/j.indmarman.2017.10.014
König, M. D., Battiston, S., Napoletano, M., & Schweitzer, F. (2011). Recombinant knowledge and the evolution innovation networks. *Journal of Economic Behavior & Organization, 79*(3), 145.
Konishi, H., & Ray, D. (2003). Coalition Formation As a Dynamic Process. *Journal of Economic Theory, 110*(1), 1-41. doi:http://www.sciencedirect.com/science/journal/00220531
Koza, M. P., & Lewin, A. Y. (1998). The co-evolution of strategic alliances. *Organization Science, 9*(3), 255-264.
Kusari, S., Hoeffler, S., & Iacobucci, D. (2013). Trusting and Monitoring Business Partners throughout the Relationship Life Cycle. *Journal of Business to Business Marketing, 20*(3), 119.
Kwon, S.-W., Rondi, E., Levin, D. Z., De Massis, A., & Brass, D. J. (2020). Network Brokerage: An Integrative Review and Future Research Agenda. *Journal of Management, 46*(6), 1092-1120. doi:10.1177/0149206320914694
Lahiri, S., Kundu, S., & Munjal, S. (2021). Processes Underlying Interfirm Cooperation. *British Journal of Management, 32*(1), 7-19. doi:https://doi.org/10.1111/1467-8551.12476
Lane, P. J., & Lubatkin, M. (1998). Relative absorptive capacity and interorganizational learning. *Strategic Management Journal, 19*(5), 461.
Lane, P. J., Salk, J. E., & Lyles, M. A. (2001). Absorptive capacity, learning, and performance in international joint ventures. *Strategic Management Journal, 22*(12), 1139-1161.
Langley, A. (1999). Strategies for theorizing from process data. *Academy of Management Review, 24*(4), 691-710. doi:Doi 10.2307/259349
Laumann, E., V. Marsden, P., & Prensky, D. (1983). *The Boundary Specification Problem in Network Analysis* (Vol. 61).
Lavie, D. (2006). The Competitive Advantage of Interconnected Firms: An Extension of the Resource-Based View. *Academy of Management Review, 31*(3), 638-658. doi:10.5465/amr.2006.21318922
Lavie, D., & Drori, I. (2012). Collaborating for Knowledge Creation and Application: The Case of Nanotechnology Research Programs. *Organization Science, 23*(3), 704-724.
Lee, C. S., & Vonortas, N. S. (2002). Toward an integrated model of strategy formulation for strategic technical alliances. *International Journal of Technology Transfer and Commercialisation, 1*(3), 292-312.
Lee, H. L. (2004). The Triple-A Supply Chain. *Harvard Business Review, 82,* 102-112.
Lee, K., & Yoo, J. (2019). How does open innovation lead competitive advantage? A dynamic capability view perspective. *PLOS ONE, 14*(11), 1-18.
Lee, N., & Lings, I. (2008). *Doing Business Research: A Guide to Theory and Practice*: Sage Publications.

Lennox, R., & Jurdi-Hage, R. (2017). Beyond the empirical and the discursive: The methodological implications of critical realism for street harassment research. *Women's Studies International Forum, 60*, 28-38. doi:https://doi.org/10.1016/j.wsif.2016.11.010
Levy, D. (2007). Chaos theory and strategy: Theory, application, and managerial implications. *Strategic Management Journal, 15*, 167-178. doi:10.1002/smj.4250151011
Leydesdorff, L., & Meyer, M. (2006). Triple Helix indicators of knowledge-based innovation systems: Introduction to the special issue. *Research Policy, 35*(10), 1441.
Lin, F.-j., & Lin, Y.-h. (2012). The determinants of successful R&D consortia: government strategy for the servitization of manufacturing. *Service Business, 6*(4), 489-502. doi:http://dx.doi.org/10.1007/s11628-012-0157-7
Link, A. N., Paton, D., & Siegel, D. S. (2002). An analysis of policy initiatives to promote strategic research partnerships. *Research Policy, 31*(8,9), 1459-1466.
Link, A. N., Teece, D. J., & Finan, W. F. (1996). Estimating the benefits from collaboration: The case of SEMATECH. *Review of Industrial Organization, 11*(5), 737-751.
Luecke, R. (2003). Managing creativity and innovation.
Lumineau, F., & Oliveira, N. (2018). A Pluralistic Perspective to Overcome Major Blind Spots in Research on Interorganizational Relationships. *Academy of Management Annals, 12*(1), 440-465. doi:10.5465/annals.2016.0033
LuxResearch. (2014). *Nanotechnology Update: Corporations Up Their Spending as Revenues for Nano-enabled Products Increase*. Retrieved from Boston: https://portal.luxresearchinc.com/research/report_excerpt/16215#executivesummary
M'Chirgui, Z. (2009). Dynamics of R&D networked relationships and mergers and acquisitions in the smart card field. *Research Policy, 38*(9), 1453.
M Alshammari, M. P., BAAL Qaied. (2016). Chaos theory in Strategy Research. *American Journal of Business and Management*.
Majchrzak, A., Jarvenpaa, S., & Bagherzadeh, M. (2015). A Review of Interorganizational Collaboration Dynamics. *Journal of Management, 41*(5), 1338-1360. doi:10.1177/0149206314563399
Marion, T. J., Eddleston, K. A., Friar, J. H., & Deeds, D. (2015). The evolution of interorganizational relationships in emerging ventures: An ethnographic study within the new product development process. *Journal of Business Venturing, 30*(1), 167.
Martínez-Noya, A., & Narula, R. (2018). What more can we learn from R&D alliances? A review and research agenda. *BRQ Business Research Quarterly, 21*(3), 195-212. doi:https://doi.org/10.1016/j.brq.2018.04.001
Martinkenaite, I. (2011). Antecedents and consequences of inter-organizational knowledge transfer. *Baltic Journal of Management, 6*(1), 53-70.
McNamara, M. (2012). Starting to Untangle the Web of Cooperation, Coordination, and Collaboration: A Framework for Public Managers. *International Journal of Public Administration, 35*(6), 389.
Mena, C., Humphries, A., & Wilding, R. (2009). A comparison of inter- and intra-organizational relationships. *International Journal of Physical Distribution & Logistics Management, 39*(9), 762-784. doi:http://dx.doi.org/10.1108/09600309011008193
Merle, J., Hellstrom, T., Adler, N., & Norrgren, F. (2000). From sponsorship to partnership in academy-industry relations. *R & D Management, 30*(3), 255-262.
Mertens, D. M. (2010). Literature Review and Focusing the Research *Research and Evaluation in Education and Psychology* (Third ed., pp. 552): SAGE Publications, Inc.
Messeni Petruzzelli, A., Albino, V., Carbonara, N., & Rotolo, D. (2010). Leveraging learning behavior and network structure to improve knowledge gatekeepers' performance. *Journal of Knowledge Management, 14*(5), 635-658.
Meyer, A. D., & Goes, J. B. (1988). Organizational assimilation of innovations: a multilevel contextual analysis. *Academy of Management Journal, 31*(4), 897-923. doi:10.2307/256344
Milagres, R., & Burcharth, A. (2019). Knowledge transfer in interorganizational partnerships: what do we know? [Knowledge transfer]. *Business Process Management Journal, 25*(1), 27-68. doi:http://dx.doi.org/10.1108/BPMJ-06-2017-0175

Miles, M. B., Huberman, A. M., & Saldana, J. (2014). *Qualitative Data Analysis* (3rd ed.). US: Sage.
Mindruta, D. (2013). Value creation in university-firm research collaborations: A matching approach. *Strategic Management Journal, 34*(6), 644.
Mingers, J., Mutch, A., & Willcocks, L. (2013). Critical realism in information systems research. *MIS Q., 37*(3), 795–802. doi:10.25300/misq/2013/37:3.3
Mohr, J., & Spekman, R. (1994). Characteristics of partnership success: Partnership attributes, communication behavior, and conflict resolution techniques. *Strategic Management Journal, 15*(2), 135-152.
Monge, P. R. (1990). Theoretical and Analytical Issues in Studying Organizational Processes. *Organization Science, 1*(4), 406-430.
Mothe, C., & Quelin, B. V. (2001). Resource creation and partnership in R&D consortia. *Journal of High Technology Management Research, 12*(1), 113-138.
Mowery, D. C., Oxley, J. E., & Silverman, B. S. (1996). Strategic alliances and interfirm knowledge transfer. *Strategic Management Journal, 17*, 77-91.
Müller-Seitz, G. (2012). Leadership in Interorganizational Networks: A Literature Review and Suggestions for Future Research. *International Journal of Management Reviews, 14*(4), 428-443.
Narula, R. (2001). Choosing Between Internal and Non-internal R&D Activities: Some Technological and Economic Factors. *Technology Analysis & Strategic Management, 13*(3), 365-387. doi:10.1080/09537320120088183
Narula, R., & Hagedoorn, J. (1999). Innovating through strategic alliances: moving towards international partnerships and contractual agreements. *Technovation, 19*(5), 283-294.
Ness, H. (2009). Governance, Negotiations, and Alliance Dynamics: Explaining the Evolution of Relational Practice. *The Journal of Management Studies, 46*(3), 451.
Newell, S., & Swan, J. (2000). Trust and inter-organizational networking. *Human Relations, 53*(10), 1287-1328.
Niesten, E., & Jolink, A. (2015). The Impact of Alliance Management Capabilities on Alliance Attributes and Performance: A Literature Review. *International Journal of Management Reviews, 17*(1), 69-100. doi:10.1111/ijmr.12037
Niesten, E., & Jolink, A. (2020). Motivations for Environmental Alliances: Generating and Internalizing Environmental and Knowledge Value. *International Journal of Management Reviews, 22*(4), 356-377. doi:10.1111/ijmr.12228
Niosi, J., & Bergeron, M. (1992). Technical Alliances in the Canadian Electronics Industry: An Empirical Analysis. *Technovation, 12*(5), 309.
Nippa, M., & Reuer, J. (2019). On the Future of International Joint Venture Research. *Journal of International Business Studies, 50*, 555-597. doi:10.1057/s41267-019-00212-0
Nonaka, I. (2008). *The Knowledge-Creating Company (Harvard Business Review Classics)*. Retrieved from https://hbr.org/2007/07/the-knowledge-creating-company
Nooteboom, B. (2002). *Interfirm Alliances: International Analysis and Design*: Taylor & Francis.
NSF. (2014). *Market report on emerging nanotechnology*. Retrieved from http://www.nsf.gov/news/news_summ.jsp?cntn_id=130586&org=CISE&from=news
O'Dwyer, M., & Gilmore, A. (2018). Value and alliance capability and the formation of strategic alliances in SMEs: The impact of customer orientation and resource optimisation. *Journal of Business Research, 87*, 58-68. doi:10.1016/j.jbusres.2018.02.020
OECD. (1994). *The Measurement of Scientific and Technical Activities*. Retrieved from https://www.oecd-ilibrary.org/science-and-technology/the-measurement-of-scientific-and-technical-activities_9789264063525-en
OECD. (2009). *Nanotechnology An overview based on indicators and statistics. STI working paper*. Retrieved from Paris: https://www.oecd-ilibrary.org/science-and-technology/nanotechnology-an-overview-based-on-indicators-and-statistics_223147043844
Oliveira, N., & Lumineau, F. (2019). The Dark Side of Interorganizational Relationships: An Integrative Review and Research Agenda. *Journal of Management, 45*(1), 231-261. doi:10.1177/0149206318804027

Oliver, A. L., & Ebers, M. (1998). Networking Network Studies: An Analysis of Conceptual Configurations in the Study of Inter-organizational Relationships. *Organization Studies (Walter de Gruyter GmbH & Co. KG.), 19*(4), 549-583.
Oliver, C. (2012). Critical Realist Grounded Theory: A New Approach for Social Work Research. *The British Journal of Social Work, 42*(2), 371-387.
Olk, P. (1998). A knowledge-based perspective on the transformation of individual-level relationships into inter-organizational structures: The case of R&D consortia. *European Management Journal, 16*(1), 39-49.
Osborn, R. N., & Hagedoorn, J. (1997). The institutionalization and evolutionary dynamics of interorganizational alliances and networks. *Academy of Management Journal, 40*(2), 261-278.
Oxley, J. E. (1997). Appropriability hazards and governance in strategic alliances: A transaction cost approach. *Journal of Law, Economics, and Organization, 13*(2), 387-409.
Oxley, J. E., & Sampson, R. C. (2004). The scope and governance of international R&D alliances. *Strategic Management Journal, 25*(8/9), 723.
Palomeras, N., & Wehrheim, D. (2021). The strategic allocation of inventors to R&D collaborations. *Strategic Management Journal, 42*(1), 144-169. doi:http://dx.doi.org/10.1002/smj.3233
Pan, S. L., & Tan, B. (2011). Demystifying case research: A structured–pragmatic–situational (SPS) approach to conducting case studies. *Information and Organization, 21*(3), 161-176. doi:10.1016/j.infoandorg.2011.07.001
Panda, D. K. (2017). Coevolution and coexistence of cooperation and competition in interorganizational collaboration. *Journal of Global Operations and Strategic Sourcing, 10*(1), 18-41. doi:http://dx.doi.org/10.1108/JGOSS-03-2016-0009
Park, S. H., & Ungson, G. (2001). Interfirm rivalry and managerial complexity: A conceptual framework of alliance failure. *Organization Science, 12*(1), 37-53.
Parker, H. (2012). Knowledge acquisition and leakage in inter-firm relationships involving new technology-based firms. *Management Decision, 50*(9), 1618-1633.
Parmigiani, A., & Rivera-Santos, M. (2011). Clearing a Path Through the Forest: A Meta-Review of Interorganizational Relationships. *Journal of Management, 37*(4), 1108-1136.
Patthareeya, L., & Lorsuwannarat, T. (2012). Knowledge transfer effectiveness of university-industry alliances. *International Journal of Organizational Analysis, 20*(2), 128-186. doi:http://dx.doi.org/10.1108/19348831211227819
Peeters, H., Callaert, J., & Van Looy, B. (2020). Do firms profit from involving academics when developing technology? *Journal of Technology Transfer, 45*(2), 494-521. doi:http://dx.doi.org/10.1007/s10961-018-9709-x
Pendry, J. B. (2000). Negative Refraction Makes a Perfect Lens. *Physical Review Letters, 85*(18), 3966-3969. doi:10.1103/PhysRevLett.85.3966
Pennington, D. (2015). A conceptual model for knowledge integration in interdisciplinary teams: orchestrating individual learning and group processes. *Journal of Environmental Studies and Sciences, 6*. doi:10.1007/s13412-015-0354-5
Peteraf, M. A. (1993). The cornerstones of competitive advantage: A resource-based view. *Strategic Management Journal, 14*(3), 179-191.
Petricevic, O., & Verbeke, A. (2019). Unbundling dynamic capabilities for inter-organizational collaboration: The case of nanotechnology. *Cross Cultural & Strategic Management, 26*(3), 422-448. doi:10.1108/CCSM-02-2019-0044
Pettigrew, A. M. (1990). Longitudinal field research on change: theory and practice. *Organization Science, 1*.
Pettigrew, A. M. (1997). What is a processual analysis? *Scandinavian Journal of Management, 13*(4), 337-348.
Pettigrew, A. M. (2012). Context and Action in the Transformation of the Firm: A Reprise. *Journal of Management Studies, 49*(7), 1304-1328. doi:10.1111/j.1467-6486.2012.01054.x
Pfeffer, J., & Nowak, P. (1976). Joint Ventures and Interorganizational Interdependence. *Administrative Science Quarterly, 21*(3), 398.

Pfeffer, J., & Salancik, G. R. (1978). The external control of organizations : a resource dependence perspective (pp. 0-0).
Pickvance, C. (2001). *Four Variations of Comparative Analysis* (Vol. 16).
Porac, J. F., Wade, J. B., Fischer, H. M., Brown, J., Kanfer, A., & Bowker, G. (2004). Human capital heterogeneity, collaborative relationships, and publication patterns in a multidisciplinary scientific alliance: a comparative case study of two scientific teams. *Research Policy, 33*(4), 661-678. doi:https://doi.org/10.1016/j.respol.2004.01.007
Porter, A. L., Garner, J., Newman, N. C., Carley, S. F., Youtie, J., Kwon, S., & Li, Y. (2019). National nanotechnology research prominence. *Technology Analysis & Strategic Management, 31*(1), 25-39. doi:10.1080/09537325.2018.1480013
Porter, A. L., & Youtie, J. (2009). How interdisciplinary is nanotechnology? *Journal of Nanoparticle Research, 11*(5), 1023-1041. doi:10.1007/s11051-009-9607-0
Porter, M. E. (1987). From competitive advantage to corporate strategy. *Harvard Business Review, 65*(3), 43-43.
Porter, M. E. (1998). Clusters and the new economics of competition. *Harvard Business Review, 76,* 77-90.
Powell, W. W., Koput, K. W., & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly, 41*(1), 116.
Prahalad, C. K., & Hamel, G. (1990). The core competence of the corporation. *Harvard Business Review, 68*(3), 79.
Prange, C., Eng, T.-Y., & Li, J. (2015). Collaborative New Product Alliances: A Review of the Literature and Research Perspectives. *Strategic Change, 24*(4), 351.
Rajala, A. (2018). Examining the effects of interorganizational learning on performance: a meta-analysis. *Journal of Business & Industrial Marketing, 33*(4), 574-584. doi:10.1108/JBIM-08-2017-0205
Rampersad, G., Quester, P., & Troshani, I. (2010). Managing innovation networks: Exploratory evidence from ICT, biotechnology and nanotechnology networks. *Industrial Marketing Management, 39*(5), 793-805. doi:10.1016/j.indmarman.2009.07.002
Randhawa, K., Wilden, R., & Hohberger, J. (2016). A Bibliometric Review of Open Innovation: Setting a Research Agenda. *The Journal of Product Innovation Management, 33*(6), 750-772. doi:http://dx.doi.org/10.1111/jpim.12312
Ratten, V. (2003). Collaborative experience and alliance performance: The mediating role of market orientation. *ANZMAC 2003*, 1255-1261.
Remenyi, D., Williams, B., Money, A., & Swartz, E. (1998). *Doing Research in Business and Management: An Introduction to Process and Method*. London: Sage.
Reuer, J. J., & Zollo, M. (2005). Termination outcomes of research alliances. *Research Policy, 34*(1), 101-115.
Rice, J., & Galvin, P. (2006). Alliance patterns during industry life cycle emergence: the case of Ericsson and Nokia. *Technovation, 26*(3), 384-395.
Ring, P. S., Doz, Y. L., & Olk, P. M. (2005). Managing Formation Processes in R&D Consortia. *California Management Review, 47*(4), 137-156.
Ring, P. S., & Van de Ven, A. H. (1994). Developmental processes of cooperative interorganizational relationships. *Academy of Management. The Academy of Management Review, 19*(1), 90.
Roco, M. C., Mirkin, C. A., & Hersam, M. C. (2011). Nanotechnology research directions for societal needs in 2020: summary of international study. *Journal of Nanoparticle Research, 13*(3), 897-919. doi:10.1007/s11051-011-0275-5
Roijakkers, A. H. W. M. (2003). *Inter-firm cooperation in high-tech industries: A study of R&D partnerships in pharmaceutical biotechnology.* (PhD), Maastricht University.
Roll-Hansen, N. (2008). *Why the distinction between basic (theoretical) and applied (practical) research is important in the politics of science*. London: London School of Economics and Political Science, Contingency and Dissent in Science Project.
Rousseau, D. M., & Fried, Y. (2001). Location, location, location: contextualizing organizational research. *Journal of Organizational Behavior, 22*(1), 1-13. doi:10.1002/job.78

Ryan, A., Tähtinen, J., Vanharanta, M., & Mainela, T. (2012). Putting critical realism to work in the study of business relationship processes. *Industrial Marketing Management, 41*(2), 300-311. doi:https://doi.org/10.1016/j.indmarman.2012.01.011
Sakakibara, M. (1997). Evaluating government-sponsored R&D consortia in Japan: who benefits and how? *Research Policy, 26*(4-5), 447-473. doi:10.1016/s0048-7333(97)00018-8
Sakakibara, M. (2002). Formation of R&D consortia: Industry and company effects. *Strategic Management Journal, 23*(11), 1033-1050. doi:10.1002/smj.272
Sakakibara, M., & Branstetter, L. (2003). Measuring the Impact of US Research Consortia. *Managerial & Decision Economics, 24*(2/3), 51-69.
Sakakibara, M., & Dodgson, M. (2003). Strategic research partnerships: Empirical evidence from Asia. *Technology Analysis & Strategic Management, 15*(2), 227-245.
Saldana, J. (2009). *The Coding Manual for Qualitative Researchers* (Second ed.). London: SAGE.
Salk, J. E. (2005). Often called for but rarely chosen: alliance research that directly studies process. *European Management Review, 2*(2), 117-122.
Sambasivan, M., Siew-Phaik, L., Mohamed, Z. A., & Leong, Y. C. (2013). Factors influencing strategic alliance outcomes in a manufacturing supply chain: Role of alliance motives, interdependence, asset specificity and relational capital. *International Journal of Production Economics, 141*(1), 339.
Sampson, R. C. (2007). R&D alliances and firm performance: The impact of technological diversity and alliance organization on innovation. *Academy of Management Journal, 50*(2), 364-386.
Saunders, M., Lewis, P., & Thornhill, A. (2012). *Research Methods for Business Students* (Seventh ed.). Italy: Pearson.
Sayer, A. (2000). *Realism and Social Science* Retrieved from http://sk.sagepub.com/books/realism-and-social-science doi:10.4135/9781446218730
Schiavone, F., & Simoni, M. (2016). Prior Experience and Co-opetition in R&D Programs. *Journal of the Knowledge Economy, 7*(3), 819-835. doi:http://dx.doi.org/10.1007/s13132-015-0251-x
Schultz, L. I. (2011). Nanotechnology's triple helix: a case study of the University at Albany's College of Nanoscale Science and Engineering. *Journal of Technology Transfer, 36*(5), 546-564.
Schurig, D., Mock, J. J., Justice, B. J., Cummer, S. A., Pendry, J. B., Starr, A. F., & Smith, D. R. (2006). Metamaterial Electromagnetic Cloak at Microwave Frequencies. *Science, 314*(5801), 977.
Seale, C. (1999). Quality in Qualitative Research. *Qualitative Inquiry, 5*(4), 465-478. doi:10.1177/107780049900500402
Seo, R. (2020). Interorganizational learning for R&D consortium performance: a social capital perspective. *Journal of Knowledge Management, 24*(2), 395-414. doi:10.1108/JKM-06-2019-0265
Shantz, A. F. S., Kistruck, G. M., Pacheco, D. F., & Webb, J. W. (2020). How Formal and Informal Hierarchies Shape Conflict within Cooperatives: A Field Experiment in Ghana. *Academy of Management Journal, 63*(2), 503. doi:http://dx.doi.org/10.5465/amj.2018.0335
Shapira, P., Youtie, J., & Porter, A. L. (2010). The emergence of social science research on nanotechnology. *Scientometrics, 85*(2), 595-611. doi:10.1007/s11192-010-0204-x
Siggelkow, N. (2007). Persuasion with case studies. *Academy of Management Journal, 50*(1), 4.
Singh, K. (1997). The impact of technological complexity and interfirm cooperation on business survival. *Academy of Management Journal, 40*(2), 339-367. doi:10.2307/256886
Singleton, R. A., & Straits, B. C. (2005). *Elements of research design (Ch. 3), in Approaches to social research* (4th ed.). New York, NY, US: Oxford University Press.
Smart, P., Bessant, J., & Gupta, A. (2007). Towards technological rules for designing innovation networks: a dynamic capabilities view. *International Journal of Operations & Production Management, 27*(10), 1069-1092.
Smith, P. (2012). Where is practice in inter-organizational R&D research? A literature review. *Management Research, 10*(1), 43-63.

Sobrero, M., & Schrader, S. (1998). Structuring inter-firm relationships: A meta-analytic approach. *Organization Studies, 19*(4), 585-615.
Speldekamp, D., Saka-Helmhout, A., & Knoben, J. (2020). Reconciling Perspectives on Clusters: An Integrative Review and Research Agenda. *International Journal of Management Reviews, 22*(1), 75-98. doi:10.1111/ijmr.12216
Spender, J. C. (1996). Making knowledge the basis of a dynamic theory of the firm. *Strategic Management Journal, 17*(S2), 45-62. doi:doi:10.1002/smj.4250171106
Stacey, R. (1993). Strategy as order emerging from chaos. *Long Range Planning, 26*(1), 10-17. doi:https://doi.org/10.1016/0024-6301(93)90228-8
Steinmo, M., & Rasmussen, E. (2016). How firms collaborate with public research organizations: The evolution of proximity dimensions in successful innovation projects. *Journal of Business Research, 69*(3), 1250.
Stuart, T. E. (1998). Network positions and propensities to collaborate: An investigation of strategic alliance formation in a high-technology industry. *Administrative Science Quarterly, 43*(3), 668-698.
Sydow, J., Windeler, A., Schubert, C., & Mollering, G. (2012). Organizing R&D Consortia for Path Creation and Extension: The Case of Semiconductor Manufacturing Technologies. *Organization Studies, 33*(7), 907-936. doi:10.1177/0170840612448029
Takeuchi, H. (2013). Knowledge-Based View of Strategy. *Universia Business Review*(40), 68-79.
Teece, D. J. (2007). Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal, 28*(13), 1319-1350. doi:10.1002/smj.640
Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic Capabilities and Strategic Management. *Strategic Management Journal (John Wiley & Sons, Inc.), 18*(7), 509-533. doi:10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z
Todeva, E. (2006). Business Networks: Strategy and Structure. *Business Networks: Strategy and Structure*, 1-262. doi:10.4324/9780203028261
Todeva, E., & Knoke, D. (2005). Strategic alliances and models of collaboration. *Management Decision, 43*(1), 123-148.
Tong, L. (2008). Retrieved from https://www.nsf.gov/od/lpa/news/03/pr03147.htm
Turpin, T., Garrett-Jones, S., & Woolley, R. (2011). Cross-sector research collaboration in Australia: the Cooperative Research Centres Program at the crossroads. *Science and Public Policy, 38*(2), 87-98. doi:10.3152/030234211x12924093660354
Uzzi, B. (1997). Social Structure and Competition in Interfirm Networks: The Paradox of Embeddedness. *Administrative Science Quarterly, 42*(1), 35-67.
Van De Ven, A. H. (1992). Suggestions for studying strategy process: a research note. *Strategic Management Journal, 13*, 169-188.
Van de Ven, A. H., & Poole, M. S. (1990). Methods for studying innovation development in the Minnesota Innovation Research Program. *Organization Science, 1*(3), 313-335.
Van de Ven, A. H., & Poole, M. S. (1995). Explaining development and change in organizations. *Academy of Management. The Academy of Management Review, 20*(3), 510.
van Fenema, P. C., & Keers, B. M. (2018). Interorganizational Performance Management: A Co-evolutionary Model. *International Journal of Management Reviews, 20*(3), 772-799. doi:10.1111/ijmr.12180
Vanhaverbeke, W., & Cloodt, M. (2014). Theories of the Firm and Open Innovation (pp. 256-278).
Vincent, S. (2008). A transmutation theory of inter-organizational exchange relations and networks: Applying critical realism to analysis of collective agency. *Human Relations, 61*(6), 875-899.
Vincent, S., & O'Mahoney, J. (2018). The SAGE Handbook of Qualitative Business and Management Research Methods: History and Traditions. 55 City Road, London: SAGE Publications Ltd. Retrieved from https://methods.sagepub.com/book/handbook-of-qualitative-business-management-research-methods-v1. doi:10.4135/9781526430212
Volkoff, O., & Strong, D. M. (2013). Critical realism and affordances: theorizing IT-associated organizational change processes. *MIS Quarterly, 37*(3), 819-834.

Vonortas, N. S., & Okamura, K. (2009). Research partners. *International Journal of Technology Management, 46*(3-4), 280-306.
Wang, X., Dolfsma, W., & van der Bij, H. (2019). Individual performance in a coopetitive R&D alliance: motivation, opportunity and ability. *R&D Management, 49*(5), 762-774. doi:10.1111/radm.12370
Wang, Y., & Nicholas, S. (2007). The formation and evolution of non-equity strategic alliances in China. *Asia Pacific Journal of Management, 24*(2), 131. doi:http://dx.doi.org/10.1007/s10490-006-9034-z
Wasserman, S., & Faust, K. (1994). *Social Network Analysis: Methods and Applications*: Cambridge University Press.
Welch, C., Piekkari, R., Plakoyiannaki, E., & Paavilainen-Mäntymäki, E. (2011). Theorising from case studies: Towards a pluralist future for international business research. *Journal of International Business Studies, 42*(5), 740-762. doi:10.1057/jibs.2010.55
Welter, F. (2020). Contexts and gender – looking back and thinking forward. *International Journal of Gender and Entrepreneurship, ahead-of-print*. doi:10.1108/IJGE-04-2019-0082
Werker, C., Korzinov, V., & Cunningham, S. (2019). Formation and output of collaborations: the role of proximity in German nanotechnology. *Journal of Evolutionary Economics, 29*(2), 697-719. doi:10.1007/s00191-019-00605-2
West, J., & Bogers, M. (2014). Leveraging External Sources of Innovation: A Review of Research on Open Innovation. *Journal of Product Innovation Management, 31*(4), 814-831. doi:https://doi.org/10.1111/jpim.12125
Westbrock, B. (2010). Natural concentration in industrial research collaboration. *The Rand Journal of Economics, 41*(2), 351-371.
White, S. (2005). Cooperation Costs, Governance Choice and Alliance Evolution. *The Journal of Management Studies, 42*(7), 1383-1412.
Williams, C. K., & Karahanna, E. (2013). Causal Explanation in the Coordinating Process: A Critical Realist Case Study of Federated IT Governance Structures. *37*, 933-A938.
Williamson, O. E. (1979). Transaction-Cost Economics: The Governance of Contractual Relations. *Journal of Law & Economics, 22*(2), 233-261.
Williamson, O. E. (1989). Transaction cost economics. In R. Schmalensee & R. Willig (Eds.), *Handbook of Industrial Organization* (Vol. 1, pp. 135-182): Elsevier.
Wilson, J., & Hynes, N. (2009). Co-evolution of firms and strategic alliances: Theory and empirical evidence. *Technological Forecasting and Social Change, 76*(5), 620-628.
Wittmann, C. M. (2007). Strategic Alliances: What Can We Learn When They Fail? *Journal of Business to Business Marketing, 14*(3), 1.
Wynn, D., & Williams, C. (2012). Principles for Conducting Critical Realist Case Study Research in Information Systems. *MIS Quarterly, 36*, 787-810. doi:10.2307/41703481
Wynn, D., & Williams, C. (2020). Recent Advances and Opportunities for Improving Critical Realism-Based Case Study Research in IS. *Journal of the Association for Information Systems*, 50-89. doi:10.17705/1jais.00592
Xu, Q., & Renyong, C. (2009). Comparing R&D consortia in Taiwan and the Chinese mainland. *European Business Review, 21*(5), 481-497.
Xu, S., Fenik, A. P., & Shaner, M. B. (2014). Multilateral alliances and innovation output: The importance of equity and technological scope. *Journal of Business Research, 67*(11), 2403.
Yang, K., Zhu, J., & Santoro, M. D. (2021). The Effect of Inter-firm Managerial Social Ties on Alliance Formation: How Poorly Embedded Firms Overcome Network Disadvantages. *British Journal of Management*, 1. doi:10.1111/1467-8551.12537
Yin, R. K. (2009). *Case Study Research: Design and Methods*: SAGE Publications.
Youtie, J., Iacopetta, M., & Graham, S. (2008). Assessing the Nature of Nanotechnology: Can We Uncover an Emerging General Purpose Technology? *Journal of Technology Transfer, 33*(3), 315-329. doi:https://link.springer.com/journal/volumesAndIssues/10961
Youtie, J., & Kay, L. (2014). Acquiring nanotechnology capabilities: role of mergers and acquisitions. *Technology Analysis & Strategic Management*, 1-17. doi:10.1080/09537325.2013.872773

Zachariadis, M., Scott, S., & Barrett, M. (2013). Methodological Implications of Critical Realism for Mixed-Methods Research. *MIS Quarterly, 37*, 855-879. doi:10.25300/MISQ/2013/37.3.09

Zaheer, A., Gözübüyük, R., & Milanov, H. (2010). It's the Connections: The Network Perspective in Interorganizational Research. *Academy of Management Perspectives, 24*(1), 62-77. doi:10.5465/AMP.2010.50304417

Zajac, E. J., & Olsen, C. P. (1993). From transaction cost to transactional value analysis: implications for the study of interorganizational strategies. *Journal of Management Studies, 30*(1), 131-145.

Zervos, V., & Siegel, D. S. (2008). Technology, security, and policy implications of future transatlantic partnerships in space: Lessons from Galileo. *Research Policy, 37*(9), 1630.

Zucker, L. G., & Darby, M. R. (2001). Capturing Technological Opportunity Via Japan's Star Scientists: Evidence from Japanese Firms' Biotech Patents and Products. *Journal of Technology Transfer, 26*(1-2), 37.

Zuo, Z., & Zhao, K. (2018). The more multidisciplinary the better? - The prevalence and interdisciplinarity of research collaborations in multidisciplinary institutions. *Journal of Informetrics, 12*, 736-756. doi:10.1016/j.joi.2018.06.006

Appendix A: Partnerships literature review approach

Given the highlighted fragmentation, cacophony of terms and imbalance in the field of partnerships, the selection of a review method is critical to ensure the integrity and coherence of the review on partnerships in Chapter 2 and the subsequent review on RDI partnerships in Chapter 3. The purpose of this two-phased review is to allow the review on partnerships to inform and, thus, strengthen, the review on RDI partnerships. In what follows the selected review scope is presented followed by the description of the review approaches for the characteristics and dynamics of partnerships.

i. Review scope

It is also important to note that the reviews on partnerships and RDI partnerships also draw from the literature related to two other types of inter-organizational relations, alliances and triple and quadruple helix relations, because of their overlap with the literature on partnerships and RDI partnerships. This approach also minimizes the risk of missing relevant scholars and publications when undertaking a literature review within a field that is heavily fragmented (Bergenholtz & Waldstrøm, 2011; A. L. Oliver & Ebers, 1998; Osborn & Hagedoorn, 1997).

As shown in Table 1, there is a clear overlap between alliances and partnerships since the alliance literature encompasses the literature on partnerships and, thus, findings can have many similarities and extend to the literature on partnerships (Casson & Mol, 2006; Ratten, 2003). Furthermore, triple and quadruple helix relations are a relatively recent area of research initiated by Etzkowitz and Leydesdorff where either university-industry-government and societal-university-industry-government establish contractual or equity based relations (Carayannis & Campbell, 2012; Etzkowitz & Leydesdorff, 2000; Leydesdorff & Meyer, 2006).

When triple and quadruple relations are contractual, they can be regarded as a sub-set of public-private partnership where the public partners include, at least, a university and the government. In the same way as alliances, triple and quadruple helix relations have numerous similarities in their nature with partnerships and, thus, have been included in this literature review. Other types of contractual-based relations such as licenses and franchises are not covered in this review since they often entail limited interactions among the partners and are very different in nature. The discussed inclusion criteria are summarised in Table 48.

Table 48 Criteria for the inclusion of articles to this review

Criteria	Reason for inclusion	Exemplary evidence
Alliances, partnerships and/or triple and quadruple helix alliances	Ensure focus on different forms of partnerships which entail a high degree of collaboration and commitment over long periods of time.	(Boddy et al., 2000; Marion et al., 2015)
Contractual-based relations between private and/or public organizations	Gather all partnership studies and exclude those focused on clusters, associations, inter-personal relations…	(Ariño & de la Torre, 1998; de Rond & Bouchikhi, 2004)

This review scope delineation is common in the literature since studies often use data from several types of inter-organisational relations to draw conclusions on either partnerships, triple and quadruple helix and alliances in general (Mowery et al., 1996; Powell et al., 1996; Schultz, 2011). Furthermore, the review on the literature of partnerships is undertaken by focusing on the topics of partnership characteristics and dynamics because they are embedded and related to answering the research question of this study.

ii. Review approach of the partnership characteristics

The literature examination of partnership characteristics and dynamics is done using different types of review approaches because of the previously discussed fragmentation, imbalance and myriad of accumulated studies in the scope of this review. In the review of partnerships characteristics, within

Section 2.5, the objective of reviewing the large number of publications on partnership's characteristics is to summarise and analyse the main underpinning concepts and themes. Subsequently the outputs will be used to inform the succeeding review of the literature on RDI partnerships.

With this objective and logic in mind, the examination of studies in the field of partnerships characteristics is undertaken following a critical review approach based on peer-reviewed sources to ensure the quality of the reviewed articles (M. J. Grant & Booth, 2009). This approach is selected because of the discussed myriad of accumulated studies and the fact that a comprehensive approach is undertaken in the review of RDI partnerships. The analysis and outputs of the literature review on partnership characteristics is presented in Section 2.5.

iii. Review approach of the dynamics of partnerships

In the review of the dynamics of partnerships, it is clear from an initial examination of the literature that a different review approach must be undertaken because scholars have shown scant attention and, particularly, when doing so from a process perspective (Davis & Eisenhardt, 2011). Hence, the objective of reviewing the literature on the dynamics of partnerships is twofold. On one hand to examine and integrate the diverse available findings on the partnerships literature and on the other hand to build on these findings in in Chapter 3 with the aim of strengthening the understanding of the development of RDI partnerships.

With this objective and logic in mind, a qualitative systematic search and integrative review approach is selected to investigate the available literature on the dynamics of partnerships (M. J. Grant & Booth, 2009). Undertaking this review approach contributes to defining the research gap on the dynamics of partnerships and integrating and building on the available findings through an interpretative approach. In addition, the outputs of this review can be compared and integrated to the subsequent review outputs of the literature on the dynamics of RDI partnerships in Chapter 3.

This qualitative systematic search and integrative review approach is structured following five steps. First, the sources from which the literature review articles will be drawn are selected. Second, the criteria to pre-select articles in our searches are defined. Then the inclusion criteria already established is used to filer the pre-selected articles. Finally, the analysis of the selected articles and the review results are presented in Section 2.6.

In the first step, both narrow and wide search-types on peer-reviewed sources were considered to select the sources from which the development of partnership studies should be drawn. Wide searches in different citation databases result in large number of hits (e.g. using Proquest 4,761, EbscoHost 6,375 and Web of Science 11,218) which are beyond the time limitations and resources of this study. As not all published articles are of the same quality and impact, and the accumulated studies are heavily fragmented, the selection of sources is limited to publications in leading journals. This approach is in line with similar prior studies (Bergenholtz & Waldstrøm, 2011; Knoben & Oerlemans, 2006; A. L. Oliver & Ebers, 1998; Sobrero & Schrader, 1998). Informed by these prior studies, the identification of leading journals was performed using several journal rankings and the judgement of the researcher. The considered journal rankings were the 23 rankings grouped in the Journal Quality List (Harzing, 2014) except the ranking of Theoharakis et al.. In this ranking the journals were not ranked using a Likert-type scale as the other rankings did and, thus, it was not possible to draw meaningful journal quality comparisons across the Theoharakis et al. ranking and others found in the Journal Quality List (Harzing, 2014).

In selecting the journals from each ranking, only those in the subject areas of economics, entrepreneurship, general & strategy, international business, innovation and sociology, and with a high or intermediate ranking level were selected from the 947 journals and 16 subject areas contained in the Journal Quality List. Furthermore, to avoid the obvious inherent bias of rankings towards particular disciplines and topics, the journals included in the dynamics of partnerships review must satisfy the minimum ranking level in at least two rankings. With these criteria in mind, the 52 journals listed in Table 49 were selected. Given the range of disciplines covered, and the quality and number of the selected journals, it can be considered that the selected, and subsequently

snowballed articles, are a comprehensive representation and embodiment of the articles in the field of the dynamics of partnerships.

In the second step, previous reviews of inter-organizational relations and dynamics of partnership studies were considered to define the search terms used to pre-select articles on the dynamics of partnerships up to the date when the review was started, December 2014 (Bergenholtz & Waldstrøm, 2011; Delbufalo, 2012; Jenssen & Nybakk, 2013; Knoben & Oerlemans, 2006; Mertens, 2010; Müller-Seitz, 2012; A. L. Oliver & Ebers, 1998; Smith, 2012). Thus, the search terms with truncation characters 'evolutio*', 'developmen* process*', 'alliance* development*' and 'development* alliance*' were combined with partnership*, alliance*, 'triple*helix', 'quadruple*helix' in a search string. Furthermore, to include as many pertinent articles as possible, the search terms were considered in the title and abstract fields. Applying the justified search terms and search method to the 52 selected leading journals generated an initial list of 92 pre-selected articles for screening.

In the next step, the developed partnership inclusion criteria in Table 48 were considered to ensure that the review of articles is consistent with the previously defined scope. This reduced the number of articles for review from 92 to 15. In addition, three other articles were included because of their relevance and the fact that they complemented the perspectives of the previously selected articles.

Arising from the analysis of these 15 articles, four articles more were snowballed and two articles removed (Cooper & Wallace, 2000; Konishi & Ray, 2003). The latter articles were removed because of the difficulties in integrating their findings, extracted from complex and very specific simulations, to the rest of the selected articles. The snowballed articles were selected because they appeared three or more times in the references of the 15 articles which were initially selected, fulfilled the inclusion criteria in Table 48 and have had a big impact in the partnership literature as indicated by a high number of citations (from 270 to 1314) in the Web of Science as of June 2015. Finally, the selected 17 articles are discussed in Section 2.6 and listed in Table 4.

Table 49 List of selected journals, subject area and times listed in Journal Quality List (JQL) rankings

Journal	Subject area	Times listed in JQL rankings
American Economic Review (The)	Economics	17
American Journal of Public Health	Economics	4
Econometrica	Economics	17
Economic Geography	Economics	11
Economic History Review	Economics	12
Economic Journal	Economics	17
Economy & Society	Economics	11
European Economic Review	Economics	16
International Economic Review	Economics	17
Journal of Business & Economic Statistics	Economics	14
Journal of Development Economics	Economics	14
Journal of Econometrics	Economics	17
Journal of Economic Geography	Economics	8
Journal of Economic Growth	Economics	7
Journal of Economic Perspectives	Economics	17
Journal of Economic Theory	Economics	17
Journal of Industrial Economics	Economics	17
Journal of International Economics	Economics	15
Journal of Labor Economics	Economics	18
Journal of Mathematical Economics	Economics	12
Journal of Political Economy *	Economics	17
Journal of Public Economics	Economics	17
Journal of the European Economic Association	Economics	8
Quarterly Journal of Economics	Economics	16
RAND Journal of Economics	Economics	17
Research Policy	Economics	20
Review of Economic Studies	Economics	17
Review of Economics & Statistics	Economics	17
Journal of Business Venturing	Entrepreneurship	20
Academy of Management Journal	General & Strategy	21
Academy of Management Review	General & Strategy	21
Administrative Science Quarterly	General & Strategy	21
Journal of Business	General & Strategy	10
Journal of Management	General & Strategy	21
Journal of Management Studies	General & Strategy	21
Organizational Research Methods	General & Strategy	15
Strategic Entrepreneurship Journal	General & Strategy	9
Strategic Management Journal	General & Strategy	21
Theory, Culture & Society	General & Strategy	10
Journal of International Business Studies	International Business	21
Science, Technology & Human Values	Innovation	7
Social Studies of Science	Innovation	4
American Journal of Political Science	Sociology	5
American Journal of Sociology	Sociology	14
American Sociological Review	Sociology	14
Annals of the Association of American Geographers	Sociology	5
British Journal of Sociology	Sociology	10
Progress in Human Geography	Sociology	5
Sociological Methods & Research	Sociology	3
Sociological Review	Sociology	8
Sociological Theory	Sociology	3
Sociology of Sport Journal	Sociology	2

Appendix B: RDI partnerships literature review approach

Before looking at the results of the review on the RDI partnerships literature, this Appendix describes what review approach is undertaken and why it was selected to meet the objectives of this study. In addition, it must be highlighted that this review benefits from the previous review on partnerships in Chapter 2 by building on the developed terminology, categories and findings in that chapter. The review is therefore structured similarly to Chapter 2 around two key areas of the literature, the characteristics of RDI partnerships, covered in Section 3.4, and the dynamics of RDI partnerships, covered in Section 3.5.

The review approach is selected considering the nature and resources of this study as well as the potential size of the RDI partnerships literature on characteristics and dynamics. Similar to Chapter 2, the review approach selected is a combination of a critical and comprehensive literature review (M. J. Grant & Booth, 2009) to ensure the identification and analysis of existing research in the field as well as its relationship to this study. However, the center of gravity of this review is shifted towards a comprehensive literature review while previously in Chapter 2 a critical review was undertaken. This is because of the focus of this study and that the literature on RDI partnerships is smaller in size than the literature on partnerships.

i. Review scope and approach of the RDI partnership characteristics

The first part of the review, within Section 3.4, focuses on the characteristics of RDI partnerships and includes both a critical and comprehensive literature review. When considering the prevalence of studies on RDI partnerships, in common with the literature on partnerships, it is found that the formation stage has garnered most of the research attention. Therefore, the review on the RDI partnerships characteristics at the formation stage is undertaken following a systematic search and

critical review approach to synthetize and analyse the research available (M. J. Grant & Booth, 2009).

This comprehensive literature review on the formation stage consists of five steps. First, the scope is defined according to the inter-organizational relationships categorization in Table 1 and the adopted definition of RDI partnerships in Section 3.2. Hence, articles which do not fall within the adopted definition are excluded. In the second step, the sources from which the review articles are drawn is selected. Given the exhaustive aim of the review and the time limitations, relevant publications are identified using the database ABI/INFORM Global™ which is focused on business. ABI/INFORM Global™ is selected because it is one of the most comprehensive business databases on the market showing hundreds of thousands of search results and key journals in the areas of this study, business management, innovation and technology.

Thirdly, the criteria to pre-select articles in ABI/INFORM Global™ are defined up to the date when the review was undertaken, January 2018. Since no prior review was found on the formation stage of RDI partnerships, this review is informed by previous review studies on adjacent bodies of literature in the inter-organizational relationships and alliance fields (Bergenholtz & Waldstrøm, 2011; Delbufalo, 2012; Jenssen & Nybakk, 2013; Knoben & Oerlemans, 2006; Mertens, 2010; Müller-Seitz, 2012; A. L. Oliver & Ebers, 1998; Smith, 2012). This analysis resulted in a search string that included the terms used to discuss inter-organizational relationships (e.g. inter-organisational, inter-institutional, multi-institutional, inter-firm, intercompany, industry-university), the term formation, the names that different forms of partnerships receive (e.g. partnership, consortia, public-private partnership, private-private partnership, PPP…) and the need for the partnership articles to include R&D, research and/or innovation activities. Furthermore, the search terms are used in the title and abstract fields and only within peer reviewed articles classified by ABI/INFORM Global™ in the broad topical area of R&D. This search strategy enables the inclusion of as many pertinent and quality articles as possible from any year and peer-reviewed publications. This search string yielded a pre-selection of 54 articles.

Then the pre-selected articles are filtered by using the two screening rules shown in Table 48 which are based on the scope and focus of this review. These rules ensure that the resultant 24 selected articles adhere to the previously defined review scope, non-equity contractual RDI partnerships, but also discuss the formation stage. Finally, in the last step of the review process the 24 selected articles are reviewed and analysed before being discussed in Section 3.4.1.

In contrast, the literature on RDI partnerships characteristics at the execution and assessment stage is very scarce. As a result, a critical review is undertaken in these areas to allow for an in-depth analysis and drawing from adjacent bodies of literature within the field of alliances (M. J. Grant & Booth, 2009). These adjacent bodies of literature are equity-based alliances such as joint ventures and triple or quadruple helix alliances because they have numerous similarities with partnerships and are often analysed together in many studies (Sakakibara & Branstetter, 2003; Q. Xu & Renyong, 2009; Zervos & Siegel, 2008). Other types of inter-organizational relationships within the literature on alliances, for example licenses, franchises and cooperatives, are excluded because they often entail limited interactions among the partners or are very different in nature. The results of literature review on RDI partnerships characteristics at the execution and assessment stage is presented in Section 3.4.2 and 3.4.3.

ii. Review scope and approach of the dynamics of partnerships

Similarly, to the literature on RDI partnerships characteristics at the execution and assessment stage, the literature on the dynamics of RDI partnerships is very scarce. As a result, a critical review is also undertaken to allow for an in-depth analysis and drawing from adjacent bodies of literature within the field of alliances (M. J. Grant & Booth, 2009). As in the review of the RDI partnerships characteristics at the execution and assessment stage, the selected adjacent bodies of literature are equity-based alliances such as joint ventures and triple or quadruple helix alliances because they have numerous similarities with partnerships and are often analysed together in many studies (Sakakibara & Branstetter, 2003; Q. Xu & Renyong, 2009; Zervos & Siegel, 2008). Other

types of inter-organizational relationships within the alliance studies, for example licenses, franchises and cooperatives, are excluded because they often entail limited interactions among the partners or are very different in nature. The results of the critical review on the dynamics of RDI partnerships is presented in Section 3.5.

Appendix C: Ethical Statement and data handling

Research area and researcher: An empirical study on how can the characteristics of nanotechnology RDI partnerships mediate their development over time conducted by Victor Acinas Garzon at the Trinity Business School at Trinity College Dublin.

Research rationale and benefits: Inter-organisational relations such as partnerships are a valuable source of competitive advantage for organisations and industries. However, the literature has shown scant attention to the developmental processes of inter-organisational relations despite the failure rate of inter-organisational relations has been reported to be very high. Hence, the outcomes of this research will provide valuable insights into the management nanotechnology RDI partnerships and the characteristics that mediate their development.

Information provided to the participants of this study

- Participation in this research is voluntary and participants can withdraw at any stage without giving a reason and without any penalties by contacting Victor Acinas Garzon via mail.
- Audio recordings of the interviews/observations will only be accessible by the researcher of this study, Victor Acinas Garzon, and will be stored in a password protected and encrypted environment.
- Transcripts of the interview will contain no reference to the identity of the participant. Participants will be referred to as Participant 1, Participant 2 and so on. The data collected will also be accessible to the participants upon request by mail to Victor Acinas Garzon.
- The data collected will be anonymised through the use of pseudonyms, data masking and other techniques.
- The data collected will only be used for research purposes.
- Participants may contact at any stage the researcher of this study, Victor Acinas Garzon, by mail or phone to answer any questions on the study and the data collected.

Appendix D: Coding list

The resulting code list of the directed content analysis described in Section 4.3.5 is presented in the table below. To differentiate between the deductive and inductive codes which emerged from the directed content analysis, in the table the inductive codes are marked with an asterisk. It is also worth noting that the code categories conditions, outcomes and processes in the table were assigned as required to one of the RDI partnership stages and levels code categories through simultaneous coding.

Codes		
Code name	**Acronym**	**Category**
Champion / lead	CL	Conditions
Commitment and engagement*	CE	
Cooperation rather collaboration*	CC	
Cost	Co	
Divergent interests*	DI	
Engage in increased collaboration	EIC	
Environmental	En	
External funding	EF	
Flexibility*	F	
Goal definition accuracy*	GDA	
Goal definition inaccuracy*	GDI	
Governance	Go	
Individual capabilities & autonomy*	ICA	
Indivisibility of research outputs	IRO	
Inflated project plan*	IPP	
Limited prior knowledge*	LPK	
Maintain reputation*	MR	
Management procedures*	MP	
Need*	N	
New opportunity	NO	
Organisational assets	OA	
Partnership planning	PP	
Potential innovation	PI	
Potential learning	PL	
Potential product development	PPD	

Pre-competitive R&D	**PCRD**	
Proximity	**Pr**	
R&D spillovers	**RDS**	
RDI outcomes not shared	**RDIONS**	
Relational	**Re**	
Risk	**Ri**	
Speed of technology evolution*	**STE**	
Speed++	**Sp**	
Standards development	**SD**	
Supply chain sourcing materials*	**SCSM**	
Time to market	**TM**	
Virtual and Face to face meetings*	**VFFM**	
Innovation	**In**	**Outcomes**
IP	**IP**	
New knowledge	**NK**	
New or improved technologies	**NIT**	
Outcomes not relevant or applicable*	**ORA**	
Personal dissatisfaction*	**PD**	
Personal satisfaction*	**PS**	
Publications	**Pu**	
Socio-economic	**SE**	
Spillovers	**Sp**	
Standards development	**SD**	
Subsequent inter-organizational relations	**SIOR**	
Training	**Tr**	
(Re- &) assessment of work plan*	**RAWP**	**Processes**
Assessment of trustworthiness	**AT**	
Consensus search	**CS**	
Development of environmental interdependence awareness	**DEIA**	
Discovery of converging interests	**DCI**	
Escalation of commitment and satisfaction	**ECS**	
Establishing and strengthening relations*	**ESR**	
Governance mode establishment	**GME**	
Knowledge transfer	**KT**	
Learning	**Le**	
Meeting (virtual and F2F)*	**M**	
Partner search	**PS**	
Proposal writing*	**PW**	
Reducing the commitment and satisfaction*	**RCS**	
Research development	**RD**	
Weakening relations*	**WR**	
Inter-organisational	**IO**	**RDI partnership levels**
Organisational	**Or**	

Pre-Formation	**PF**	**RDI partnership stages**
Formation	**Fo**	
Execution	**Ex**	
Post-execution	**PE**	