Exploring the Internalization of University–Industry Collaboration and Firm Innovation

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An analysis of influential roles, problems, and implementation paths

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Abstract

The phenomenon studied here is how cooperatively developed knowledge, resulting from knowledge-related interaction in a university–industry collaboration (UIC), is internally utilized by a firm. The purpose of this research is to explore how knowledge developed in a UIC is utilized by the collaborating firm in the development of innovations. The aim is to advance our understanding of how the collaborating firm internally develops innovations using knowledge derived from collaboration by means of empirical descriptions.

The research employs a single-case study design, focusing on the Combustion Engine Research Center, as the case, and the collaboration between Chalmers University of Technology and Volvo Car Corporation. Primary data were collected through semi-structured interviews and supplemented with archival data as the secondary data. Two rounds of interviews were performed to collect data.

The first round of the study investigates the influential roles within firms that facilitate the utilization of collaboration knowledge. The research identifies three distinct roles and examines their engagement in project meetings and the industrial monitoring of collaborative research. The second round of the study explores the process of recognizing and implementing collaboration knowledge within firms. It identifies the relationship between collaboration knowledge and a problem as a key factor in recognizing the value of the collaboration knowledge. The study further explores the dynamics of implementation, identifying three implementation paths and their associated effects.

The significance of these findings lies in their potential to inform strategies for leveraging collaboration knowledge to promote innovation within firms. The study adds to the literature by building a detailed understanding of the dynamics of the recognition and implementation of collaboration knowledge, thereby offering valuable insights for both academic and industrial stakeholders.

Keywords: knowledge, university-industry collaboration, absorptive capacity, higher education, academic engagement with industry, collaborative research, capabilities problem, boundary spanner, paths of implementation.

Sammanfattning på svenska

Fenomenet som studeras här är hur kunskap, som är ett resultat av kunskapsrelaterad interaktion i ett universitets-industrisamarbete (UIC), används av ett samarbetande företag. Syftet är att utforska hur sådan kunskap används av det samarbetande företaget i utvecklingen av innovationer. Målet är att genom empiriska beskrivningar fördjupa förståelsen för hur ett samarbetande företaget internt utvecklar innovationer med hjälp av kunskap från samarbetet.

Denna forskning använder en fallstudiedesign, med fokus på Combustion Engine Research Center, som fallet, och samarbetet mellan Chalmers tekniska högskola och Volvo Car Corporation. Primärdata samlades in genom semi-strukturerade intervjuer och kompletterades med arkivdata som sekundärdata. Två omgångar av intervjuer genomfördes för att samla in data.

Den första intervjuomgången undersöker inflytelserika rollerna, inom företag, som möjliggör och underlättar användningen av kunskap från samarbetet. Forskningen identifierade tre distinkta roller och undersökte deras engagemang i projektmöten och den industriella bevakningen av samarbetet. Den andra omgången av studien utforskar processen att identifiera och implementera värdefull kunskap från samarbetet inom företag. Den andra omgången visar på en relation mellan kunskap från samarbetet och ett problem som en nyckelfaktor för att identifiera kunskapen som värdefull. Studien utforskar dynamiken i implementerande av kunskap från samarbetet, och identifierar tre implementationsvägar och deras associerade effekter.

Betydelsen av dessa resultat ligger i deras potential att informera strategier för hur kunskap från samarbetet kan nyttiggöras för att främja innovation inom företag. Studien bidrar till litteraturen genom en detaljerad förståelse av identifiering och implementering av kunskap från ett samarbete, och erbjuder därmed insikter för både akademiska och industriella intressenter.

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1 Introduction

This dissertation explores the intricate relationship between knowledge developed in a university–industry collaboration and a firm's internal utilization of this knowledge. Specifically, it explores how knowledge developed in a university–industry collaboration is utilized internally by the collaborating firm in relation to innovation.

Research that explores and enhances knowledge of firm innovation has significant societal value as it fosters economic growth and improves competitiveness. A firm's development of innovations improves its market share and value (Banbury and Mitchell, 1995; Chaney and Devinney, 1992; Zahra et al., 2006), affects its performance and survival (Smith et al., 2005), provides sustainable and competitive advantages (Dodgson et al., 2014; Zander and Kogut, 1995), and is an adaptive response to a changing market (Amit and Zott, 2001). Furthermore, innovation is important from a national perspective, since it can contribute to economic development and environmental sustainability (Dodgson et al., 2014; Ferreira et al., 2020). In line with this, the European Union underscored the importance of innovation in 2000 through the Europe Horizon 2020 strategy. This strategy was intended to transform the Union into "the most competitive and dynamic knowledge-based economy in the world" by allocating 3% of the Union's gross domestic product to research and development ("Lisbon European Council 23-24.03.2000: Conclusions of the Presidency," n.d.). In summary, firm innovation plays a vital role in advancing society by promoting economic growth, competitiveness, and sustainability.

Innovation, which encompasses problem-solving, requires the integration of diverse knowledge components, often necessitating collaboration with external knowledge sources to address the complexity of problems faced by firms. *An* innovation, in contrast, is a significant improvement or novel product/process introduced to potential users or implemented in operations (cf. OECD, 2018). The innovation process, generally described, incorporates problem-solving (Ebadi and Utterback, 1984), with the new solution utilizing information drawn from previous experience and science (Dosi, 1988). Problem-solving requires that knowledge of a problem be combined with knowledge of how to resolve the problem (Von Hippel, 1994). The innovation is then a solution that recombines knowledge, which is in line with the recombinant perspective on innovation (Nelson, 1982; Savino et al., 2017; Verhoeven et al., 2016). To develop innovation, the firm faces the decision of whether the knowledge creation, for innovation development, should be conducted internally or whether an external source is also needed.

Collaborating with an external knowledge source is essential for innovation development in almost every organization today, and, for example, due to increased technological complexity, it is difficult and unlikely for a single firm to possess all the relevant knowledge required for an innovation (Dodgson, 2013; Obradović et al., 2021). A firm collaborates for various reasons, a main one being to access knowledge in uncertain conditions (Foster and Metcalfe, 2004). The firm's choice of external knowledge source to collaborate with has implications for the firm's innovation performance (Fabrizio, 2009). There are various types of external knowledge sources, such as markets, suppliers, customers, and institutions, with which a firm can collaborate to create and recombine knowledge (Katila and Ahuja, 2002; Laursen and Salter, 2005; Rickne and McKelvey, 2013). In summary, collaboration is valuable for a firm's innovation development, and university collaboration presents one valuable type of such interaction.

Interactions between university and industry have increased in response to growing demand from both parties (Giuliani and Arza, 2009). This increase has also occurred because, in many countries, universities have taken on a new role—a third mission—

in addition to the traditional roles of research and teaching (Perkmann et al., 2013). The universities' third mission concerns transferring knowledge (and technology) to external parties (Smith, 2007) or, briefly, contributing to society (Urdari et al., 2017). The university as an external source of knowledge for collaboration provides significant advantages in terms of fostering innovation development by providing access to valuable external knowledge and facilitating knowledge creation. Previous research has identified the university as an essential source of external knowledge (Fabrizio, 2009; Köhler et al., 2012; Laursen and Salter, 2004). Cohen et al. (2002) found that public R&D has an important impact across the manufacturing sector. Knowledge originating from universities is considered essential because it promotes the development of radical innovations (Ahuja and Katila, 2004; Fabrizio, 2009; Köhler et al., 2012) and impacts technology development through person-embedded knowledge, skills, methods, and instruments (Pavitt, 1991). Theoretical knowledge develops in universities, and theoretically understanding the underlying characteristics of technical components, and their interactions, may help firms and inventors to efficiently navigate and identify useful new combinations in a complex search space (Fleming and Sorenson, 2004). University knowledge is useful for the firm's search for new inventions, and through university collaboration, the firm can improve its search for external knowledge and its ability to access and utilize it in inventions, bolstering the firm's absorptive capacity (Cohen and Levinthal, 1990). Collaboration with universities is an important source of scientific and technological knowledge that enables breakthrough inventions and products to be developed (Belderbos et al., 2004; Chen et al., 2011; Fabrizio, 2009). In essence, collaboration with universities gives firms access to knowledge that can be assimilated into the development of new products and services. From the innovation and problem-solving perspectives, knowledge contributes to the development of technology either by enabling novel technological possibilities or by providing tools and techniques with which to increase design efficiency and evaluation feasibility (Brooks, 1994). In summary, the university can be an important and valuable external knowledge source and collaboration partner for a firm and its development of innovations. Given the significant value that university collaboration offers in terms of innovation and knowledge, this matter has historically been addressed in the literature.

The interactions between firms and universities have led to various ways of utilizing university knowledge, attracting considerable interest from researchers (Agrawal, 2001; Geuna and Muscio, 2009; Perkmann and Walsh, 2007; Rothaermel et al., 2007). For example, Agrawal (2001) argued that firms can alternate between various mechanisms to increase their ability to utilize externally generated collaboration knowledge, with engaging in collaborative research being one mechanism. Geuna and Muscio (2009) addressed collaborative research projects between universities and companies as a knowledge transfer[1] activity. The review article by Perkmann et al. (2021) lists twelve different types of activities in which knowledge-related interaction between academic scientists and external organizations occurs.

Previous research on the interaction between external organizations and universities and on the third mission of universities can be grouped into two broad streams: 1) the commercialization of academic research and 2) academic engagement. The commercialization of knowledge developed at universities includes aspects such as academic entrepreneurship and technology transfer. The literature on the commercialization of academic knowledge pays attention to the output of the third mission, i.e., patenting, licensing, academic start-ups, and academic entrepreneurship (Arant et al., 2019; Bozeman et al., 2013; Markman et al., 2008; O'Shea et al., 2005; Phan and Siegel, 2006; Rothaermel et al., 2007). Academic entrepreneurship involves the generation of start-ups from innovative ideas created or still under research at universities or by academic researchers (Ray, 2013; Skute et al., 2019).

[1] In this dissertation, the term "knowledge transfer" is used at an aggregated level and generally to describe the movement of knowledge between organizations (e.g., Geuna and Muscio, 2009) or nations (e.g., Duan et al., 2010; Vaara et al., 2012). This dissertation concentrates on a lower level and therefore rarely uses the term "knowledge transfer."

The technology transfer literature considers various dimensions of technology transfer offices (Thursby and Thursby, 2002) and their role in supporting the commercialization of publicly funded research (Holgersson and Aaboen, 2019), such as patenting and various types of research licensing (Lockett and Wright, 2005; Zucker and Darby, 1996).

The academic engagement literature does not emphasize commercial exploitation, instead concentrating on the knowledge-related interactions between university researchers and external organizations (Perkmann et al., 2021). Academic engagement with external organizations is widely practiced in various forms, and its economic significance is expected to be substantial for both universities and firms, comparable to that of commercialization (Hughes et al., 2016; Hughes and Kitson, 2012; Perkmann et al., 2011). Academic engagement is a multi-level phenomenon determined by individual, organizational, and institutional characteristics (Perkmann et al., 2013). Moreover, it serves as a transmission mechanism, ensuring the impact of academic research on the economy and society (Bornmann, 2013; Martin, 2011), and is perceived as an essential way of enhancing the impact of science (Perkmann et al., 2021).

The academic engagement concept originally centered on academic researchers and their characteristics (Perkmann et al., 2013), for example: academics' countries of origin and engagement with external actors (Lawson et al., 2019); influence of peers on academics' industry engagement (Aschhoff and Grimpe, 2014; Tartari et al., 2014); academics' entrepreneurial intentions (Johnson et al., 2017); and the factors underlying the variety of interactions between academics and external actors (D'Este and Patel, 2007). The academic engagement literature examines the antecedents and consequences of academic scientists' engagement with societal and external organizations. Over time, the conceptualization has expanded to encompass various perspectives on knowledge-related interactions, including the perspective of the collaborating firm. This includes studies of the impact of joint leadership on university–industry collaboration (Sjöö and Hellström, 2021), the type of interaction beneficial for firm innovation (Mikhailov et al., 2021), and firms' creation of innovative opportunities through collaboration (McKelvey et al., 2015). This body of research accentuates the development of knowledge and the established connections between academic institutions and external organizations, encompassing both formal and informal activities facilitating knowledge transfer and benefiting society (Perkmann et al., 2013). Formal activities of this type include collaborative research with industry, contract research, and consulting, while informal activities include providing ad hoc advice and networking (Perkmann et al., 2021).

The research presented in this dissertation addresses a particular type of formal academic engagement, namely, university–industry collaboration (UIC). UIC entails the partnership and institutionalization of interactions between the university and industry aiming mainly to encourage activities of knowledge and technology exchange that eventually lead to new knowledge and innovation (Ankrah and AL-Tabbaa, 2015; Bozeman et al., 2013; Gulbrandsen, 2011; Perkmann and Walsh, 2007; Petruzzelli, 2011; Skute et al., 2019). Studies of UIC, from a firm perspective, have found that knowledge developed through such collaboration is of a fundamental type and is not immediately connected to the firm's internal development of innovations. Instead, the collaborating firm obtains and integrates collaboration knowledge inside the firm, often through collaborating individuals (McKelvey et al., 2015). The specifics of how the fundamental knowledge is recognized, internalized, and used as specific knowledge by the collaborating firm and is then exploited internally are largely unexplored (Perkmann et al., 2021). Such intrafirm specifics are examined in Ankrah and AL-Tabbaa's (2015) systematic literature review, which analyzes the UIC literature and raises the issue of whether intellectual exchange with academic collaborators contributes to the UIC-participating-firm's R&D capability.

How collaboration knowledge impacts the interacting firm's innovation capacity is conceptually accounted for by McKelvey and Ljungberg (2017). They postulated two distinct routes through which collaborative research impacts firm innovation: the direct and indirect routes. The direct route involves the tangible results of research being directly transferred to the collaborating firm and then applied and commercialized. They also referred to the direct route as commercialization. Conversely, in the indirect route, intangible outcomes of university collaboration can indirectly foster innovations in which knowledge, from the collaboration, is transferred in various ways to the collaborating firm for possible future development and use in house, thereby enhancing the firm's internal innovation capabilities. This enhancement can occur through various means, including the recruitment of academics involved in the collaboration, cultivating learning, and network development (McKelvey and Ljungberg, 2017).

A critical aspect of the indirect route, in particular, is the development of the firm's learning capability, often conceptualized through the lens of absorptive capacity (AC) (Cohen and Levinthal, 1990). This concept refers to the firm's competence to learn and innovate through the ability to recognize the value of, acquire, assimilate, and exploit external knowledge. In the context of the indirect path, this was examined by Xu et al. (2014), who provided empirical evidence and firm data supporting the connection between the indirect route and learning, showing that knowledge from a university can increase a firm's innovativeness by developing its capabilities to innovate. This strengthens the argument that the indirect route, through learning, affects a firm's innovativeness. Recent research has empirically connected the indirect route to learning and AC through the individuals involved in knowledge-related interactions. For example, McKelvey et al. (2015) demonstrated that hiring of junior academic researchers, who had been engaged in the collaboration, increases a firm's innovation capability by adding to the firm's knowledge base and increasing its AC. Berg and McKelvey's (2020) empirically based research on graduate students and firm innovation specified how student activities support the firm's development of innovation capabilities, specifically the recognition of value and assimilation of external knowledge in the AC stages. Berg (2022) connected firm and university activities to both the direct and indirect routes using empirical data on firm-employed Ph.D. students' contribution to the firm's AC. This research illustrates how academic engagement and the indirect path are connected to the development of innovative capabilities.

The present research addresses university–industry collaboration as a formal type of academic engagement, emphasizing an intrafirm perspective and thereby contributing to the literature by expanding on the specifics of how collaboration knowledge is integrated and utilized by a firm in a UIC (cf. McKelvey et al., 2015; McKelvey and Ljungberg, 2017). A form of UIC where this research is needed is in the "center of excellence" context (Jansson et al., 2017; Ramsten and Benner, 2019). The following section presents an overview of the center of excellence, which serves as the empirical context in which to better understand firm utilization of knowledge developed through collaboration.

1.1 The empirical context: the Combustion Engine Research Center

The essential characteristics of the center of excellence, the type of university–industry collaboration investigated in this dissertation, are outlined in this section. This is followed by a presentation of the specific studied center, i.e., the Combustion Engine Research Center located at Chalmers University of Technology in Gothenburg. In this research, this center is the case and is contextualized in this section. To clarify the empirical context, the above center is a center of excellence, which is a form of UIC, which is in turn a type of academic engagement.

The center of excellence (CoE), a significant form of knowledge-related interaction, has become internationally established in recent decades. As of 2010, two-thirds of the OECD member states had introduced various sorts of initiatives to encourage research excellence, and among them the CoE was the most common such initiative (OECD, 2014). Located within a university, a CoE in general terms is a research and innovation funding instrument, originating in the 1980s (Ramsten and Benner, 2019; Stampfer, 2019; Stern et al., 2013), involving industry participants and interdisciplinary research in conducting R&D. A CoE usually has the objective of producing knowledge that drives innovation and the participants' research practice (OECD, 2013; Stern et al., 2013). The focuses of CoE research are the requirement for research quality to achieve international standards of excellence and innovation, and the encouragement of cooperative research as part of the center's operations to develop innovative results (OECD, 2014). In this Ph.D. research, the CoE is understood to encompass both excellence and competence in striving toward interdisciplinary scientific excellence with industrial impact.

The Swedish CoE program is intended to foster university–industry collaboration, primarily focusing on producing high-quality, need-based research and innovation. The program was established to create a forum for external organizations to collaborate with universities in conducting research (Aksnes et al., 2012). Research conducted under the auspices of the Swedish CoE program aims for excellence—i.e., high-quality research practice—and need-based research and innovation—i.e., meeting enterprises' and society's need for new knowledge (Johansson, 2020). The program, through structured initiatives, aims to enhance the long-term research, innovation, competitiveness, and capabilities of its collaborating parties (Johansson, 2020). Stern et al. (2013) analyzed the long-term industrial impacts of the Swedish CoE program on society, concluding that the program had a positive economic impact and significantly influenced firms' innovation models. However, the connection between collaboration knowledge and intrafirm usage is not clear. For example, Jansson et al. (2017) argued in their meta-analysis of eight Swedish CoEs that CoE knowledge provides a foundation for innovation development that later occurs in the firms' internal innovation processes. However, their meta-analysis does not specifically elaborate on how the CoE-produced knowledge contributes to firms' internal development of innovation, and this relationship is also addressed in later CoE analyses (Ramsten and Benner, 2019). One example of a CoE is the Combustion Engine Research Center studied here.

The Combustion Engine Research Center (CERC) was founded on 1 November 1995 as a three-party agreement between Chalmers University of Technology (Chalmers) in Gothenburg, the Swedish Board for Technical and Industrial Development (NUTEK), and a group of five Swedish industrial companies. It was founded to be a forum for industrial and academic research on internal combustion engines. CERC's fundamental purpose is to build "a concentrated interdisciplinary research pool in which the participating companies can actively take part in and benefit in a long-term perspective," and its long-term objective is to "carry out fundamental research of high industrial interest" (Karlström, 1997, p. 2). CERC's focus on basic and transdisciplinary research with industrial relevance has remained consistent over the years. CERC presents an interesting case because of its location at Chalmers University of Technology, an esteemed institution of higher education in Sweden. CERC's lifespan of over 27 years amplifies its academic significance, and the outcome of its interdisciplinary and fundamental research of industry relevance is 711 publications. The prolonged participation of its full member partners underscores CERC's achievements and relevance to its partners.

In summary, CERC is a CoE and the case examined here. CERC is a prominent source of data for research on how collaboratively developed knowledge is internalized in the collaborating firms' developmental practices. As a CoE, CERC is intended to foster and perform high-quality, interdisciplinary, need-based, applied, and collaborative research with industry, and to develop innovative results that impact participating firms and society. Having established the value of CoE, and of CERC as such a center, the following section outlines the specific research problem addressed here.

1.2 The purpose and delimitations

Prior research has addressed the firm perspective and how firms develop innovative capabilities through interaction with academic scientists in collaborative research (Berg, 2022; Berg and McKelvey, 2020a; McKelvey et al., 2015; McKelvey and Ljungberg, 2017; Sjöö and Hellström, 2021). Research examining an intrafirm perspective helps improve our understanding of how collaboration knowledge is connected to a firm's cultivation of these innovative capabilities (cf. Jansson et al., 2017; Perkmann et al., 2021; Ramsten and Benner, 2019; Skute et al., 2019). The research in this dissertation performs this examination. The phenomenon studied here is how cooperatively developed knowledge, resulting from knowledge-related interaction in a UIC, is internally utilized by a firm. The underlying purpose of this dissertation is delineated as follows:

Purpose

The purpose of this research is to explore how knowledge developed in a university–industry collaboration is utilized by the collaborating firm in the development of innovations.

This formulation centers on the firm perspective and on the intrafirm functions and practices that facilitate the firm's utilization of knowledge derived from the collaboration. The aim is, by means of empirical descriptions, to improve our understanding of how the collaborating firm internally develops innovations using knowledge derived from a collaboration. This dissertation applies a firm perspective and a qualitative single-case study design to address the research question. The purpose specifies the following delimitations. Knowledge is delimited to outcomes created at the university and through scientific activities. Among the possible types of interaction with the university, the university–industry collaboration is selected, specifically the CoE as a form of collaboration in which firms and a university engage in knowledge-related interactions, providing the context of this dissertation (see section 2.2). This dissertation applies a firm perspective in a qualitative single-case study, with CERC being the studied case, to address the research question identified in the literature review. The CERC collaboration is a prominent case because, as a CoE, its initial rationale was to foster and perform industry-relevant research of high scientific quality generating innovations in the participating companies. The research employs a qualitative approach using semi-structured interviews inspired by case study research, here focusing on the comparison of innovations. It is further delimited to studying one firm, i.e., Volvo Car Corporation (VCC), within CERC, as the firm has been a long-term full member partner participating from the Center's inauguration to its end. The firm's extended participation increases the probability that it used collaboration knowledge as a source of knowledge for innovation. The purpose emphasizes innovation, so both product and process innovations created with or influenced by the collaboration knowledge are of interest. AC (Cohen and Levinthal, 1990) is the dissertation's theoretical framework, due to its account of a firm's competence to learn and innovate based on external knowledge (see section 2.3, below) by means of its ability to recognize the value of, acquire, and assimilate external knowledge, with the UIC potentially being the external knowledge source. Additionally, the utility of AC is established in the prior UIC literature, including in the literature on academic engagement (Berg and McKelvey, 2020a; McKelvey and Ljungberg, 2017; Santoro and Chakrabarti, 2002; Skute et al., 2019; Tether and Tajar, 2008). By employing AC as a theoretical framework, it is anticipated that this thesis will contribute to clarifying the relationship between cooperatively developed knowledge, resulting from knowledge-related interaction, and its internal effect on the firm. These delimitations limit the theoretical implications to university–industry collaborations and the automotive industry. The results are therefore to be understood within the limitations of the studied context.

1.3 Research activities connected to this Ph.D. dissertation

This Ph.D. dissertation is a monograph addressing a single topic. Subsequent sections and chapters elucidate the reasoning, method, data collection, and analysis that in the end led to the theoretical contributions concerning the research question. The research reported here has been performed independently. Therefore, in accordance with the open access standard, this dissertation must be regarded as the author's original text. The dissertation is part of my doctoral studies in Innovation, Entrepreneurship and Management of Intellectual Assets at the University of Gothenburg. Consequently, I have had the opportunity to formally present and defend the dissertation thrice, as an integral part of my doctoral studies at the Department of Economy and Society and the Unit for Innovation and Entrepreneurship: the first time was my defense at the planning seminar after one year; the second was my defense at the mid-way seminar half way through the doctoral program; and the last time was at the final seminar or the pre-defense evaluation of the manuscript. All seminars were integrated into the Department's doctoral program, with assigned discussants to ensure the educational quality.

Besides the three seminars, the doctoral program included various activities and outcomes that will be mentioned here but are not further accounted for in this dissertation. Writing this Ph.D. dissertation was enabled through a process of developing papers and participating in academic conferences throughout my doctoral studies. These activities were carried out within the scientific community, and they provided valuable insights and experience that informed this dissertation. These activities and publications are presented in Table 1.

Table 1: Publications and conference participation

Year	Type	Author	Title	Reference
2021	Conference paper	D. Hemberg	Recognizing the value of academic research: a routine dynamics and individual-level perspective (EGOS, Routine dynamics: Relating micro-actions and organizational outcome, 2021)	Hemberg 2021
2021	Book	M. McKelvey, K. Berg, E. Bourelos, L. Brunnström, E. Gifford, D. Hemberg, I. Hermansson, S. Lindmark, D. Ljungberg, R. Saemundsson, V. Ström, O. Zaring	Forskningssamverkan och kommersialisering: samhällets långsiktiga försörjning av ingenjörsvetenskaplig kunskap	McKelvey et al. 2021
2018	Ph.D. workshop presentation	D. Hemberg	Managing information for innovation (IIE, Ph.D. workshop at Alingsås, 2018)	Hemberg 2018b
2018	Conference paper	D. Hemberg	Managing knowledge for innovation (21st Uddevalla Symposium, 2018)	Hemberg 2018a
2017	Ph.D. workshop participation	D. Hemberg	Data and Algorithms – summer workshop, Leuven, 2017	
2021	Conference paper	D. Hemberg	Recognizing the value of academic research: a routine dynamics and individual-level perspective (EGOS, Routine dynamics: Relating micro-actions and organizational outcome, 2021)	Hemberg 2021
2021	Book	M. McKelvey, K. Berg, E. Bourelos, L. Brunnström, E. Gifford, D. Hemberg, I. Hermansson, S. Lindmark, D. Ljungberg, R. Saemundsson, V. Ström, O. Zaring	Forskningssamverkan och kommersialisering: samhällets långsiktiga försörjning av ingenjörsvetenskaplig kunskap	McKelvey et al. 2021
2018	Ph.D. workshop presentation	D. Hemberg	Managing information for innovation (IIE, Ph.D. workshop at Alingsås, 2018)	Hemberg 2018b

The activities and publications presented in Table 1 focus on specific topics and on the further development of my research agenda. In cases of co-authorship, all authors were active, especially in theoretical framing, analysis, and writing up the results into publications. All authors also presented these research results at conferences. The activities and presentations in the above table have been valuable for this dissertation's development through verbal and written feedback from diverse perspectives. Additionally, I have taken part in seminars and workshops with business and public policy representatives; during the course of my doctoral studies, my research team and the U-GOT KIES Center hosted popular science debates at these events several times a year.

1.4 Outline of the thesis

This doctoral thesis is structured as follows: Chapter 0 develops an overarching theoretical frame of reference corresponding to the purpose of the thesis and formulates the research question. Chapter 0 addresses the methodological considerations and presents the research design used to address the research question, with a single-case study design being employed and the firm's perspective on the collaboration being the focus. Chapter 0 introduces the results by providing the background and context of the university–industry collaboration and the CoE, which is necessary in order to understand the findings. This chapter also presents the results and analysis of the first round of interviews, specifically addressing influential firm roles, the approach to collaboration, and individuals influencing the utilization of knowledge in developing firm innovations. Chapter 5 presents the results and analysis of the second round of interviews, focusing on how collaboration knowledge is recognized, acquired, and assimilated into firm innovations, to understand in detail the mechanisms and paths involved. Chapter 0 discusses the research and presents its final conclusions concerning the research question, followed by the theoretical, managerial, and policy implications of the research; this is followed by the reference list and the appendixes.

2 Literature review

The objective of this chapter is twofold: first, to develop a state-of-the-art overarching theoretical frame of reference corresponding to the purpose of the thesis; second, to develop a research question. To investigate how knowledge developed in a UIC is utilized in the development of firm innovation, this chapter concentrates on the UIC and AC literatures. Combining these fields of literature, which are identified as valuable for this research and for the development of the research question, creates the frame of reference. Furthermore, AC is valuable as a theoretical framework because of the concern with the ability of firms to recognize the value of, acquire, assimilate, and exploit external knowledge. An overview of these fields of literature is structured in the following sections: 2.1 "Defining the terminology" specifies the important terms used in the dissertation; 2.2 "Overview of the literature on university–industry collaboration" describes how such collaboration has hitherto been investigated and explores current perspectives on the universities' third mission; 2.3 "Collaborative research impact on firm innovation through two routes" elaborates on the impact of collaboratively developed knowledge through academic engagement and the indirect route; and 2.4 "Absorptive capacity as a theoretical framework for knowledge exploitation" details this dissertation's theoretical framework, describing how an organization recognizes, assimilates, and exploits external knowledge, with the UIC being the external knowledge source. This section is delimited to outlining the fundamental components of absorptive capacity, its relationship to UIC, and how it is applied in this research. Section 2.5 "Theoretical summary," which presents an overview of the literature, is followed by 2.6 "Research question development."

2.1 Defining the terminology

This section describes and specifies the terms used throughout this research and that are useful for understanding the scope of the dissertation. These terms are “innovation” and “university–industry collaboration.”

2.1.1 Definition of “innovation”

The concept of innovation is central to this research. As widespread use of the term both colloquially and in research for nearly a century has generated multiple interpretations, it is important to establish the rationale for the current working definition.

Historically, the term “innovation” became tied to technological production and economic growth after World War II (Godin, 2019). The term’s popularization is accredited to Joseph Schumpeter, who defined “innovation,” or “development” (see Fagerberg, 2009, p. 20), in 1934 as “new combinations” of new or existing knowledge, resources, equipment, and other attributes (Schumpeter et al., 1934/1983). Rephrased, innovations are new ideas evolved and commercialized from novel combinations of knowledge and resources. Schumpeter also emphasized the entrepreneurial role of the recognition of value and the novel recombination of materials and forces (Galunic and Rodan, 1998; Schumpeter et al., 1934/1983). Later, the relationship between innovation and the entrepreneur was emphasized by Drucker (2006, p. 6), who described innovation as the seizing of new business opportunities, a structured process, and a proactive search for resources to exploit, all of which are tools that the entrepreneur uses.

The innovation process is primarily about problem-solving (Arthur, 2007; Ebadi and Utterback, 1984), with the new solution (i.e., the invention) utilizing and recombining knowledge gained from previous experience and science (Dosi, 1988; Nelson, 1982; Savino et al., 2017; Verhoeven et al., 2016). In a problem-solving process, the problem to address must be chosen, but the choice is limited by the existing knowledge, which is often insufficient. It is therefore important to address valuable problems, the solutions to which can generate desirable knowledge or capabilities (Nickerson and Zenger, 2004). In this research, an innovation/invention is understood as the outcome of a problem-solving process. In interpreting the results presented here, what constitutes a problem must be clarified. There is a rich literature on the concept of the problem that considers various views and perspectives (Arthur, 2007; Björkdahl et al., 2022; Landry, 1995, 1988; Pounds, 1969). In this dissertation, the problem is grounded in a certain object and subject. When a subject recognizes the failure of their adaptation and understands the importance of investigating the cause of the failure, a problem arises. Here, we focus on the problem's function within an organizational context, further distinguishing among problem finding, problem formulation, and problem-solving, as well as investigating and selecting a useful solution (Landry, 1995). In summary, a problem is essentially "an unfulfilled want" (Arthur, 2007, p. 274).

More recently, the OECD has contributed to research on innovation with its 2018 publication of the fourth edition of the *Oslo Manual*, which introduced a revised definition and clarified issues arising in previous editions. The OECD's general definition of an innovation is as follows: "An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)" (OECD/Eurostat, 2018, p. 60). This definition accounts for two types of innovations, i.e., product and process innovations, and two main features of innovations, here summarized as implementation and novelty. In the manual, the previous list-based definition of innovations as comprising four types (i.e., product, process, organizational, and market innovations) is condensed into two main types: product and business process innovations. A product innovation is defined as "a new or improved good or service that differs significantly from the firm's previous goods or services and that has been introduced on the market" and a business process innovation as "a new or improved business process for one or more business functions that differs significantly from the firm's previous business processes and that has been brought into use by the firm" (OECD/Eurostat, 2018, p. 60). By products, the OECD means tangible objects or knowledge-capturing products (i.e., goods) defined as "objects for which current or potential demand exists and for which ownership rights can be established" (OECD/Eurostat, 2018, p. 246). Products can also be intangible activities (i.e., services) that are the outcome of a production activity, defined as "the result of a production activity that changes the conditions of users or facilitates the exchange of products, including financial assets" (OECD/Eurostat, 2018, p. 53). By business process, the OECD is referring to the core business functions that produce goods or services (OECD/Eurostat, 2018). In short, a product innovation concerns goods or services and a business process innovation concerns a core business function. As mentioned above, the definition summarizes two features of an innovation as implementation and novelty. Implementation refers to the usage of the new product or process. A product innovation is considered to be implemented when it is available to the intended user, but usage is not required (e.g., a new car is available on the market). A process innovation is considered to be implemented when it is used in the firm's operations (e.g., the introduction and usage of new software). Novelty refers to a characteristic of the product or process being significantly different from that of a previous product or process (OECD/Eurostat, 2018). The novelty characteristics of a product innovation refer to improved quality, technical specifications, reliability, durability, economic efficiency during use, affordability, convenience, usability, and user friendliness. The novelty characteristics of a process innovation refer to improved efficacy, resource efficiency, reliability and resilience, affordability, convenience, and usability (OECD/Eurostat, 2018).

Table 2, below, summarizes the distinction between product and process innovations and the two features, implementation and novelty; the two features are also criteria for identifying cases of innovation.

Table 2: List of criteria for an innovation

Type	Implementation	Novelty
Product innovation (goods and services)	When available to intended user	Significantly different in one or more of: quality, technical specifications, reliability, durability, economic efficiency during use, affordability, convenience, usability, and user friendliness
Business process innovation (core function)	When used in firm operations	Significantly different in one or more of: efficacy, resource efficiency, reliability and resilience, affordability, convenience, and usability

In

Table 2 the first column describes the two types of innovations identified by the OECD (2018). The second column describes the implementation features of the two types of innovations. Here, “available” refers to the act of introduction, with the organization having made a systematic effort to make the innovation accessible to potential users (OECD, 2018). The third and last column defines the features of what is considered a novel change in the two innovation types. By implementing this definition of innovation and the features implementation and novelty, it is possible to identify innovations that result from collaboration knowledge.

Innovations are central to this dissertation’s purpose, that is, to explore how knowledge developed in a university–industry collaboration is utilized by the collaborating firm in the development of innovations. Therefore, the working definition of an innovation used in this thesis is as follows: An innovation must be either a product or a process (type), available to users or applied in the firm’s operations (implementation), and significantly different from the firm’s previous product or process (novelty).

2.1.2 Definition of “university–industry collaboration”

University–industry collaboration is here treated as a form of interaction between parties from the higher education system and industrial firms. Interaction is here a broad and inclusive concept, comparable to Bekkers et al.’s (2008, p. 1838) use of “channels” through which “knowledge flows between universities and industrial firms.” UIC also encompasses both formal and informal activities, as well as actors from both the university and the firm. Formal activities entail the presence of a contract and can include face-to-face interaction as in, for example, collaborative research, contract research, and consultation (Schaeffer et al., 2018). Informal activities include face-to-face interaction (Schaeffer et al., 2018) such as networking between the university and industry (Perkmann et al., 2021). The formal activity of research collaboration has been examined from different perspectives, including those of public–private research centers (Gulbrandsen et al., 2015), hybrid organizations (Gulbrandsen, 2011), and research collaboration (McKelvey et al., 2015). With this distinction in mind, this Ph.D. thesis refers to both formal and informal activities between universities and industrial firms when using the concept of university–industry collaboration.

University–industry collaboration is here defined as the partnership and institutionalization of interactions between any parts of the higher educational system and industry aiming mainly to encourage the activities of knowledge and technology exchange (Ankrah and AL-Tabbaa, 2015; Bozeman et al., 2013; Perkmann and Walsh, 2007; Petruzzelli, 2011; Skute et al., 2019), activities that over time lead to new knowledge and innovations. The definition underlines that the interactions are formalized (i.e., structured and recurrent events), being designed to enable collaborative work between actors that eventually creates collaboration knowledge and innovations. As stated above, formalized interaction does not exclude informal interaction, and here both are included. Collaboration here refers to the shared commitment of resources to the mutually agreed aims of several partners (Dodgson, 2013), including the social processes whereby human beings pool their human capital for "the objective of producing knowledge" (Bozeman et al., 2013, p. 3). Perkmann and Walsh (2007) argued that three categories of university–industry links can be identified depending on the degree of relational involvement (i.e., the various ways publicly funded research benefits industry). These three categories are *relationship*, *mobility*, and *transfer* links, with relationship having a high degree of relational involvement, mobility an intermediate degree, and transfer a low degree. This thesis addresses the relationship link, with a focus on the UIC called the Combustion Engine Research Center (CERC), and by extension the mobility link, whereby some UIC employees have migrated to Volvo Car Corporation (VCC).

For this Ph.D. thesis, the definition of university–industry collaboration contributes by emphasizing the formalized structures of the collaboration and both the formal and informal activities of knowledge exchange.

2.2 Overview of the literature on university–industry collaboration

To explore how firms use knowledge from university–industry collaboration, this section begins by treating the rationale for university–industry collaboration, followed by an overview of the literature on university–industry collaboration, including accounts of scholarly perspectives and findings. It additionally presents research streams that address the third mission of universities. The section concludes with an application of the aforementioned research and its findings within the scope of this dissertation, and as relevant to the development of the research question.

2.2.1 Reasons for university–industry collaboration

Collaborations between universities and industry are growing in terms of both frequency and demand. Universities have a long history of interacting with external parties, such as industry (for the case of the English Staffordshire potteries in 1775, see Dodgson, 2011; Mowery and Rosenberg, 1999), and the number of interactions is increasing in response to rising demand from both parties (Giuliani and Arza, 2009) and increased government incentives (Etzkowitz and Klofsten, 2005; Geuna and Muscio, 2009; OECD/Eurostat, 2018). This increase in demand for interaction from university and industry participants is due to the perceived benefits accruing to both parties. For example, universities gain access to market opportunities, practical examples of how to apply research (Ankrah et al., 2013), and additional technology (Dooley and Kirk, 2007), whereas industry participants can gain access to knowledge, expertise, and cutting-edge technology (Ankrah et al., 2013). From an innovation perspective, industrial access to collaboration knowledge is valuable because innovation is derived from knowledge-based activities, that is, the practical application of information and knowledge for different purposes (OECD/Eurostat, 2018, p. 46). Collaboration knowledge can inform inventors of more useful configurations of components when solving complex problems or striving to avoid less useful solutions (Bellucci and Pennacchio, 2016; Fleming and Sorenson, 2004). In this way, universities can facilitate innovation in industry by introducing new ideas (Laursen and Salter, 2005). The benefits accruing to both parties have given rise to a new field of research focused on understanding this symbiotic relationship.

2.2.2 Four perspectives on university–industry collaboration

Research on university–industry collaboration is an extensive field that has grown over the past decade and is here condensed into four main perspectives[2] that have influenced the conversation: distance, ecosystem, interaction channels, and innovation.

The *distance* perspective describes the role of the UIC partners' knowledge complementarity and how it contributes to scientific and technological advancement.

[2] For more comprehensive insights, I suggest the following systematic literature reviews by Agrawal (2001), Geuna and Muscio (2009), Perkmann and Walsh (2007), and Rothaermel et al. (2007).

Skute et al. (2019) observed how the shared capabilities of both parties are influential for the recognition, acquisition, assimilation, and exploitation of each party's resources for regional economic development; additionally Cohen and Levinthal (1990) described how the partners' AC was found to be pivotal for the successful exploitation of shared resources and knowledge (see also Santoro and Chakrabarti, 2002; Tether and Tajar, 2008).

University–industry collaboration has also been analyzed as an *ecosystem.* Investigators have evaluated the different roles of an ecosystem (Park et al., 2005) and how economic exchange, scientific and technological innovation, and institutional control as subsystems within the "Triple Helix" model (Leydesdorff and Fritsch, 2006) generate productivity (regarding university–industry–government relations within this model, see Etzkowitz and Leydesdorff, 1997, 1995; Leydesdorff, 2010). In the model, the government occupies an entrepreneurial and venture capitalistic role (Etzkowitz, 2003; Leydesdorff and Fritsch, 2006) and the university has the role of knowledge producer and research administrator (Etzkowitz and Klofsten, 2005). Ecosystem perspective research has aimed to comprehend the interrelationships among the actors in the ecosystem, along with the knowledge generators and consumers (Skute et al., 2019). In summary, the ecosystem perspective helps to elucidate the dynamics of UIC with an analysis focusing on the national or regional level.

University–industry collaboration has been studied through the lens of the *interaction channels* that the university and industry partners use, for example, journal articles, published reports, conferences and meetings, and contract research (Wright et al., 2008). The interaction channel perspective explores how and why specific channels of interaction are chosen (Bekkers and Bodas Freitas, 2008; Geuna and Muscio, 2009) and suggests that the characteristics of the transferred knowledge, involved researchers, and environment determine the selected interaction channel

(Bekkers and Bodas Freitas, 2008). Additionally, barriers to collaboration have been investigated by Bruneel et al. (2010). They found that orientation barriers (e.g., when the university and industry have different orientations) and transaction-related barriers (e.g., intellectual property and administration) are both mitigated by the interacting parties' level of trust, and that the orientation barrier is also lowered by previous experience of collaborative research (Bruneel et al., 2010). Trust refers to the partners' capacity to collaborate and solve problems, and to their willingness to understand and align with the needs of the collaborating partner (Bruneel et al., 2010).

Another important perspective on university–industry collaboration concerns its role in fostering *innovation*, with studies examining the impact of such collaboration on the development of new products or processes. George et al. (2002) showed that the links between university and industry are important for the creation of innovations without increasing in-house R&D expenses. Mascarenhas et al. (2018) reviewed the literature on university–industry cooperation (here comparable to collaboration) from an innovation and research strategy perspective. Their review showed that UIC is important for the development and distribution of new technologies and the creation of new products. UIC can be a strategy for both innovation and research because mutual strategies can coexist, although empirical studies are needed to better understand the relevant aspects of UIC (Mascarenhas et al., 2018). Sjöö and Hellström's (2019) UIC literature review identified seven central factors stimulating the co-production of innovations in a UIC. The authors argued that the experience factor was the strongest predictor of participation in a UIC, being hypothesized to stimulate various learning processes (Sjöö and Hellström, 2019). That being said, this overview of the UIC literature has illuminated various views on UIC, such as partner distance and complementarity, AC, ecosystems, interaction channels, innovation factors, and strategies. While each of the four perspectives constitutes a valuable approach for addressing UIC, this dissertation emphasizes the innovation perspective, given the present aim of understanding the impact of UIC knowledge on the intrafirm development of innovations. Specifically, this dissertation will contribute an empirical account of how collaboratively developed knowledge is utilized in the firm's development of innovations.

Having presented and discussed these four main perspectives, I now return to the purpose of this research. The purpose narrows the scope to knowledge developed in a collaboration and how this knowledge is used to develop firm innovations. Research that addresses the contribution of collaboration knowledge is the topic of the next section.

2.2.3 Universities' third mission and the use of collaboration knowledge

Universities' missions to conduct research and educate the population are known as their two main missions; in recent decades, a third mission to contribute to society has obtained more acceptance as a valid additional objective for universities. One central aspect of the third mission concerns transferring knowledge (and technology) to external parties—or as Etzkowitz (2003) put it, "to see that the knowledge is put to use" (p. 323). This aspect of the third mission, i.e., putting the knowledge to use, is aligned with the purpose of this dissertation. In many countries, the third mission has been encouraged by policy makers to stimulate various links that enable the exchange and contribution of university-derived knowledge to knowledge users (Perkmann et al., 2013).

Previous research on the transfer[3] of knowledge can be divided into two broad areas: commercialization of academic research and academic engagement. Commercialization of knowledge developed at universities includes aspects such as academic entrepreneurship and technology transfer. The literature on the commercialization of academic knowledge pays attention to the outputs of the third

[3] Transfer here refers to aggregated levels, for example, the meso and macro levels.

mission, for example, patenting, licensing, academic entrepreneurship, and spin-outs (Arant et al., 2019; Markman et al., 2008; O'Shea et al., 2005; Phan and Siegel, 2006; Rothaermel et al., 2007). This literature views the exchange of knowledge from the university to external parties through the lens of commercialization. Academic entrepreneurship entails the creation of start-ups from innovative ideas either created at the university or still being developed by an academic researcher (Ray, 2013; Skute et al., 2019). This literature has elaborated on the role of the characteristics of universities and researchers (Bercovitz and Feldman, 2008; Etzkowitz, 2003; Mansfield, 1995; O'Shea et al., 2005), incentives for and barriers to engaging in entrepreneurial activities (Siegel et al., 2003), and how policy settings influence academic entrepreneurship (Debackere and Veugelers, 2005). Research has found that expenditures on intellectual property protection, the business development capability of technology transfer offices, and the royalty structure of the university are positively associated with the number of spin-out companies (Lockett and Wright, 2005). Research on technology transfer offices focuses on various dimensions of these offices (Bengoa et al., 2021; Thursby and Thursby, 2002) and on their role in supporting the commercialization of publicly funded research (Holgersson and Aaboen, 2019), such as patenting and various types of research licensing (Lockett and Wright, 2005; Zucker and Darby, 1996). A technology transfer office is important to a university because it facilitates technological diffusion through licensing the inventions or intellectual property that result from university research (Bengoa et al., 2021). Historically, technology transfer research has focused on patenting and licensing, more recently considering the spin-off as a means of commercialization (Siegel and Wright, 2007). Dasgupta and David (1994) explored the effect of policy incentives to encourage the exchange of knowledge, compared with open science, research, and commercial development. They concluded that the organizational interaction benefits gained by an open science researcher could not be achieved by economic stimulation (Dasgupta and David, 1994). The *academic engagement* literature does not emphasize commercial exploitation, instead focusing on the interactions between university researchers and external organizations, defining such engagement as “knowledge-related interactions by academic researchers with non-academic organizations” (Perkmann et al., 2021, p. 1). The academic engagement literature is striving for a better understanding of how formal and informal activities shape processes and outcomes that are related to non-academic organizations’ use of knowledge resulting from interaction with academia.

In summary, one aspect of the third mission concerns the transfer and use of knowledge originating from the university, and two associated areas of research have been presented. Among the areas addressing the application of knowledge as an outcome of knowledge-related interaction, the academic engagement perspective and its focus on formal and informal activities is useful to this thesis. One reason for this is the academic engagement perspective’s inclusion of the industry perspective, a necessary premise derived from the formulation “utilized by the collaborating firm” in this dissertation’s statement of purpose. Accordingly, the next section details the main themes found in the academic engagement literature.

2.2.4 University–industry collaboration: academic engagement

Academic engagement is a multi-level phenomenon determined by individual, organizational, and institutional characteristics (Perkmann et al., 2013). Furthermore, it acts as a transmission mechanism, ensuring the impact of academic research on the economy and society (Bornmann, 2013; Martin, 2011), and is seen as an essential method of increasing the impact of science (Perkmann et al., 2021). Through its various forms, academic engagement is widely practiced, and its economic significance is expected to be substantial for both universities and firms, compared with commercialization (Hughes et al., 2016; Hughes and Kitson, 2012; Perkmann et al., 2011). For example, the frequency of articles including the term “academic engagement" significantly increased over the 1990–2020 period (see the Appendix A for an academic engagement keyword analysis).

The initial focus of the academic engagement concept centered on the academic researchers and their characteristics (Perkmann et al., 2013, 2021). This literature has studied, among other things, the antecedents of academic engagement, including prior scientific accomplishment (Bekkers and Bodas Freitas, 2008; D'Este et al., 2019; Zi and Blind, 2015), prior experience (Aschhoff and Grimpe, 2014; Barbieri et al., 2018; D'Este and Patel, 2007; Gulbrandsen and Thune, 2017; Hughes et al., 2016), academic rank (D'Este et al., 2019; Lawson et al., 2019; Tartari et al., 2014; Tartari and Breschi, 2012), gender (Abreu and Grinevich, 2017; Blind et al., 2018; Gulbrandsen and Thune, 2017; Kongstedt et al., 2017; Lawson et al., 2019; Tartari and Salter, 2015), how academic engagement affects the university scientist's productivity (Banal-Estanol et al., 2015; Bekkers and Bodas Freitas, 2008; Bikard et al., 2019; D'Este et al., 2019), the academic's country of origin and engagement with external actors (Lawson et al., 2019), peer influence on the academic's industry engagement (Aschhoff and Grimpe, 2014; Tartari et al., 2014), academic entrepreneurial intentions (Johnson et al., 2017), and factors underlying the variety of interactions (D'Este and Patel, 2007). A growing body of literature has examined various factors influencing academic engagement, setting the stage for further exploration of its implications and outcomes. Over time, the conceptualization has evolved to accommodate a variety of views of knowledge-related interactions, including views taking account of the collaborating firm. This area of research emphasizes knowledge growth and established links between academic institutions and external organizations, comprising both formal and informal activities that facilitate knowledge transfer and benefit society (Perkmann et al., 2013). Formal academic engagement activities include collaborative research with industry, contract research, and consulting, whereas informal activities include providing ad hoc advice and networking (Perkmann et al., 2021). For example, this research stream studies the impact of joint leadership on university–industry collaboration (Sjöö and Hellström, 2021), the type of interaction beneficial for firm innovation (Mikhailov et al., 2021), and firms' creation of innovative opportunities through collaboration (McKelvey et al., 2015). Research related to the academic engagement literature and applying a firm perspective is presented in section 2.4.3, which assesses the connection between AC and UIC.

The focal point of this dissertation is university–industry collaboration (UIC), a form of academic engagement exhibiting unique formal characteristics. Drawing on prior studies of UIC, it has been recognized that from the standpoint of the collaborating firms, the acquired knowledge is often of a fundamental nature and typically does not integrate seamlessly with the ongoing innovation processes within the firm (also see Jansson et al., 2017; McKelvey et al., 2015). The assimilation of this collaboration-derived knowledge within the firm frequently occurs via the collaborating individuals. However, the detailed process through which such fundamental knowledge is recognized, internalized, and effectively utilized within the firm as specific knowledge warrants exploration (Perkmann et al., 2021). This intrafirm dimension is accentuated in the systematic literature review conducted by Ankrah and AL-Tabbaa (2015), which examines the UIC literature and raises the question of whether the intellectual exchange with academic collaborators contributes substantially to the R&D capabilities of the firms participating in the UIC. This question is also addressed by the bibliometric analysis of Skute et al. (2019). A form of UIC, about which intrafirm research is needed, is situated within the context of CoE.

Various studies have investigated the outcome and effects of Swedish CoEs (e.g., Bergström and Österberg, 2021; Jansson et al., 2017; OECD, 2014; O'Kane and Vinnova, 2016; Reeve et al., 2009; Stern et al., 2013). An early analysis of the long-term impact of Swedish CoEs concluded that they have positive impacts on the economy and on the collaborating firms' innovation models (Stern et al., 2013). Jansson et al.'s (2017) meta-analysis of eight Swedish CoEs underlined that knowledge development was a central and valuable outcome for the firms participating in CoEs, suggesting that the knowledge was transferred mainly through the recruitment of CoE individuals (cf. Berg, 2022; Berg and McKelvey, 2020a; McKelvey et al., 2015). The meta-analysis (Jansson et al., 2017) further claimed that the CoE-developed knowledge forms a foundation for innovation development that occurs internally in the firms and later in the innovation process. However, the specifics of this process and how the collaboration knowledge is transferred from the recruited individuals into the wider firm is unclear or, as is how the CoE-developed knowledge advances the firms' internal development of innovations. Understanding the relationship between CoE-developed knowledge and how it contributes to the collaborating firms' innovation development is also addressed in later CoE analyses (Ramsten and Benner, 2019). In this dissertation, CERC as the studied case is a CoE.

2.2.5 Summary of university–industry collaboration

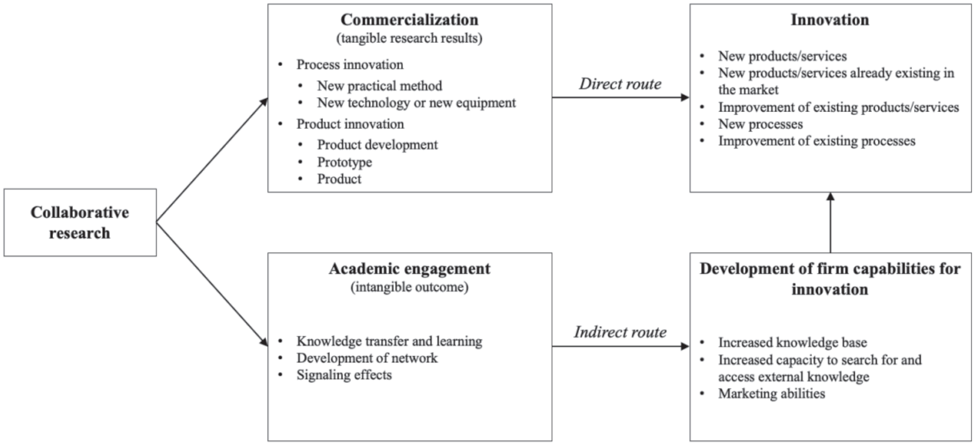
In the context of this thesis, these previous findings are of significant value. The innovation perspective within the UIC literature shows that UIC is important for the development of knowledge and its contribution to innovation development in firms; accordingly, previous experience of research collaboration is hypothesized to stimulate learning processes, and such experience is related to innovations. The academic engagement literature with its focus on knowledge interactions offers a valuable perspective advancing our understanding of how collaboration knowledge is utilized. Taken together, the literature supports the notion that UIC is connected to the industry participants' development of innovations.

The need to understand how knowledge from a UIC is conveyed from the universities to be applied by the collaborating firms has become increasingly important for the development of a comprehensive theory. Because previous research has emphasized the academic perspective, accounts from the industry perspective are scarce. This calls for further research that explores how knowledge from UIC participation contributes to firm innovation development. To perform such an inquiry, AC as a theoretical framework is a prominent choice because: first, it describes how an organization recognizes, assimilates, and exploits external knowledge of which the UIC can be the external knowledge source; and, second, it has already established its utility in the UIC literature (Santoro and Chakrabarti, 2002; Skute et al., 2019; Tether and Tajar, 2008). Having discussed the UIC literature and its various perspectives, the next section of this literature review concerns a conceptual model that incorporated AC.

2.3 Collaborative research impact on firm innovation through two routes

The conceptual framework of McKelvey and Ljungberg (2017) draws on the differentiation between commercialization and academic engagement with industry (Perkmann et al., 2013) and postulates two distinct routes through which collaborative research impacts firm innovation: the direct and indirect routes. McKelvey and Ljungberg's (2017) conceptual model is illustrated in Figure 1, which also includes some other of their findings.

Figure 1: Conceptual framework of how collaborative research impacts firm innovation, including McKelvey and Ljungberg's (2017) findings



In Figure 1, the solid-outlined box on the left-hand side labeled "collaborative research" depicts the collaboration between the university and the firm. Following the collaborative research box are the two routes: commercialization and the direct route located at the top of the figure, and academic engagement and the indirect route located at the bottom of the figure. The direct route involves the tangible results of research being directly transferred to the collaborating firm and then commercialized. The indirect route shows how the intangible outcomes of university collaboration can indirectly foster innovations in which knowledge from the collaboration is transferred in various ways to the collaborating firm for possible internal use and further development. This in turn enhances the firm's internal capabilities to innovate, a detailed process described by AC (Cohen and Levinthal, 1990). In the top-right corner is the outcome of the collaboration, presenting different types of innovation. In this box, "product" refers to tangible or intangible goods and services sold on the market, and "processes" refers to technical processes, machinery, and organizational factors related to the production and delivery of products (Cohen and Levinthal, 1990).

McKelvey and Ljungberg (2017) found that collaborative research between universities and firms seldom results in the creation of new products, and they argued that collaborative research should not be expected to be directly applicable by the collaborating firms. Instead, collaborating firms should focus on developing and strengthening firm-specific capabilities for future innovation development (McKelvey and Ljungberg, 2017). Their case study found that, in the direct route, process innovations were the most common outcome, specifically the new practical methods subcategory. The numbers of process and product innovations were comparable, i.e., 32 process versus 29 product innovations. Among the product innovations, the product development subcategory was the most reported. The authors concluded that collaborative research is not a substitute for in-house R&D, emphasizing that collaborating firms need capabilities to internalize collaboration results (McKelvey and Ljungberg, 2017; cf. Cohen and Levinthal, 1990).

Within the indirect route, McKelvey and Ljungberg (2017) found three categories potentially stimulating the firm's development of innovative capabilities through academic engagement: knowledge transfer and learning, network development, and signaling effects. In knowledge transfer, the firm develops its innovation capability by increasing its knowledge base. The knowledge base includes knowledge of how to perform new analytical methodologies, specific technology developed in the project, and general knowledge of existing technologies. Knowledge transfer could occur through labor mobility and involvement in learning. This recalls earlier research by McKelvey et al. (2015) connecting the hiring of junior academic researchers to improved innovation capability by means of additions to the knowledge base. Recent research has further empirically connected the indirect route to the firm's development of its innovation capability through the individuals involved in academic engagement. Two examples of this are Berg and McKelvey's (2020a) empirically based research on firm-employed Ph.D. students who served as boundary spanners positioned between firms and universities. The authors investigated the students' activities as a form of academic engagement resulting in firm innovations. Their activities were interlinked with early stages of the innovation process, specifically the AC components' recognition of value and assimilation of external knowledge, thereby bolstering the firm's competence to learn and innovate. Within the context of collaborative research, the same authors explored the empirical phenomenon of industrial Ph.D. students (Berg and McKelvey, 2020b). First, they identified the defining characteristics of an industrial Ph.D. student (including education and employment conditions, specific activities, and frequency of university–firm bridging activities) during their education and their dual involvement in the university and the firm. Then they explored how the students perceived that they contributed to firm innovation during their education. Their findings identified activities related to the development of firm innovation capabilities (Berg and McKelvey, 2020b). Berg (2022) further connected firm and university activities to both the direct and indirect routes using empirical data on firm-employed Ph.D. students' contributions to the firm's AC. Within the CoE context, Jansson et al. (2017) suggested that collaboratively developed knowledge is mainly transferred to the collaborating firm through the recruitment of CoE personnel. These articles exemplify research on the first identified category of the indirect route, i.e., knowledge transfer and learning, which stimulate the development of firm innovation capability. In the second category, i.e., network development, the firm develops innovation capabilities by increasing its search capacity and thereby expanding its access to external knowledge. Through its collaboration-developed network, the firm can later find and access external knowledge (McKelvey and Ljungberg, 2017). In the third category, signaling effects contribute to the firm's innovation capability as a branding tool indicating high quality by providing third parties with valuable information (McKelvey and Ljungberg, 2017). In this way, the indirect route can enhance the development of innovation capabilities.

This research shows how academic engagement, through the indirect path, is connected to development of innovative capabilities. A critical aspect of the indirect route is the development of the firm's learning capability, often conceptualized through the lens of AC (Cohen and Levinthal, 1990). This concept elucidates the firm's competence to learn and innovate as its ability to recognize the value of, acquire, assimilate, and exploit external knowledge. AC thus describes how the firm develops the capability to innovate, specifically from an external source of knowledge. The following section focuses on AC as the theoretical framework.

2.4 Absorptive capacity as a theoretical framework for knowledge exploitation

To examine how knowledge gained from participation in a university–industry collaboration results in firm innovation, the AC theoretical framework is an appropriate choice due to its holistic view, encompassing the firm's utilization of external knowledge for innovation; accordingly, this framework has been applied in previous UIC research. This section can be outlined as follows: The foundation of the AC framework is presented in subsection 2.4.1, starting with its evolution over three main articles and ending with a definition. An overview of the theoretical extensions of the AC framework is presented in subsection 2.4.2, followed by AC research within the UIC context in subsection 2.4.3. The exploitation of external knowledge via the AC as a theoretical framework for this thesis is proposed in subsection 2.4.4, in a context that includes UIC.

2.4.1 The foundations: A relationship between learning and innovation

Wesley M. Cohen and Daniel Levinthal, both strategy researchers, are known for their three seminal articles, published between 1989 and 1994, that constitute the foundation of the AC framework. Their primary rationale for proposing the AC framework was that a firm's investment in R&D activities generates the development of domain knowledge linked to the firm's product and market, knowledge that can be internally shared and used for commercial ends and strategic forecasting. The knowledge obtained through the R&D activities also enables the firm to acquire external knowledge that permits it to create something different, in contrast to learning by doing, which develops knowledge of more efficient doing. The foundation of the AC idea is that R&D not only creates additional knowledge that can be exploited through new products and processes, but also facilitates the ability to understand the value of external knowledge and its assimilation into new products and processes.

How an organization's investments in R&D affect its ability to learn from external knowledge was not originally discovered by Cohen and Levinthal. For example, Tilton et al. (1971) argued that firms in the semiconductor industry, through investing in R&D, gained the ability to understand the latest developments in their field. Evenson and Kislev (1975) investigated R&D's role in international diffusion within the field of agricultural technology and found a linkage between research outlays and benefit streams. Mowery (1983) connected internal R&D to the assimilation of external knowledge in numerous industries, concluding that firms "without in-house research facilities were handicapped in their ability to pursue R&D and innovation" (p. 369). Cohen and Levinthal's work differs in its use of industrial-organization- and economic-based explanations of the role of R&D (Lane et al., 2006). Cohen and Levinthal built on these earlier findings by developing a more comprehensive theoretical framework for understanding the relationship between R&D and AC. The concept of AC underwent rapid evolution between 1989 and 1994.

Cohen and Levinthal (1989) posited that a firm's AC is determined by its prior investment in learning and plays a critical role in acquiring external knowledge. Originally, they defined AC as a by-product of R&D, stating that "while R&D obviously generates innovations, it also develops the firm's ability to identify, assimilate, and exploit knowledge from the environment—[called] … a firm's ‘learning’ or ‘absorptive’ capacity” (Cohen and Levinthal, 1989, p. 569). This definition describes AC as consisting of three abilities, i.e., the identification, assimilation, and exploitation of external knowledge. AC may provide the firm with the ability to recognize the significant value of external knowledge and to apply it in creating something new and different. Cohen and Levinthal (1989) further claimed that “external knowledge,” such as basic research from outside the firm’s R&D efforts, can be more easily applied within the firm to create new innovations. A firm’s AC is dependent on prior investment in R&D that contributes to the firm’s knowledge base, defined as the stock of pre-existing knowledge. A knowledge base developed in a specific technological or scientific domain increases the firm’s learning ability and therefore reinforces its AC (Cohen and Levinthal, 1989). For example, if a firm has developed a knowledge base about a specific technique, such as an x-ray application, it can more easily absorb knowledge within the field of optics and photonics.

Building on their initial work, Cohen and Levinthal (1990) later refined their definition by emphasizing that the firm’s individual members develop the firm’s AC. In their new definition, AC is the firm’s ability to “recognize the value of new, external information, assimilate it, and apply it to commercial ends,” with the term “value” having been added and “exploit” changed to “apply.” They further emphasized the role of an organization’s individuals in AC:

> An organization’s absorptive capacity will depend on the absorptive capacities of its individual members. To this extent, the development of an organization’s absorptive capacity will build on prior investment in the development of its constituent, individual absorptive capacities, and, like individuals’ absorptive capacities, organizational absorptive capacity will tend to develop cumulatively. (Cohen and Levinthal, 1990, p. 131)

Cohen and Levinthal used the metaphor of learning a language to describe the logic of AC development. In essence, when learning a language, a student has to understand the basic words and rules before simple sentences can be made. When the basics are known, more words and knowledge of the language can be deployed to create more complex sentences. In a similar way, a firm has to understand the basics of a specific technology or science before it can develop something new from that knowledge. For Cohen and Levinthal, the firm's development of something new depends on its members' AC. The firm's performance and outcome of learning are enhanced if the learning objective is related to the individual members' prior knowledge. However, a firm's AC is not simply the sum of its members' AC. External knowledge must also be recognized, acquired, assimilated, and exploited during its flow from point of entry to point of exploitation. In 1990, Cohen and Levinthal emphasized that, whereas they previously attributed knowledge exchange solely to the organization, they now conceded that individuals are significant in acquiring external knowledge.

In 1994, Cohen and Levinthal expanded on their previous work, emphasizing the role of AC in enabling firms to evaluate the possible economic returns of technological advancement. In the article, they described AC as a set of abilities that facilitate a firm's evaluation of technological development and its economic returns. Hence, AC is conceptualized as:

> The capacity to "exploit" outside knowledge is comprised of the set of closely related abilities to evaluate the technological and commercial potential of knowledge in a particular domain, assimilate it, and apply it to commercial ends. (Cohen and Levinthal, 1994, p. 227)

Cohen and Levinthal (1994) argued that the evaluation of technological development also includes uncertainty about its economic returns. They highlighted the correlation between uncertainty and the value of information, asserting that as uncertainty increases so does the value of information and the incentive for firms to acquire knowledge. AC enhances the firm's capability to interpret information regarding the value of the developing technology and to resolve uncertainty. Therefore, AC facilitates the organization's ability to predict future technological advancements. Investment in AC helps the organization to identify and take advantage of emergent technological opportunities in an area where the firm had previously invested in R&D (Cohen and Levinthal, 1994).

Cohen and Levinthal's concept of AC evolved significantly between 1989 and 1994, highlighting its importance for firm innovation and learning. Initially, AC was described as a valuable by-product of R&D (Cohen and Levinthal, 1989) that gave the ability to recognize the value of external knowledge and apply it to create something new. Then the authors addressed AC as partly dependent on the organization's members and internal knowledge sharing (Cohen and Levinthal, 1990). Lastly, AC was described as integral to the firm's ability to better predict the future of technological advancements (Cohen and Levinthal, 1994). In essence, Cohen and Levinthal have tied a firm's learning and innovation to its R&D, reasoning that AC is dependent on the firm's prior accumulated knowledge. Following their introduction of the concept, AC became more widely used and its definition began to solidify.

Historically, Cohen and Levinthal's 1989 paper supplied a foundational definition of AC that has become the most cited and utilized in the literature (Volberda et al., 2010). Throughout this thesis, the term "absorptive capacity" is defined as "the firm's ability to identify, assimilate and exploit knowledge from the environment" (Cohen and Levinthal, 1989, p. 569). The 1989 definition is used here for two reasons: first, due to its use in prior literature and, second, because extensions of the definition impose analytical limitations such as a process view (see, e.g., Lane et al., 2006) or treat AC as a dynamic capability (see, e.g., Lichtenthaler and Lichtenthaler, 2009).

For the purpose of this dissertation, i.e., to explore how knowledge developed in a UIC is utilized by the collaborating firm in developing innovations, AC is valuable as a theoretical framework due to its concern with a firm's ability to recognize the value of external knowledge, assimilate it, and exploit it to create something new. Given the importance of AC in understanding the firm's exploitation of external knowledge, the following section will explore the subsequent literature that has expanded on and refined the AC concept.

2.4.2 Theoretical extensions of absorptive capacity

Since 1994, a large amount of literature has contributed to the extension and expansion of the absorptive capacity concept through empirical, quantitative, and review studies. This literature has specifically investigated: individual AC, internal knowledge sharing within a firm, external knowledge interchange between firms, and reconceptualization of the concept as comprising two or four factors. The literature presented here was selected based on its application areas in the field of AC, as indicated by citation patterns. Areas of application were limited to ones contributing to the purpose of this dissertation. The literature is presented in terms of six themes: the role of learning and AC, knowledge base similarity, internal dimensions of knowledge utilization, the individual's personal knowledge and AC, internal knowledge sharing, and, lastly, knowledge and AC.

Now we consider one of the most prominent themes within the literature, namely, the role of learning, particularly in the context of firm collaboration and alliances. A central theme of the AC extension literature is learning, and numerous studies have examined how a firm's prior knowledge and R&D investment affect its ability to learn and adapt. Cohen and Levinthal (1989) argued that a firm's learning is primarily determined by its prior knowledge and R&D investments, a contention supported by empirical research (Ahuja, 2000; Cockburn and Henderson, 1998; Lane and Lubatkin, 1998; Mowery et al., 1996; Pisano, 1994; Shane, 2000; Tsai, 2001;

Volberda et al., 2010). An early contribution by Dyer and Singh (1998) extended the idea of AC from the individual firm to learning between firms, introducing the concepts of relational rents and partner-specific AC. Relational rents refer to the short-term costs incurred by the firms participating in a partnership, costs, however, that are exceeded by the returns that the firms gain: in other words, the firm earns "interest" on the rent. Partner-specific AC refers to a firm's ability to recognize and assimilate valuable knowledge from a particular alliance partner. This ability depends on overlapping knowledge bases that ensure a common understanding of a specific domain, and on well-developed interaction routines that maximize the frequency and intensity of social interactions for effective learning. The latter are important for the exchange of "know-how," or non-verbal knowledge, which depends on face-to-face interaction (Dyer and Singh, 1998). Expressed differently, for effective learning, the two learning parties must share knowledge bases, meaning that they have a common understanding of a specific domain (as used by Arthur, 2009, p. 22) and frequently interact. An interorganizational firm view of AC and learning was adopted by Lane and Lubatkin (1998), who emphasized the role of similarity between firms in interorganizational learning. Using survey data from pharmaceutical–biotechnology R&D, their results show that an organization's ability to learn in an interorganizational collaboration is dependent on three components, namely, the similarity of both firms': (i) knowledge bases, i.e., the firms' possession of the same amount of prior basic knowledge; (ii) organizational structure, i.e., the degree of formalization and centralization used by the firms; and (ii) dominant logics influencing their commercial objectives and project preferences (Lane and Lubatkin, 1998). This indicates that the more similar firms are, the greater their potential for joint learning, which in turn impacts their AC. Lane and Lubatkin (1998) concluded that AC is a relative quality, dependent on the similarity of the collaborating parties; they reasoned that one firm is the teacher and the other a student, reconceptualizing the AC concept from the firm level to what they refer to as the learning dyad level. The AC extension literature supports the idea that the potential to acquire, assimilate, and exploit learned external knowledge is influenced by the similarity of collaborating parties' understanding of a knowledge domain, which will be further examined in the following studies.

Knowledge base overlap has been found to play a significant role in external knowledge assimilation and organizational learning. Similarly to Lane and Lubatkin (1998), Puranam et al. (2009) found that knowledge base overlap can mitigate knowledge assimilation. Sancho-Zamora et al. (2022) surveyed 306 Spanish firms to study the connection between organizational learning and AC. They found that AC increases the organizational learning when knowledge commonality exists and becomes innovation when the learning capacity (e.g., the capacity to create, acquire, transform, and integrate knowledge) is involved (Sancho-Zamora et al., 2022). Their research shows that knowledge similarity and active knowledge integration are important to AC and innovation development. Escribano et al. (2009) used the CIS[4] survey to measure the impact of AC on innovation performance, concluding that AC improves the management of external knowledge flow. This finding stands in contrast to that of Santoro et al. (2019), who did not find that internal R&D had a moderating role. Concisely stated, that two collaborating parties have a similar understanding of a knowledge domain affects their potential to acquire, assimilate, and exploit learned knowledge.

The next area of the AC extension literature focuses on the role of a firm's internal dimensions and their effects in knowledge utilization. Cohen and Levinthal (1990) described how AC is dependent on the links between individual capabilities, so Van den Bosch et al. (1999) used the term "combinative capability" to point to the firm's integration and configuration of acquired knowledge. These authors defined a combinative capability as "a firm's capability to synthesize and apply current and

[4] CIS is the Community Innovation Surveys for 2000 and 2002, produced by the Spanish National Statistics Institute, and Escribano et al. (2009) used a sample of 2265 Spanish firms.

acquired knowledge" (Van den Bosch et al., 1999, p. 556). In other words, the combinative capability encompasses a firm's ability to integrate external knowledge and internally configure it to a commercial end. Their case studies of traditional publishing firms show that a firm's organizational form and combinative capability affect its assimilation of external knowledge. They found that managerial intention can change the firm's organizational form and its combinative capability to increase its AC, meaning that the firm can adapt depending on its knowledge environment. Furthermore, their research also indicated that AC feedback loops' size and speed are dependent on the combined effect of the firm's organizational form and combinative capability, and can have a negative effect. This negative effect occurs when the firm focuses on prior knowledge and becomes unaware of alternative developments (Van den Bosch et al., 1999). How knowledge is utilized was an important perspective in the work of Zahra and George (2002), who reconceptualized AC as comprising two subcomponents, redefined AC, and introduced the notion of transformation. The first AC subcomponent, *potential capacity*, refers to acquisition and assimilation and describes the firm's capability to value and acquire new knowledge but not guarantee knowledge exploitation. The second AC subcomponent, *realized capacity*, is a function of the transformation and exploitation capabilities and reflects the firm's capacity to utilize the absorbed knowledge. The authors redefined AC as "a set of organizational routines and processes by which firms acquire, assimilate, transform, and exploit knowledge to produce a dynamic organizational capability" (Zahra and George, 2002, p. 186). This definition differs from Cohen and Levinthal's (1989) by introducing a fourth component and including routines and processes. In a minor clarification, Zahra and George (2002) used the term "capability" while Cohen and Levinthal (1989) used the term "ability" when defining the AC concept. In line with the chosen definition, the term "ability" is here used for AC and the term "component" is used for the AC subcomponents. Zahra and George (2002) introduced the *transformation* component to refer to a firm's ability to develop and refine routines that facilitate the combining of existing knowledge, newly acquired knowledge, and assimilated knowledge (Zahra and George, 2002). Todorova and Durisin (2007) also used the term "transformation" for internal knowledge utilization, but somewhat differently from Zahra and George (2002). Todorova and Durisin (2007) argued that if the external knowledge matches the existing knowledge base, it is slightly altered by assimilation. But when the external knowledge differs from the existing knowledge base it cannot easily be absorbed, so the cognitive structure has to be transformed so that the external knowledge can be assimilated and later exploited. However, the authors did not elaborate on the term "cognitive structure," understood in this context as an individual's knowledge and mental framework that facilitate the understanding and interpretation of new information. The cognitive structure is influenced by the transformation component (e.g., the firm's linking of situations and ideas perceived as incompatible with its current knowledge), doing so through the process of bisociation as a means of coping with path dependency (Todorova and Durisin, 2007). In other words, Todorova and Durisin (2007) used transformation to explain how an external knowledge set that is very different from the existing one is transformed by the individual. This account of transformation seems to include an individual aspect (i.e., cognitive structure), in contrast to Zahra and George's (2002) use of the term. Hence, transformation is the firm's capability to combine two incongruous sets of information to create new knowledge. In the context of internal knowledge utilization, Zahra and George's (2002) and Todorova and Durisin's (2007) account of transformation is more specific than the combinative capability of Van den Bosch et al. (1999), which incorporates the broader integrating of external knowledge. While both concepts concern internal knowledge utilization, the identified facilitation routines (Zahra and George, 2002) and the cognitive structure (Todorova and Durisin, 2007) in transformation more narrowly concern how the firm combines different sets of information to create and exploit new knowledge. Having discussed AC and the firm's internal utilization of external knowledge at the firm level, in the next section I explore the individual's personal knowledge and AC.

Lane et al.'s (2006) literature review explored the role of learning in AC and its connection with an individual's personal knowledge (or mental models), arguing for a process-oriented view. They argued that specific choices made in previous research on the AC concept led to its reification: one such choice was the focus on the R&D aspect of AC, leading to the neglect of AC's potential broader implications; another limiting choice was the neglect of the individual's role in AC, as it is individuals who contribute the creativity necessary for generating value from new knowledge through unique combinations arising from their mental models. Lane et al. (2006) used the term "mental model" synonymously with "personal knowledge." Their analysis of 289 papers from 14 journals showed that only 64 papers made substantive use of the AC concept. Drawing on five studies that focus on the concept and extend the AC concept with a process view on learning, they suggested a new definition of AC as:

> "a firm's ability to utilize externally held knowledge through three sequential processes: (1) recognizing and understanding potentially valuable new knowledge outside the firm through exploratory learning, (2) assimilating valuable new knowledge through transformative learning, and (3) using the assimilated knowledge to create new knowledge and commercial outputs through exploitative learning". (Lane et al., 2006, p. 856)

The authors synthesized previous work and emphasized three sequential learning processes: exploratory learning, transformative learning, and exploitative learning. They argued that the breadth of the knowledge base determines the boundaries of the firm's *explorative learning* (Cohen and Levinthal, 1989, 1990, 1994; Lane and Lubatkin, 1998; Van den Bosch et al., 1999). The efficiency of processing acquired knowledge through assimilation to exploitation is what they referred to as *exploitative learning*. The linkage between these two forms of learning is *transformative learning*, referring to the process of combining new and existing knowledge so the latter can be utilized in a new way (Lane et al., 2006). They used transformation, in the same way as did Zahra and George (2002), to denote the firm's combination of different knowledge sets into something new. Lane et al.'s (2006) redefinition highlights the significance of individual learning and personal knowledge in AC, emphasizing the process view. By means of the process focus, they extended the concept from its previous attention to R&D and detailed the personal knowledge of individuals in the firm to create new knowledge with unique value (Lane et al., 2006). In this context, the exploratory learning is affected by the prior knowledge of the firm. The firm's prior knowledge is a function of individuals' existing personal knowledge, thereby affecting how the firm values the potential of the new external knowledge. Transformative learning, to assimilate new external knowledge, occurs when new external knowledge is related to the firm's prior knowledge. Exploitative learning is the application of the assimilated knowledge (Lane et al., 2006). Lane et al. (2006) also acknowledged that the "output" of AC, either commercial output (e.g., products, services, and patents) or knowledge output (e.g., scientific and organizational knowledge), can influence and change the personal knowledge of the firm's individuals. This, in turn, impacts the firm's prior knowledge and consequently influences its AC. By connecting the AC output to individuals' personal knowledge and the firm's prior knowledge, the authors theoretically explain how the firm's AC evolves. This recalls Todorova and Durisin (2007), who also adopted a process view and argued that feedback loops explain the dynamic evolution of the firm's AC. Feedback loops, as described by Todorova and Durisin (2007), entail investments in one knowledge area, fostering future development in the same area, with a particular focus on the feedback between the newly absorbed knowledge and the organization's prior knowledge.

Building on the process view of AC and the role of individual knowledge, internal knowledge sharing is another major area of AC extension, characterized by challenges in non-verbal knowledge and the need for mechanisms to convert knowledge into action. Szulanski (1996) studied internal knowledge sharing by investigating 122 best-practice transfers at eight companies and identified difficulties of internal knowledge transfer due to non-verbal knowledge. The non-verbal knowledge component "sticks" with the individual and is therefore difficult for other firms to imitate and constitutes an obstacle to internal transfer. Szulanski's research identifies three major knowledge-related barriers limiting knowledge transfer: the recipients' lack of AC, causal ambiguity, and an arduous (i.e., distant) relationship between source and recipient. The recipient's, or individual's, AC can be regarded as the individual's ability to exploit external sources of knowledge and how the individual values, assimilates, and applies such knowledge to commercial ends (Szulanski, 1996). Szulanski (1996) highlighted the difficulties of internal knowledge transfer, whereas research in organizational learning by Dutta and Crossan (2005) emphasized the importance of transferring individual knowledge to the organizational level. Even if internal knowledge exchange is successful, Dahlin et al. (2019) noted that organizations find it challenging to use and transform knowledge into meaningful outcomes and, consequently, to improve their innovation performance. Overcoming these challenges and utilizing external knowledge require focus on the development of firm-level mechanisms to facilitate the conversion of knowledge into action, a dynamic underlying a firm's AC. In other words, knowledge as a non-verbal entity is difficult to internally integrate but can be mitigated by firm-level initiatives aiming to convert knowledge to action, such as a structural approach to assimilating external knowledge. Further exploring the AC literature casts light on the role of knowledge and its relationship to AC.

Knowledge is crucial to AC, and the creation of knowledge that can be absorbed is needed (Rohenkohl et al., 2021). The importance of knowledge is evident in studies by Vega-Jurado et al. (2008), Rohenkohl et al. (2021), and Tu et al. (2006), which explore various aspects of knowledge and their relationships to AC. Vega-Jurado et al. (2008) used survey data from 84 firms to explore the roles of different knowledge attributes in AC; they defined organizational knowledge, i.e., a set of "skills, knowledge, and experience," as one of three factors (besides formalization and social integration mechanisms) determining AC and the application of external knowledge. Rohenkohl et al. (2021) used survey data from 71 firms that collaborated with universities to identify the necessary conditions for the collaborating firms' AC. They used Zahra and George's (2002) conceptualization of AC (e.g., potential and realized) and found that, to achieve a high level of AC, the level of potential AC (e.g., acquisition and assimilation) must also be high and the level of realized AC (e.g., transformation and exploitation) must be at least medium. In other words, the organization must have the capacity to acquire, analyze, interpret, and understand external knowledge in order to gain greater AC benefits. AC is also found to be related to the ability to recognize relevant areas of knowledge. Tu et al. (2006) used a survey that conceptualized AC in terms of 29 items, notably finding that worker knowledge and manager knowledge have marginal impacts on AC. According to the authors, concluding that the knowledge of employees and managers is "unimportant" may be incorrect; they then emphasized the importance of having an internal communication network to distribute knowledge to appropriate receivers (Tu et al., 2006). However, it should be noted that their survey targeted manufacturing managers' perceptions, which, methodologically, could cause information and variance bias, as acknowledged by the authors. The findings of these studies highlight the need for organizations to prioritize the acquisition and assimilation of AC, as well as the importance of internal communication networks for distributing knowledge effectively.

Despite the importance of knowledge to AC, the treatment of knowledge in the AC literature has been inconsistent. Knowledge as a fundamental research subject in the AC field has attracted varied attention in prior research, subject to limitations in measuring AC. Evidence from studies by, for example, Volberda et al. (2010), Rohenkohl et al. (2021), and Vega-Jurado et al. (2008) highlights these limitations, while Lane et al.'s (2006) literature review identified the primary focus of prior research. In a bibliometric analysis, Volberda et al. (2010) found that proxies (e.g., R&D expenditures) were used for measuring AC and called for more research on prior knowledge usage and knowledge absorption at lower levels. Rohenkohl et al. (2021) stated that "the attributes of knowledge have been ignored theoretically, empirically and analytically" in the AC literature and claimed that the abstract and tacit nature of knowledge has the consequence that AC "can hardly be measured by well-defined quantifiers" (p. 6). Vega-Jurado et al. (2008, p. 393) argued that conceptual models of AC have taken "no account of the nature of the external knowledge." On the other hand, Lane et al.'s (2006) literature review noted that prior AC research, in relation to knowledge, has mainly been theoretical, lacking empirical evidence and focusing on two aspects of AC: how different knowledge types influence the firm's ability to recognize value, and the firm's ability to assimilate that knowledge. Moreover, the scarcity of empirical evidence, the limited attention paid to different knowledge types and the firm's ability to utilize them, and the assumption that acquisitions enhance firm performance were all noted in the reviewed research (Lane et al., 2006). These studies reveal that prior research on knowledge and AC has been primarily theoretical, focusing on how different knowledge types influence a firm's ability to recognize value and assimilate external knowledge.

In essence, these studies have emphasized absorptive capacity and the roles of learning, knowledge base similarity, internal dimensions of knowledge utilization, the individual's personal knowledge, and internal knowledge sharing, followed by knowledge and absorptive capacity. The presented literature has made three major contributions to this dissertation: first, the importance of knowledge similarity for learning (Dyer and Singh, 1998; Lane and Lubatkin, 1998; Puranam et al., 2009; Sancho-Zamora et al., 2022); second, the dependence of external knowledge transformation on individual characteristics (Di Stefano et al., 2014; Dutta and

Crossan, 2005; Javalgi et al., 2014; Lane et al., 2006; Szulanski, 1996; Todorova and Durisin, 2007; Van den Bosch et al., 1999; Zahra and George, 2002); and, third, the peripheral role of knowledge as a research subject in previous literature. With these contributions noted, the relationship between UIC and AC is of particular relevance, and is discussed in the next section.

2.4.3 Assessing the relationship between absorptive capacity and university–industry collaboration

This section focuses on previous research on the relationship between AC and UIC. Awareness of this relationship is essential when examining collaborative knowledge exchange between university scientists and the collaborating firms that utilize this knowledge, with AC as a theoretical framework and UIC as an external source of knowledge.

The relationship between absorptive capacity and university–industry collaboration has been studied from various perspectives, yielding diverse conclusions. Key research in this area includes studies by the following scholars: Vega-Jurado et al. (2020), who examined AC at the regional level; Bishop et al. (2010), who focused on the benefits firms accrue from university interaction; Apa et al. (2021), who emphasized the role of informal interaction; and Kobarg et al. (2018), who obtained mixed results regarding the moderating effect of AC on UIC. Vega-Jurado et al. (2020) evaluated AC at a regional level by surveying 634 firms and the activities and production of 1757 faculty members. They found that, in regions with low AC (i.e., less developed regions with less R&D-intensive industries), UIC had no positive effects on firms' technological innovations or on academic production. Bishop et al. (2010) examined the benefits firms accrue from university interaction and found that such interaction nurtures various AC facets, specifically enhancing firms' explorative and exploitive learning capabilities; their results also suggest that continuous involvement in such interaction is more important to the firm than its

R&D activity. Apa et al. (2021) showed that informal interactions have a positive effect on collaboration, even in the absence of formal collaboration; this result is of interest since it underlines the influence of personal interaction. Biedenbach et al. (2018) examined whether AC moderates the effect of UIC and firm innovation by surveying 1532 Swedish firms, concluding that AC is critical for firm innovativeness. Bellucci and Pennacchio (2016) found that firms with higher AC (i.e., in-house R&D expenditures) place greater value on university collaboration and gain more benefits from academic research. Dezi et al. (2018) argued that high levels of internal AC (i.e., prior knowledge acquisition activities) are important for the firm to benefit from university collaboration. In contrast, Kobarg et al. (2018) found negative effects, with AC moderating both UIC and incremental innovation and having no effect on radical innovation. Kobarg et al. (2018) measured AC and specifically R&D in terms of intensity (i.e., expenditure as a proportion of total turnover) and activities, whereas Biedenbach et al. (2018) used a survey based on Lane et al.'s (2006) conceptualization of learning. One explanation could be that AC is often measured in terms of R&D variables (Lane et al., 2006). Kobarg et al. (2018) argued that high AC equals a large stock of internal knowledge and strong internal R&D, which might lead to the "not-invented-here" syndrome and path dependence (Cohen and Levinthal, 1990; Lichtenthaler and Lichtenthaler, 2009; Schmidt, 2010). Biedenbach et al. (2018) focused on innovation in general, not distinguishing between radical and incremental innovation and therefore not reaching the same conclusion as Kobarg et al. (2018). These various discoveries establish correlations, but do not account for how UIC activities lead to innovation. While these studies offer valuable insights, they reveal a lack of consensus on the relationship between AC and UIC, indicating a need for further exploration.

Several factors, including AC gap, cognitive distance, technological relatedness, barriers to UIC, and informal collaboration, are important parts of the relationship between AC and UIC. Researchers who have elaborated on these factors include

Lascaux (2019) on the AC gap, Petruzzelli (2011) and Fothergill (2017) on technological relatedness, Bruneel et al. (2010) on barriers to UIC, and Fabrizio (2009) on the role of informal collaboration. Lascaux (2019) introduced the idea of an AC gap in UIC, with the gap being the discrepancy between the two parties' abilities to acquire, internalize, and utilize the external knowledge. Lascaux (2019) argued that the cognitive distance between the two parties determines their sharing and capturing of the collaboration research, with similarity increasing the probability of success in this. Petruzzelli (2011) used university–industry joint patents to, among other things, measure the effect of technological relatedness (which he argued is strictly related to AC) on joint innovation value, finding an inverted U-shaped relationship. Fothergill (2017) later supported Petruzzelli's findings. Bruneel et al. (2010) investigated the barriers to UIC and used a proxy (e.g., the percentage of staff with higher education) to capture an organization's level of AC. In their conclusion, they stated that the university's long-term orientation remains a substantial barrier to UIC participation but is mitigated by prior collaboration experience. They also found that levels of trust are correlated with reductions in both orientation and transaction barriers (Bruneel et al., 2010); see also de Wit-de Vries et al. (2019), above. By comparing publications with patents, Fabrizio (2009) showed how firms that access university research can assimilate and exploit external knowledge at a faster rate. These studies collectively suggest that informal collaboration and prior experience of collaboration are beneficial for collaboration and for overcoming barriers, whereas knowledge similarity increases the probability of knowledge acquisition, assimilation, and exploitation. What still seems to be unknown is how informal prior experience facilitates positive outcomes, and how similarity in knowledge benefits AC. Further investigation is thus needed to understand how these positive outcomes are achieved. The prior research on absorptive capacity presented and discussed in this review, concerning the foundations, theoretical extensions, and connections of UIC, is summarized in Table 3.

Table 3: Summary overview of absorptive capacity

Area	Implication	Definition	Sources
Original	AC development is cumulative, path-dependent, and facilitates a firm's ability to appraise and monetize technological advancement. AC is a dual product of innovation and problem-solving, relying on individual AC and internal knowledge sharing.	"the firm's ability to identify, assimilate, and exploit knowledge from the environment" "recognize the value of new, external information, assimilate it, and apply it to commercial ends" "the set of closely related abilities to evaluate the technological and commercial potential of knowledge in a particular domain, assimilate it, and apply it to commercial ends"	Cohen and Levinthal, 1989, p. 569; 1990, p. 128; 1994, p. 1
Learning	A firm's learning, influenced by prior knowledge and R&D, can be extended to other firms, necessitating overlapping knowledge bases and regular interaction. Concepts of partner-specific AC and relational rents are introduced.		Cohen and Levinthal, 1989, 1990; Dyer and Singh, 1998; Lane and Lubatkin, 1998
Knowledge base overlap	Overlapping knowledge bases enhance knowledge assimilation and organizational learning. Knowledge similarity and integration are pivotal for AC and innovation, improving the handling of external knowledge flow.		Cohen and Levinthal, 1989, 1990; Puranam et al., 2009; Lane and Lubatkin,1998; Sancho-Zamora et al., 2022; Escribano et al., 2009; Santoro et al., 2019
Knowledge utilization	AC is dependent on the integration of individual capabilities and the firm's ability to synthesize and apply knowledge (combinative capability). AC is viewed as a capability with varying capacities, and its assimilation and transformation aspects are differentiated.	"a set of organizational routines and processes by which firms acquire, assimilate, transform, and exploit knowledge to produce a dynamic organizational capability" (Zahra and George, 2002, p. 186)	Cohen and Levinthal, 1989, 1990; Van den Bosch et al., 1999; Zahra and George, 2002; Todorova and Durisin, 2007
Individual knowledge	AC is seen as a three-step learning process (explorative, transformative, exploitative), in which individuals' creativity and personal knowledge play a vital role.	"a firm's ability to utilize externally held knowledge through three sequential processes: (1) recognizing and understanding potentially valuable new knowledge outside the firm through exploratory learning, (2) assimilating valuable new knowledge through transformative learning, and (3) using the assimilated knowledge to create new knowledge and commercial outputs through exploitative learning." (Lane et al., 2006, p. 856)	Cohen and Levinthal, 1990; Lane et al., 2006; Todorova and Durisin, 2007
Individual knowledge sharing	Individual AC affects knowledge stickiness, and non-verbal knowledge poses challenges in internal sharing. Effective utilization of AC requires firm-level mechanisms to convert knowledge into action.	"a set of processes by which firms acquire, assimilate, transform, and exploit knowledge to produce a dynamic organizational capability of four dimensions." (Javalgi et al., 2014)	Cohen and Levinthal, 1990; Zahra and George, 2002; Szulanski,1996; Dahlin et al., 2019; Javalgi et al., 2014; Vega-Jurado et al., 2008

Knowledge	An organization's ability to process external knowledge is crucial for AC benefits, but the AC literature often neglects the attributes of knowledge. The intangible and tacit nature of knowledge influences AC measurement.		Cohen and Levinthal, 1990; Zahra and George, 2002; Lane et al., 2006; Volberda et al., 2010; Lane et al., 2006
University–industry collaboration	UIC effectively augments firm AC, fostering utilization of collaboration knowledge. High AC potentially influences innovation trajectories, possibly affecting phenomena such as the "not-invented-here" syndrome and path dependence. Internal AC bolsters the benefits derived from UIC. The cognitive distance between collaborative entities and knowledge similarity modulates the success of knowledge dissemination, acquisition, and exploitation. Informal collaboration, antecedent cooperative experiences, and technological relatedness can further potentiate successful collaboration and innovation.	"refers to technological capabilities of firms and is measured as the ratio between in-house R&D expenditures and the total market sales of good and services" (Bellucci and Pennacchio, 2016, p. 17)	Cohen and Levinthal, 1989, 1990; Van Den Bosch et al., 1999; Zahra and George, 2002; Lane et al., 2006; Vega-jurado et al., 2020; Bishop et al., 2010; Apa et al., 2021; Kobarg et al., 2018; Biedenbach et al., 2018; Bellucci and Pennacchio, 2016; Dezi et al., 2018; Lascaux, 2019; Petruzzelli, 2011; Fabrizio, 2009

Table 3, provides a comprehensive summary of the presented AC literature organized by area, source, implication, and definition. The first column of the table categorizes the AC research by area, mirroring the structure of the research presented in this framework section. In the area category, original is the foundational concept (section 2.3.1), whereas the areas learning, knowledge base overlap, knowledge utilization, individual knowledge, internal knowledge sharing, and knowledge represent the presented extensions of the AC concept (section 2.3.2), and the area university–industry collaboration represents research on the relationship between AC and UIC (section 2.3.3). These are the AC research extension areas that proved useful for the research undertaken in this dissertation. The second column lists the AC-related implications of each area, differentiated by publication. The next column, definition, presents the definition of AC that each publication uses. Finally, the last column provides the reference information for each publication. The presented research areas indicate that the firm's learning is influenced by prior knowledge, interaction, and overlapping knowledge bases. Overlapping knowledge bases between collaborators enhance the assimilation of knowledge and thereby AC and the firm's development of innovations. AC is dependent on the integration of individual capabilities and on the firm's ability to combine and apply knowledge. As the individual's creativity and knowledge affect the firm's AC and internal knowledge sharing, a firm-level mechanism is needed to utilize AC and convert knowledge into action. The intangible and tacit nature of knowledge influences AC measurement. A firm's collaboration with a university augments its AC and fosters its utilization of collaboration knowledge. Internal AC increases the benefits of UIC, while knowledge similarity is also important for the successful utilization of collaboration knowledge. Having presented this summarizing table, the next section explores the proposed framework and its relationship to the presented research.

2.4.4 Exploiting external knowledge by means of absorptive capacity: a proposed framework

The theoretical framework of this dissertation is absorptive capacity because of its significance in the context of university–industry collaboration and the development of innovations. Absorptive capacity has been characterized as an ability (e.g., Cohen and Levinthal, 1989), capability (e.g., Cohen and Levinthal, 1994), and dynamic capability (e.g., Zahra and George, 2002) in prior research. This dissertation adopts Cohen and Levinthal's (1989) definition of AC as an ability, meaning an organizational competence having the subcomponents of recognizing, acquiring, assimilating, and exploiting external knowledge. The definition of AC as an ability (i.e., the quality of being able) was chosen to enable a broad analytical lens, in comparison with capability and dynamic capability, which are theoretically more specific concepts (see Winter, 2003).

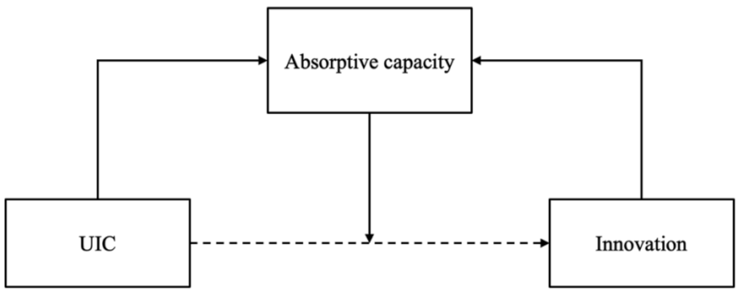
The four components of AC are viewed as a sequence of events related to strategy-relevant issues (Kouamé and Langley, 2018), in this case, the development of innovations. As such, AC denotes a process (e.g., Cohen and Levinthal, 1989; Lane et al., 2006), here specifically an innovation process. AC is the firm's ability to execute an innovation process that utilizes external knowledge in its development of innovations. The completion of this innovation process generates outcomes that subsequently enhance the firm's AC, when the outcomes are accumulated, processed, and fed back into the organization (Lane et al., 2006; Todorova and Durisin, 2007).

The incremental development of the firm's AC enhances the efficiency of the firm's ability to exploit external knowledge for innovation. In other words, and in line with Cohen and Levinthal (1990), AC is about a firm's learning. The firm's incremental development of AC can be understood and illustrated in the context of this dissertation's purpose, i.e., to explore how knowledge developed in a university–

industry collaboration is utilized by the collaborating firm in the development of innovations.

Within the context of this dissertation, the firm's participation in a university–industry collaboration can lead to outcomes that increase the firm's ability to execute the innovation process. When outcomes of the UIC are processed through the AC components and finally are exploited, the resulting innovation increases the firm's AC. This process, facilitated by participation in UIC (Bishop et al., 2010; Fabrizio, 2009), enhances the firm's ability to execute the innovation process. This relationship is illustrated in Figure 2.

Figure 2: Relationship between AC, UIC, and innovation



Since Cohen and Levinthal's pioneering research, the AC concept has been expanded in its definitions, applications, and limitations. As Cohen and Levinthal (1989) argued, a firm's learning is primarily determined by its prior knowledge and R&D investments, as supported by empirical research (Ahuja, 2000; Cockburn and Henderson, 1998; Lane and Lubatkin, 1998; Mowery et al., 1996; Pisano, 1994; Shane, 2000; Tsai, 2001; Volberda et al., 2010).

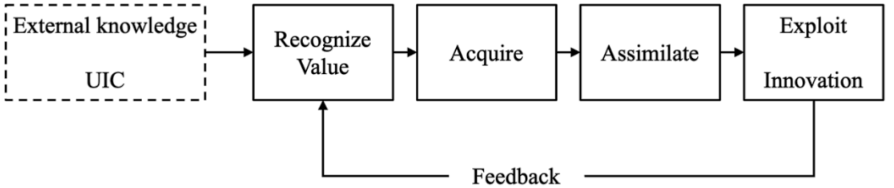
A similarity of knowledge base between two interacting parties has been found to enhance their learning potential (Dyer and Singh, 1998; Lane and Lubatkin, 1998; Sancho-Zamora et al., 2022), increase assimilation (Puranam et al., 2009), and augment the potential for exploitation outcome (Fothergill, 2017; Petruzzelli, 2011).

A firm's prior knowledge, rooted in the individual members' existing personal knowledge, influences the firm's exploratory learning and is in turn influenced by the firm's exploitative outcome (Lane et al., 2006). This interplay accentuates a feedback process that elucidates the dynamics of AC (Lane et al., 2006; Todorova and Durisin, 2007; Van den Bosch et al., 1999).

Effective knowledge sharing hinges on social interactions, systematic integration (Dyer and Singh, 1998), and active involvement to secure exploitative outcomes (Sancho-Zamora et al., 2022). The individual plays a key role in the sharing and integrating of knowledge (Lane et al., 2006; Szulanski, 1996), the firm's utilization of knowledge (Dutta and Crossan, 2005; Javalgi et al., 2014), and the assimilation and transformation of knowledge (Lane et al., 2006; Todorova and Durisin, 2007; Van den Bosch et al., 1999). Notably, knowledge assimilation and transformation can be moderated by the firm (Di Stefano et al., 2014; Lane et al., 2006; Van den Bosch et al., 1999; Zahra and George, 2002). Thus, while individuals are important in knowledge sharing, assimilation, and transformation, firms can moderate these processes to optimize learning and innovation development.

Moving forward, Zahra and George (2002) reconceptualized the AC concept in terms of a two-factor model encompassing both potential and realized absorptive capacities, emphasizing routines and processes. Their reconceptualization was criticized by Todorova and Durisin (2007), who underlined the importance of the transformation component to the AC concept and the firm's knowledge integration, differentiating it from assimilation as a distinct process. They argued that "firms transform their knowledge structures when knowledge cannot be assimilated" (Todorova and Durisin, 2007, p. 778). However, this cannot be the entire explanation, as initiating the transformation of the knowledge structure entails understanding and comprehending the external knowledge to a certain degree. In other words, the firm needs to understand the value of, and assimilate, the external knowledge enough to decide to initiate the transformation of the knowledge structure. Given this interwoven relationship between assimilation and transformation, the two are combined and treated as a single component of AC. is a conceptual model of the AC framework inspired by Cohen and Levinthal (1990), Zahra and George (2002), Lane et al. (2006), and Todorova and Durisin (2007).

Figure 3: Absorptive capacity conceptual model



The solid-outlined boxes in the model are the four components of the absorptive capacity concept, comparable to the three components (i.e., recognize value, assimilate, and apply) described by Cohen and Levinthal (1990). These components are: recognize value, acquire, assimilate, and exploit. On the left, the dashed-outlined box is external knowledge, with the UIC as an external knowledge source. The result of the scientific activities at the university in the UIC is collaboration knowledge that can be utilized in the firm's development of innovations.

Following the external knowledge box is the first component of AC, i.e., *recognize value*, in the first solid-outlined box. In collaboration with an external knowledge source, i.e., the university in the UIC, the firm must first recognize the value of the collaboration knowledge that this source can provide. When valuable knowledge is recognized, the firm can then acquire it. The ability to recognize valuable knowledge is dependent on the prior knowledge base, which is linked to the firm's R&D investments (Cohen and Levinthal, 1989). The knowledge base influences the firm's ability to recognize external knowledge as valuable, by means of the relationship of the external knowledge to the firm's knowledge base (Cohen and Levinthal, 1990, used the terms "evaluate" and "utilize"). The knowledge base is also connected to the personal knowledge of individuals in the firm, due to its role in creating new knowledge of unique value (Lane et al., 2006). In this model, the firm must first recognize the external knowledge as valuable before it can be acquired, ensuring that this component is essential for AC. This is consistent with Todorova and Durisin (2007) but in contrast to Zahra and George (2002), who merge the identification and acquisition of external knowledge under the label "acquisition." The distinguishing of recognition as a unique component follows the AC definition used here and underlines the individual aspect of creating unique value from external knowledge (Lane et al., 2006).

The *acquisition of external knowledge* component is initially tied to an individual aspect (Dyer and Singh, 1998; Sancho-Zamora et al., 2022; Szulanski, 1996) and is expanded by the potential of the firm's knowledge (Dutta and Crossan, 2005; Lane et al., 2006). Acquisition of external knowledge is initially individual due to the significance of the individual's relationship to the firm's prior knowledge (Lane et al., 2006), the non-verbal nature of knowledge (Szulanski, 1996), the dependency of AC on social interaction (Dyer and Singh, 1998), and informal collaboration (Apa et al., 2021). These cited studies emphasize the importance of the individual aspect in knowledge acquisition, suggesting that understanding this aspect is crucial for leveraging the firm's knowledge potential. Thus, the individual aspect has a significant role in knowledge acquisition.

The *assimilate* component is of key importance in combining and utilizing the valuable and acquired external knowledge. This component facilitates the combining of new and existing knowledge to facilitate utilization of the latter (Lane et al., 2006; Zahra and George, 2002). Even if a firm has the capacity to understand the basic knowledge (i.e., the traditions on which a technology or science rests) of an idea or concept, this knowledge could still be incompatible with the prior knowledge base and thereby limit the capacity for exploitation. If the external knowledge is similar to the firm's prior knowledge, then it can more easily be assimilated. For example, a physics researcher has a basic understanding of the laws of nature and therefore has the capacity to assimilate new external knowledge from the field of natural science. On the other hand, if the firm recognizes the value of external knowledge that is distant from the firm's previous knowledge, then the firm's cognitive structure must change before the knowledge can be utilized. The change of the cognitive structure is initiated on the individual level (Lane et al., 2006; Todorova and Durisin, 2007). On the firm level, using and transforming knowledge into meaningful outcomes can be challenging (Dahlin et al., 2019); this can be mitigated by developing firm-level mechanisms to facilitate the conversion and assimilation of knowledge into action. The above-mentioned physics researcher could recognize the value of computational simulation but does not possess the knowledge to execute this on a computer, so the researcher must transform her cognitive structure to assimilate the new knowledge. When the external knowledge is assimilated, then the firm can exploit the knowledge to commercial ends.

The exploitation component is the last of the four components of AC whose outcome generates feedback that underlines the evolving dimension of AC (Lane et al., 2006; Todorova and Durisin, 2007).

2.5 Theoretical summary

In the context of the research conducted for this Ph.D. thesis, the research on absorptive capacity and university–industry collaboration contributes in the following way. AC provides an overarching theoretical framework for the firm's ability to execute an innovation process, which includes learning and feedback and describes the process components a firm proceeds through when exploiting external knowledge to a commercial end. In the context of this dissertation, the academic engagement perspective, the AC framework, the UIC literature, and the defined terminology are applied as follows. In UIC, the university is the external source of knowledge. The academic engagement literature emphasizes the need for an industry perspective when exploring the underlying mechanisms that drive and facilitate the utilization of collaboration knowledge for innovation (Ankrah and AL-Tabbaa, 2015; OECD and Eurostat, 2018; Ramsten and Benner, 2019; Skute et al., 2019). In this way, the industry perspective is the main concern. The academic engagement literature and the UIC definition narrow the perspective to the AC components recognize value, acquire, and assimilate (Cohen and Levinthal, 1989; Lane et al., 2006; Todorova and Durisin, 2007; Zahra and George, 2002), and to the formal and informal knowledge interactions (Perkmann et al., 2021). The exploitation component in AC is the commercialization of academic knowledge, for example, patenting, licensing, and academic entrepreneurship (Arant et al., 2019; Markman et al., 2008; O'Shea et al., 2005; Phan and Siegel, 2006; Rothaermel et al., 2007). This dissertation adopts how the innovation literature defines and distinguishes the nature of a deployed innovation, and thus the outcome of the AC exploitation component.

2.6 Research question development

The developed research question, outlined in this section, revolves around how a collaborating firm uses collaboratively developed knowledge.

As stated in the introduction, the purpose of this dissertation is to explore how knowledge developed in a university–industry collaboration is utilized by the collaborating firm in the development of innovations. From research on AC, university–industry collaboration, and academic engagement, it remains difficult to discern the mechanisms that produce firm innovations from collaboration knowledge (e.g., regarding the role of R&D, see Escribano et al., 2009; Santoro et al., 2019; Perkmann et al., 2021). Therefore, the present research examines how knowledge developed through UIC is recognized as valuable, assimilated, and exploited by a participating firm. Understanding how the collaborating firm internally develops innovations by utilizing UIC-acquired knowledge is crucial for several reasons: it addresses the limited accounts in existing literature; it relates to the growing number of UICs; and it sheds light on the factors affecting the firm's utilization of collaboration knowledge, which has only been addressed in general terms. By examining how collaboration knowledge is transformed into firm innovations, this research will contribute to a more comprehensive understanding of the impact of collaboration knowledge on firm innovation. The following discussion outlines the rationale for the development of the research question, beginning by addressing the employee role.

This literature review has addressed important research areas and questions regarding the role of employees in the context of absorptive capacity and the development of innovations from university-industry collaboration knowledge. In previous research on AC and UIC, the contrasting findings of Biedenbach et al. (2018) and Kobarg et al. (2018) revealed the need for further research on the possible relationship between AC levels and innovative outcome. Biedenbach et al. (2018) argued that both levels are related, while Kobarg et al. (2018) argued that this is not the case regarding internal R&D but that it is regarding employee "know-how" and radical innovation. However, both their analyses overlap and agree that high levels of AC in terms of employee know-how positively moderate the effect of radical innovation performance. Expressed differently, employee know-how is linked to AC and innovation development by using UIC as an external source of knowledge. This raises the question of the role of the employee on AC in a UIC or, as Kobarg et al. (2018, p. 1721) suggested, "an investigation of the reasons for the effects." How different roles in the organization affect AC has been considered by other scholars, for example: knowledge absorption on a lower level of analysis and the connection between prior knowledge and firm-level AC (Volberda et al., 2010); the impact of individual agents (Volberda et al., 2010); the claim that it is "assumed" that UIC fosters business innovation processes and scientific activities that result in collective learning and the exploitation of opportunities (Vega-Jurado et al., 2020); and the role of gatekeepers and their importance in order to "identify new and relevant knowledge" (Cohen and Levinthal, 1990; see also Rohenkohl et al., 2021). Taken together, the different roles of the organizational members have an impact on the AC and the utilization of external knowledge, including in the UIC context. However, it remains unclear clear which elements are influencing these roles and facilitating their impact. Therefore, research attention needs to be directed toward the influential roles that are connected to AC in UIC. The identification and analysis of the influential roles in UIC are important for a better understanding of AC and UIC by clarifying the function of these roles, and for the academic engagement literature by linking these to the formal and informal activities. From a public perspective, analysis of these roles and a deeper understanding of them can be useful for policy making.

This leads to a question: How is knowledge from a university–industry collaboration recognized as valuable by the firm and how is it acquired and assimilated by the firm? The AC framework requires the creation of knowledge that can be absorbed (Rohenkohl et al., 2021); knowledge is thus of key importance but has attracted only limited attention in previous research. Vega-Jurado et al. (2008) argued that conceptual models of AC have taken "no account of the nature of the external knowledge" (p. 398). Similarly, Rohenkohl et al. (2021) stated that "the attributes of knowledge have been ignored theoretically, empirically and analytically" (p. 6) in the AC literature due to the abstract and tacit nature of knowledge, and that AC "can hardly be measured by well-defined quantifiers" (p. 6). The use of proxies in previous AC literature has provided insights into correlations between variables, but not into why these variables are related; for example, see Lane et al.'s (2006) critique of R&D as an AC proxy. Research on AC seeking to understand the impact of prior related knowledge is needed (Volberda et al., 2010), as is research on how the hiring of academics enables the exchange of the "tacit aspect of knowledge" (de Wit-de Vries et al., 2019, p. 1250). Additionally, the relationship between collaboration knowledge and innovation (i.e., the AC component *exploitation*) has been the topic of earlier studies, but researchers have not elaborated on the details of how recognition occurs or how assimilation happens (Fabrizio, 2009). Knowledge produced in a UIC has individual traits (e.g., being performed by individual academics) and the use in prior AC research of quantitative measures such as surveys, patents, and publications (Apa et al., 2021; Biedenbach et al., 2018; Escribano et al., 2009; Fothergill, 2017; Kobarg et al., 2018; Petruzzelli, 2011; Santoro et al., 2019; Vega-Jurado et al., 2020) has limited our understanding of the relationships among AC, UIC, and collaboratively developed knowledge. There is accordingly a need for a qualitative approach to exploring these complex interactions of knowledge, leading to the research question guiding this dissertation:

RQ

How does a collaborating firm recognize, acquire, and assimilate knowledge from a university–industry collaboration to develop firm innovations?

Understanding the connection between collaboration knowledge and firm-developed innovations will contribute insights into knowledge usage, which is fundamental to the AC, UIC, and academic engagement literatures.

It is important to clarify that the research question encompasses multiple forms of collaboration knowledge (e.g., explicit artifacts and implicit know-how) and is not limited to a single interpretation of usefulness. The question makes an assumption of intention, as a consequence of the term "recognize," which necessitates that a subject should assign value, i.e., an individual determines that particular collaboration knowledge is useful. A caveat to this is the possible scenario in which collaboration knowledge is unintentionally utilized. Regardless of whether the application is intentional or unintentional, the important factor is that collaboration knowledge at some point has been understood as useful. After establishing the research question, the following chapter addresses the methodological choices made in this dissertation research.

3 Method

This chapter explores the methodological considerations of this dissertation and the research design used to investigate how collaboration-developed knowledge is internally utilized in the collaborating firm's innovation development. A single-case study design, with the CERC collaboration as the case, is used and the firm's perspective within the collaboration is the focus. Specifically, one firm participating in a UIC is the main research object. A qualitative approach is chosen for its ability to provide in-depth and contextualized insights into how collaboration-developed knowledge contributes to the firm's development of innovations. The chapter is structured as follows: section 3.1 presents the rationale for the chosen research method; section 3.2 outlines the single-case-study research method; section 3.3 describes the case and the advantages of choosing a center of excellence as a case; and section 3.4 presents the empirical data, including interview and archival data. Subsequently, section 3.5 presents the analysis, section 3.6 examines the research quality, and section 3.7 addresses ethical considerations; finally, the chapter concludes with a summary in section 3.8.

3.1 Selecting a research method

To address the stated research question, a single-case study design was prominent among the different methodological approaches of conceivable usefulness, such as grounded theory, process study, and case study research. Given that a firm's development of innovations often takes 10–15 years (Fitzgerald et al., 2011), the possibility of directly observing the innovation process itself is limited, making the option of a process study impractical (Langley, 1999; Langley et al., 2013). Moreover, the conducted research draws upon the theoretical orientation of absorptive capacity and academic engagement, constraining the ability to implement a rigorous grounded theory approach. While the characteristics of this research are aligned with the aim of an inductive method that generates theory from data, this research does not completely fulfill the criterion of being "without predefined constructs" (Eisenhardt et al., 2016). However, some characteristics of this research are aligned with an inductive method, such as: embracing diverse data sources that appropriately address the research question; selecting respondents based on their potential to further clarify the underlying processes; and conducting a coding analysis, influenced by grounded theory, of the obtained data. These characteristics argue for a research approach that includes theoretical development. A method that builds on existing research to advance and improve theory is essential, and a case study research design meets this requirement (Eisenhardt, 1989; Yin, 2018). Case study research allows the prior specification of constructs and accommodates the above-mentioned inductive characteristics. Case study research can focus on a single case or multiple cases; here a single case was chosen, i.e., the CERC collaboration. CERC was an appropriate source of information with which to address the research question (i.e., "How does a collaborating firm recognize, acquire, and assimilate knowledge from a university–industry collaboration to develop firm innovations?"), for reasons elaborated on in section 3.3. Therefore, given the predefined theoretical framework of absorptive capacity, the research conducted in this Ph.D. thesis is a single-case study. The next section further describes the single-case study conducted for this thesis.

3.2 The single-case study design

This research conducts a single-case study, with CERC as the case, to answer the research question by means of two rounds of interviews addressing how the collaborating firm internalized knowledge from the collaboration in its development of innovations. Both rounds of interviews fundamentally focused on the research question, offering important perspectives on it. Whereas the first round applied a general intrafirm perspective to understand the how and who of the matter, the second focused on the intrafirm perspective and how the collaboration knowledge was utilized in innovation development. The main reason for choosing the CERC collaboration as the case was that, as a "center of excellence" initiative, its fundamental rationale was to perform industry-relevant research of high scientific quality, generating innovations in the participating companies (Stern et al., 2013). In this way, CERC is a valuable case in which to explore the research question (further elaborated on in section 4.1). To address the aforementioned firm focus, one participating firm, namely, Volvo Car Corporation, was focused on in the case. The research question was investigated by collecting data in two interview rounds. To use and extend prior theory, the method in this dissertation was inspired by Eisenhardt's (1989) case study research.

The case study is a research process for inducting theory by iterating and linking data from different cases (Eisenhardt, 1989). Case study research is especially appropriate for new topics and should result in a theory that is "novel, testable, and empirically valid" (Eisenhardt, 1989, p. 532). The foundation for the development of new theories should be connected to empirical data, hence the case study's focus on building theory from data. Eisenhardt (1989) described the process of building theory from case study research in eight steps ranging from initiation to reaching closure. In this dissertation, "case study method" and "case study research" are used interchangeably to refer to the approach Eisenhardt presented that conceptualizes theory building (Gehman et al., 2018). While Eisenhardt's (1989) case study method entails the comparison of data from several cases, i.e., a multiple-case study, this dissertation compares primary and secondary data sources within one singular case (i.e., CERC) and from one specific firm (i.e., VCC). This research is thus not a multiple-case study but a single-case study whose methodological approach to developing theory from data comparison has been inspired by Eisenhardt's (1989) case study method. We turn now to examples from prior research employing the case study method.

The application of the case study method in theory building has grown since Eisenhardt's (1989) seminal work, with examples across various fields and research questions. Some notable examples using case study research for theory building concern: dynamic communities (Galunic and Eisenhardt, 2001); the expected and serendipitous value creation of acquired leaders (Graebner, 2004); acquisition as courtship and the syndicated view of governance (Graebner and Eisenhardt, 2004); how the organization of relationship management can help explain the dynamics of a start-up's development of social capital (Maurer and Ebers, 2006); how alternate control can trigger greater access to capabilities at collaborating firms and enhance innovative performance (Davis and Eisenhardt, 2011); how creating concept coherence within a team is an ongoing accomplishment in dynamic environments (Seidel and O'Mahony, 2014); and how organizational routines are employed to balance stability and flexibility in an innovative setting (Dönmez et al., 2016). The case study method has also been employed in research on innovation, for example, concerning: change and innovation in hybrid organizations (Jay, 2013); cooperation with competitors for technological innovation (Gnyawali and Park, 2011); external knowledge and green innovation (Ben Arfi et al., 2018); the role of individual determinants and processes related to implementation (Watson et al., 2020); environmental regulations and innovation (Ramanathan et al., 2017); service development and business model innovation (Paiola and Gebauer, 2020); service innovation and dynamic capabilities (Kindström et al., 2013); and innovation in family-owned firms (De Massis et al., 2013). These studies demonstrate the versatility of case study research, highlighting its ability to address diverse research questions and generate insights into various research domains. The case study method has been used for inspiration due to its ability to synthesize: qualitative methods, quantitative data, single or multiple cases (Yin, 1984), grounded theory building (Glaser and Strauss, 1967; Strauss, 1987), and construct and hypothesis testing. By employing a variety of research tools and techniques, case study research provides a valuable means for building and improving new theoretical knowledge. Table 4 presents the eight steps of case study research.

Table 4: Case study methodology

Step/title	Activity	Objective
1. Getting started	Definition of research question	To focus the effort.
	Possible a priori construct	To find building blocks of new constructs or comparisons, narrow the search and the selected population.
	Neither theory nor hypothesis	Ideally, no prior theory affects the research.
2. Selecting cases	Specified population	To collect data from research-relevant sources.
	Theoretical sampling	Identify and select cases that can replicate or extend theory.
3. Crafting instruments and protocol	Multiple data collection methods	Make triangulation possible, providing stronger constructs and hypotheses.
	Qualitative and quantitative data	The combination can be synergistic and maintain focus.
	Multiple investigators	Enhance creative potential and confidence in findings.
4. Entering the field	Overlap of data collection and analysis	Allow investigation of emergent themes and features.
	Flexible and opportunistic data collection	Altering or adding data can allow better understanding of the phenomenon.
5. Analyzing data	Within-case analysis	Site write-ups enable familiarity with each case.
	Cross-case pattern search	Avoid poor data processing and enable divergent data view.
6. Shaping hypotheses	Iterative tabulation of constructs	Constantly compare theory with data to develop a theory.
	Replication logic across cases	Case series are treated as experiments, confirming or disconfirming the hypotheses.
	Evidence for "why"	Seek evidence of the underlying relationships.
7. Enfolding literature	Comparison with contrasting literature	Strengthen the findings and force thinking that can sharpen or limit the generalizability of the findings.
	Comparison with similar literature	Can tie together similarities and enable stronger internal validity.
8. Reaching closure	Theoretical saturation when possible	The same thing is observed repeatedly.

Table 4 (adapted from Eisenhardt, 1989) has three columns, namely, step/title, activity, and objective. From left to right: the first column presents the number and title of each step; the second column provides a brief explanation of the various activities in each step; and the third column addresses the objective of each step. In the single-case study performed here, the selected case, CERC, is a CoE, and the rationale for using such a center as the case is addressed in the next section.

3.3 Defining the case

In case study research, one must first specify the defining requirements of a population from which a case relevant to the research objective can be selected. In the present research, the research question and the theoretical orientation create requirements for the case. The research question and the literature on academic engagement outline three criteria each, and four criteria are identified from the AC literature. These criteria are presented in Table 5.

Table 5: Criteria identified from the research phenomenon and theoretical orientation

Research question	**Academic engagement**	**Absorptive capacity**
Firm	Non-academic organization	Firm
Collaboration knowledge	University	External knowledge source
Innovation	Knowledge-related collaboration	Learning/absorption
Research question	Academic engagement	Absorptive capacity
Firm	Non-academic organization	Firm

All three areas require the presence of a *firm* or non-academic organization, while the research question and the AC have an *innovation* criterion. Academic engagement and the AC both require *interaction*: in academic engagement this is knowledge-related collaboration and in AC it is learning. While AC involves a general description of the firm's interactive part (i.e., an external knowledge source), academic engagement is more specific, involving a university.

The specified case must meet the criteria of involving a firm, a technological university, knowledge-related interaction, and innovation. To study how the collaborating *firm* integrates collaboratively developed knowledge into its innovation development, a firm that participates in collaboration with a university is required. The *technological university* criterion refers to the research question's mention of knowledge originating from a collaboration and to the academic engagement aspect of a partner from the higher education system (Ankrah and AL-Tabbaa, 2015). That the university is "technological" is not specified in the research question, but it improves the likelihood that the developed knowledge will be an applied science making use of the natural forces for practical intentions (Klemke et al., 1998). The criterion of *knowledge-related interaction* refers to collaboration between a firm and an external source of knowledge. The last criterion of *innovation* refers to the utilization of collaboratively developed knowledge in the form of product or process innovations (OECD/Eurostat, 2018).

Cases that fulfill these criteria are publicly funded center constellations involving both academic and industrial parties. Frost et al. (2002) found that CoEs are used by firms across various industries to focus and leverage expertise in specific areas, with some including partnerships with the higher education system. When an academic institution is part of such a center, the two terms "competence center" or "center of excellence" are commonly used. The US National Research Council (1999) identified four differences between an academic CoE and the traditional university research mode, including a clear research focus, multidisciplinary research collaboration, access to shared facilities, and an industrial outreach program. They further argued that an advantage of such a center is that it "identifies industry segments interested in specific research projects" and that it "commonly recruits industrial participants" (US National Research Council, 1999, p. 62). Therefore, the presence of CoEs including academia is promising for identifying a population of interest.

For this research, the main unit of analysis is collaboratively developed knowledge, and the aim is to accentuate usage links between the collaboration-developed knowledge and the collaborating firm's development of innovations. The collaboration-developed knowledge is the result of scientific activities performed at the university, conveyed in objects or subjects that contain and represent the knowledge, which can be individuals, methods, tools, working practices, and digital and physical objects. The operationalization of collaboration knowledge as the unit of analysis includes, but is not limited to, explicit and tacit knowledge developed in the CERC collaboration between the years 1995 and 2017 (i.e., the UIC). Explicit collaboration knowledge comprises artifacts such as annual reports, scientific publications, and conference contributions. Tacit collaboration knowledge is individual knowledge such as know-how, experience, and meaning structures. For example, the reference lists in the CERC collaboration's annual reports state scientific publications and conference contributions directly connected to the collaboration and also name these publications' authors. The annual report-listed publications constitute an explicit form of the authors' collaboration knowledge, but do not represent the authors' tacit collaboration knowledge. The authors' tacit collaboration knowledge comprises the know-how and experiences that frame their evaluation of new information. In the context of the dissertation's purpose, which is to explore how knowledge developed in a university–industry collaboration is utilized by the collaborating firm in the development of innovations, understanding and examining how both forms of collaboration knowledge contribute to the firm's innovation development are valuable.

3.4 Empirical data

This research focuses on comparing innovations developed and owned by VCC; to gather primary data, semi-structured interviews were conducted with 27 respondents, encompassing individuals with practical experience of the CERC collaboration, patent inventors, industry experts, and influential decision makers. As secondary data, CERC annual reports, scientific publications, patents, VCC press releases, and participant observation were used to substantiate the analysis. The respondents were the primary data sources and were selected based on their involvement in CERC and their ability to provide detailed insights into the specifics of how the firm used knowledge from the collaboration in its development of innovations.

Two rounds of interviews were performed. The first round focused on respondents who, as firm participants, directly or indirectly interacted with CERC. Such respondents could provide information on how knowledge from the collaboration has been beneficial for the firm's creation of innovations. The second round of interviews focused on innovations and their inventors, who provided information that usefully showed how collaboration knowledge has been utilized. The second round also involved industry experts and influential decision makers. Specific interview guides were written for each round of interviews.

3.4.1 First round of interviews

The first interview round focused on firm participants with practical experience of the CERC collaboration, to explore how collaboratively developed knowledge was utilized in firm innovation development. These participants were selected based on their involvement in CERC and their ability to provide detailed insights into specific roles, helping address the research question. Their accounts constitute the primary data. Lastly, these firm participants could also help identify innovations for the second round of interviews. Table 6 presents the respondents in the first round of interviews.

Table 6: Respondents, first round of interviews

No.	Interview date	Length	Type	Case	Alias	Professional role	CERC relationship
1	2018-12-13	1:22:13	Face-to-face	1	Viktor	Technical specialist	Industrial representative
2	2018-12-20	1:02:26	Face-to-face	2	Qvintus	Technical specialist	Industrial representative
3	2019-01-14	54:13	Face-to-face	3	Willhelm	Technical specialist	Industrial representative
4	2019-01-22	1:23:55	Face-to-face	4	Martin	Manager	Former board member
5	2019-01-25	47:19	Face-to-face	5	Xerxes	Technical specialist	Industrial representative
6	2019-01-29	1:02:05	Face-to-face	6	Yngve	Manager	Board member / Industrial representative
7	2019-01-31	57:34	Face-to-face	7	Zäta	Group manager	Board member / Industrial representative
8	2019-02-13	22:49	Phone	8	Åke	Manager	Board member / Industrial representative
9	2019-03-12	1:07:30	Face-to-face	9	Olle	Manager	Former board member

The above table provides an overview of and essential information about the interviews conducted in the first round. The table is organized into nine columns, with the first column enumerating the interviews, followed by the interview date, duration (total nine hours), type of interview, case number, respondent alias, respondent's professional role when engaged in CERC, and the nature of the respondent's relationship to CERC. Apart from the interviews, secondary data sources were beneficial for examining the research question.

To substantiate the analysis and strengthen the findings, two main data sources were used, namely, interviews and archival data. The semi-structured interviews, which constituted the primary data, followed a predesigned four-part interview guide. Archival data, the secondary data, comprised the collaboration's annual reports and scientific publications. By comparing coherent elements of the interviewees' comments, through coding the transcribed interviews, the important roles could be described on a historical basis.

The first interview round focused on firm participants who had interacted with CERC, to identify and explore how the firm used knowledge from the collaboration in the development of innovations. Such respondents could provide information on how knowledge from the collaboration has been beneficial for the firm's creation of innovations. Consequently, these individuals possess insights into the roles relevant to the utilization of collaboration knowledge. A qualitative approach involving semi-structured interviews was employed (see Table 6, above), as individual perspectives and descriptions were critical to gain a comprehensive understanding of all actors involved. The interviews were conducted in person or by phone between December 2018 and March 2019, following a snowball sampling approach to identify suitable participants. All the interviews were recorded after consent was given by the respondents. The respondents were selected, using snowball sampling, after initial contact with a respondent relevant to the research topic (Bryman and Bell, 2007). To identify the first respondent, we contacted the director of the CERC university–industry collaboration, who identified an individual at the firm who had been active in the collaboration. This individual, who was then interviewed, provided information on other individuals who had practical experience of participating in the collaboration. This process continued until respondents representing the targeted time span of VCC's participation in CERC (1995–2017) had been identified and interviewed. This time span was targeted because VCC decided to leave the collaboration in 2019 and the interviews in the first round were initiated in 2018.

This enabled coverage of a period that would yield findings valuable to practitioners (Langley et al., 2013), as it made it possible to identify and explore the formalization of practices and patterns. Most of the interviews were performed at the respondents' workplaces, in a separate room to ensure that the interviews were not interrupted. Two interviews were conducted at Gothenburg University in the office of the Unit for Innovation and Entrepreneurship, and one interview was conducted in the respondent's home.

The application of semi-structured interviews enabled a systematic approach to gathering and analyzing information in the first interview round. The interviews followed a predesigned interview guide focusing on four themes: respondent background, application of collaboration knowledge, identification of relevant collaboration knowledge, and assimilation of collaboration knowledge. A summary section included in the guide was used after each interview ended. To initiate the conversation, the interview guide was designed to first capture background and historical information. To underline the AC components, the respondent was encouraged to think about and discuss how collaboration knowledge was applied. The guide's questions were formulated to generate open and descriptive answers, by emphasizing *how*, *when*, *who*, and *what*. When possible, the respondent was asked to provide examples and elaborate on situations or events. To understand the root cause of relationships, inspiration was drawn from courtroom procedure and its focus on facts and events (Eisenhardt, 1989; Graebner and Eisenhardt, 2004). The guide thus traced the process starting from how the collaboration knowledge was first identified and extending until this knowledge was later assimilated in the firm, thereby enabling influential roles in this process to be accounted for. By means of this design, the interviews with the CERC-experienced individuals concentrated on the AC components of recognizing value, acquisition, and assimilation, and on individuals and their roles that had been important for the incorporation of collaboration knowledge.

3.4.2 Second round of interviews

The second interview round focused on identifying innovations developed by VCC from or with knowledge stemming from the CERC collaboration, to address the research question. Because the industrial partners in CERC could be competitors outside the collaboration, it was advisable not to disclose certain knowledge gained through the collaboration, limiting the disclosed knowledge to firm innovations mentioned in the CERC annual reports. Although specific innovations are not addressed in the annual reports, the reports share some guidance to identify innovations. For example, in the 2005 report, Hiljemark summarized the first ten years and commented on the Center's outcome. Hiljemark (2006) wrote that competitors "believe that their involvement with CERC provides scope to reduce their in-house research efforts on fundamental processes and, to some extent, technical applications" (p. 3). Here, it is suggested that both process innovations (i.e., fundamental processes) and product innovations (i.e., technical applications) have arisen from the collaboration. Therefore, both product and process innovations were sampled in the second interview round. In the second round of interviews, innovations were conceptualized as patents, an approach used in prior research (Arts and Fleming, 2018; Veugelers and Wang, 2019); the identified patents are discussed in the next section.

The second round of interviews aimed to further explore how the firm utilized knowledge from the collaboration in innovation development by examining and comparing CERC-related patents. Existing CERC-related patents were used to identify and recruit respondents who could outline and provide insights into how collaboration knowledge was used in the firm's innovation development. In the second round of interviews, the primary data were from semi-structured interviews and the secondary data were from archives and patents. In comparison with the first round of interviews, the second round drew more inspiration from Eisenhardt's (1989) case study method for theory development, specifically conducting within-and cross-case comparisons, hypothesis shaping and replication, and comparison with prior literature. While Eisenhardt (1989) called for cases to be compared, innovations were compared in this second round of interviews.

To clarify terminology, the term "used" here refers to the act of implementing or the process of making something active or effective. It addresses the deliberate actions taken, or processes implemented, to apply collaboration knowledge to reach an intentionally expected outcome (e.g., the expected implementation results). It is also possible for unexpected outcomes to emerge from the implementation of collaboration knowledge. Independent of whether or not the outcome was expected, the use of collaboration knowledge was recognized as advantageous by the user. Expressed differently, knowledge from the collaboration was first perceived as valuable prior to its implementation. In the context of patents, the use of this knowledge illustrates intentional action and the patents indicate the existence of innovations. However, it is essential to note that the mere use of CERC knowledge does not guarantee innovation, which has its own specific criteria. While CERC knowledge can contribute to the development of innovations, its successful implementation does not per se create a case of innovation, as there are distinct criteria that must be met. The aforementioned definition of innovation includes specific criteria (e.g., usage), and it is possible for a firm to attempt to implement collaboration knowledge without successfully satisfying these criteria. Therefore, the innovation must be the result of implementing collaboration knowledge. The main subject of interest is the use of collaboration knowledge in relation to the identified patents. Having clarified what "used" refers to, I outline below how the patents were identified.

This research employed a multi-step process to identify CERC-related patents. Analysis of the first round of interviews included making a list of innovations associated with the collaboration (i.e., the innovations listed in chapter 4). This innovation list, together with the interview excerpts, indicated areas of knowledge valuable for innovation. These knowledge areas were compared to the CERC annual reports to confirm the existence of collaboration research within these knowledge areas. The outcome of this process identified knowledge areas and associated keywords, individuals, and scientific publications (including author and title). Then, a list of patents for which VCC was the applicant was imported from the Swedish Intellectual Property Office (PRV) for the 1997–2017 period, resulting in 544 patents. The list provides a range of information on the patents: application and publication number, title, classification, applicant, inventor, and filing date. The patent titles were initially compared to the knowledge areas and associated keywords to find similar phrasing. For example, patent titles including the term “engine” were more likely to be aligned with CERC collaboration knowledge. When a patent’s title included one or more CERC-associated keywords, the full patent application was accessed to compare the abstract text and listed requirements with the relevant CERC annual publication. This process is exemplified by the product innovation examined in Innovation one (see appendix v), in which the knowledge area connected to the keywords “direct injection,” “injection strategies,” and “spray angles” was of specific interest. Therefore, a query search for the keywords was conducted in the patent text and the annual report text. The patent’s title, filing date, and text were then compared to the findings in the CERC reports published prior to the patent’s filing date. A patent was considered a match if one or more of its authors was connected to the CERC collaboration and the relevant knowledge area, and if the publication date of the associated CERC report preceded the patent’s filing date.

For example, the passages referring to process innovations quoted in the third column of Table 7, below, for innovation numbers two to four, emphasize that steering and controlling the engine is a major area of research with a critical role in the combustion engine. In CERC, research on steering and engine control (i.e., a knowledge area) was mainly conducted at the Department of Electrical Engineering at the university.

To isolate a specific process innovation, all publications associated with the Department of Electrical Engineering were imported from the CERC annual reports (i.e., the comparison knowledge area) to a list presenting titles, authors, and years of publication. Each article's title, summary, and introduction inform us of the research area of interest. The PRV patent list and the list of articles were compared for similarities between the patents and the articles' titles and abstracts. Additionally, individuals acknowledged in the articles were compared with the list of patents. A patent was regarded as matching when one or more of its authors could be connected to a published article or a CERC collaboration and the knowledge area, and when the publication was older than the patent. Innovation numbers two to four in Table 7, below, resulted from comparing these lists. The first innovation was identified by the same process, except for the acknowledged individuals. The process innovations numbered five and six were identified during the data collection for the initial four innovation cases, established by respondents as valuable patents or as good examples of patents connected to collaboration knowledge.

Through this process, the patents were identified as feasible for examination in the second round of interviews. The choice of innovations also limited the range of respondents for data collection; for example, industrial representatives, inventors, and managers were of significant interest for a more detailed account of the mechanisms important for collaboration knowledge to become firm innovations. The identified patents are presented in Table 7.

Table 7: Identified patents.

No.	Type		Interview	Patent	Article
1	Product	Injector	“ Yes, especially in direct injection overall. And I'm still working on it today. I'm sure there are projects on spray angles, and it's often linked to theoretical calculations as well. Only then, like Chalmers..” (Martin, own translation)	A more efficient engine combining improved geometry and injection timing	“By injecting the fuel shortly before the time of ignition, a stratified mixture is created. In the region of the spark plug, the mixture will ideally be close to the stoichiometric, while in the rest of the combustion chamber the mixture will be extremely lean (not ignitable).” (Karlström, 1998, p. 6)
2	Process	Model	“Well, there we had two researchers working [...] who could experimentally and computationally verify that. [...] could implement in our modeling tools. Immediately then. Which increased the accuracy of predictions.” (Zäta, own translation)	More efficient conservation of emissions after passing the combustion chamber	“Therefore, an advanced pulse-experiment method has been developed. […] Importantly, these studies showed that kinetic models of soot oxidation must account for adsorbed oxygen species.” (CERC Report, 2015, p. 43-44; Englund, 2015, conference paper)
3		Model	“A typical thing that is extremely difficult is spray modeling. [...] That is, fuel injection in the combustion chamber. Different models that are supposed to capture physical processes. [...] So, you often need really good measurement data to calibrate the model, and of course, at Chalmers, you can also measure” (Willhelm, own translation)	Enabling multiple injections	“The main contribution to NO mass emissions was, as expected, the bulk gases originating from the main combustion event. However, the presence of NO at the end of the exhaust stroke was observed, both for homogeneous and for stratified charge.” (CERC Report, 2001, p. 8, Sandquist Ph.D. student, later Industrial Representative)
4		Control system	“"But you control the injection timing, ignition angle, air-fuel ratio, turbo regulation, number of injections on a diesel, [...] It's a huge area. And there is knowledge from CERC in that field." (Xerxes, own translation)	An invention to ensure a pleasurable driving experience by using a control system to control the engine	“By changing valve overlap the internal EGR rate was increased to induce a disturbance to the ignition control system. The increased EGR rate lowers the burn rate and the combustion phasing became later. This was detected by the torque ratio estimation algorithm, and the integrating controller could compensate by shifting ignition timing.” (Larsson and Andersson, 2005, p. 149)
5		Control system	Identified during data collection, established as good or valuable patents connected to collaboration knowledge	An invention to control the external environment for issues when the driver is absent	Collaboration knowledge, gained by Ph.D. research, provided a work method to solve problem in a complex environment.
6		Method	Identified during data collection, established as good or valuable patents connected to collaboration knowledge	An invention to perform the combustion through a new method	Collaboration knowledge, gained by Ph.D. research, provided an ability to identify the most important factor(s) causing a problem.

Table 7 provides an overview of the identified patents, organized by number, innovation type, interview excerpt, paraphrased patent description, and related CERC report or article. From left to right in the table, in the first column is the innovation number, followed by the type of innovation (either product or process) and a descriptive label of the innovation. The third column presents excerpts from the first round of interviews, except in the case of innovation numbers five and six, for which paraphrased summaries of the respondents' accounts are presented. In the fourth column are descriptions of the patents, paraphrased because the respondents have been anonymized. The paraphrased descriptions concern the effects achieved, excluding the patent name and number. The last column presents excerpts from either the CERC reports or articles linked to the patent, except in the case of innovation numbers five and six, for which the contribution of collaboration knowledge to the patent is described. Now consider whether these patents are examples of collaboration knowledge being utilized.

The identified patents can reasonably be regarded as innovations based on collaboration knowledge. This is because the similarity of description between each patent's text and the text in the matching CERC publication suggests the implementation of collaboration knowledge in the patent's development. This is also due to the relevance of certain individuals, such as industrial representatives, specifically declared in some of the CERC publications and later identified as the innovations' inventors in the matched patent texts. Additionally, the aforementioned knowledge areas and associated keywords are connected to CERC collaboration knowledge and linked to the firm innovations. These three rationales make it plausible that collaboration knowledge has been implemented in the identified patents or in the process of making the patents. However, it is not argued here that that the implementation of collaboration knowledge has been proven; rather, it is argued that it is reasonable, or justifiable, to think that the identified patents used collaboration knowledge from CERC. Therefore, the patents are the compared innovations, and their inventors can provide information valuable for comparison. Since correlation is not causation, the emphasis is on the conditions and events within the innovations that produced the innovations and on the empirical requirement for comparable innovations to allow pattern comparison (Parsons, 2007). In summary, it is reasonable to think that collaboration knowledge was utilized in these patents and that the inventors could provide information about how such knowledge utilization occurred.

In the second round, 22 respondents were interviewed, encompassing patent inventors, industry experts, and influential decision makers, to gather information on how collaboration knowledge was utilized in the firm's development of innovations. Interviews for the second round were performed between 2020 and 2021. Eleven respondents were initially identified as patent inventors; two additional respondents were identified as inventors and included during the interviews, and eight additional respondents were interviewed due to their industry experience or as representing influential actors. Table 8 offers information about the respondents.

Table 8: Respondents, second round of interviews

No.	Date	Length	Type	Alias	Professional role	CERC relation	Patent relation
1	2020-06-30	01:02:00	Video	Adam	Development engineer	Indirect interaction	Inventor
	2021-03-18	00:42:00	Video				
	2021-02-12	01:14:00	Video	Johan	Technical specialist	CERC doctoral student	Inventor
	2021-03-15	00:44:49	Video				
	2021-02-19	01:33:00	Video	Ludvig	Test engineer	No direct interaction	Inventor
2	2020-07-02	00:56:00	Video	Bertil	Project leader	Industrial representative	Inventor
	2020-07-29	01:03:00	Video	Cecar	Manager	CERC representative	Inventor
	2021-06-07	00:59:05	Video				
	2020-08-12	00:59:00	Video	Erik	Calculation engineer	Industrial representative	Inventor
	2021-06-29	00:49:42	Video				
	2021-02-23	01:38:00	Video	Niklas	Calculation engineer	Indirect interaction	Inventor
3	2020-08-06	01:02:00	Video	David	Analysis engineer	No direct interaction	Inventor
	2021-02-04	01:04:00	Video	Gustav	Analysis engineer	No direct interaction	Inventor
	2021-02-10	01:06:00	Video	Ivar	Project leader and technical specialist	Indirect interaction	Inventor
4	2021-01-19	01:31:00	Video	Filip	Function developer	Industrial representative	Inventor
	2021-03-31	00:39:56	Video				
	2021-04-13	01:05:00	Video	Urban	Technical specialist	CERC doctoral student	Industry expert
5	2021-02-09	01:20:00	Video	Helge	Function developer	Indirect interaction	Inventor
	2021-03-10	00:32:09	Video				
	2021-02-16	01:24:00	Video	Kalle	Function developer	CERC doctoral student	Inventor
6	2021-03-25	01:07:36	Video	Adam	Development engineer	Indirect interaction	Inventor
Not innovation specific	2021-02-22	00:51:00	Video	Martin	Manager	CERC board member	Decision maker
	2021-02-23	00:54:00	Phone	Olle	Group manager	Former board member	Decision maker
	2021-02-24	00:52:00	Video	Petter	Patent attorney	None	Decision maker
	2021-02-24	00:59:00	Video	Qvintus	Manger	Industrial representative	Decision maker
	2021-02-25	01:51:00	Video	Rudolf	Manager	None	Industry expert
	2021-02-26	00:45:00	Video	Sigurd	Patent attorney	None	Decision maker
	2021-03-30	00:27:00	Video	Tore	Technical specialist	None	Industry expert

Table 8 presents an overview of the respondents in the second round of interviews, organized by innovation number, interview date, length, type, alias, professional role, relationship to CERC, and relationship to the identified patent. Twenty of the 22 respondents have higher education qualifications, including eleven with Ph.D.s. Thirteen of the 22 had been interacting either directly or indirectly with CERC. In line with Eisenhardt's (1989) case study research, an additional eleven respondents were interviewed in their roles as decision makers (e.g., person responsible for engine development, committee member, patent department member, or industry expert). The rationale for including more respondents was to allow for cumulative data collection until the interviewees' responses converged and repeated each other.

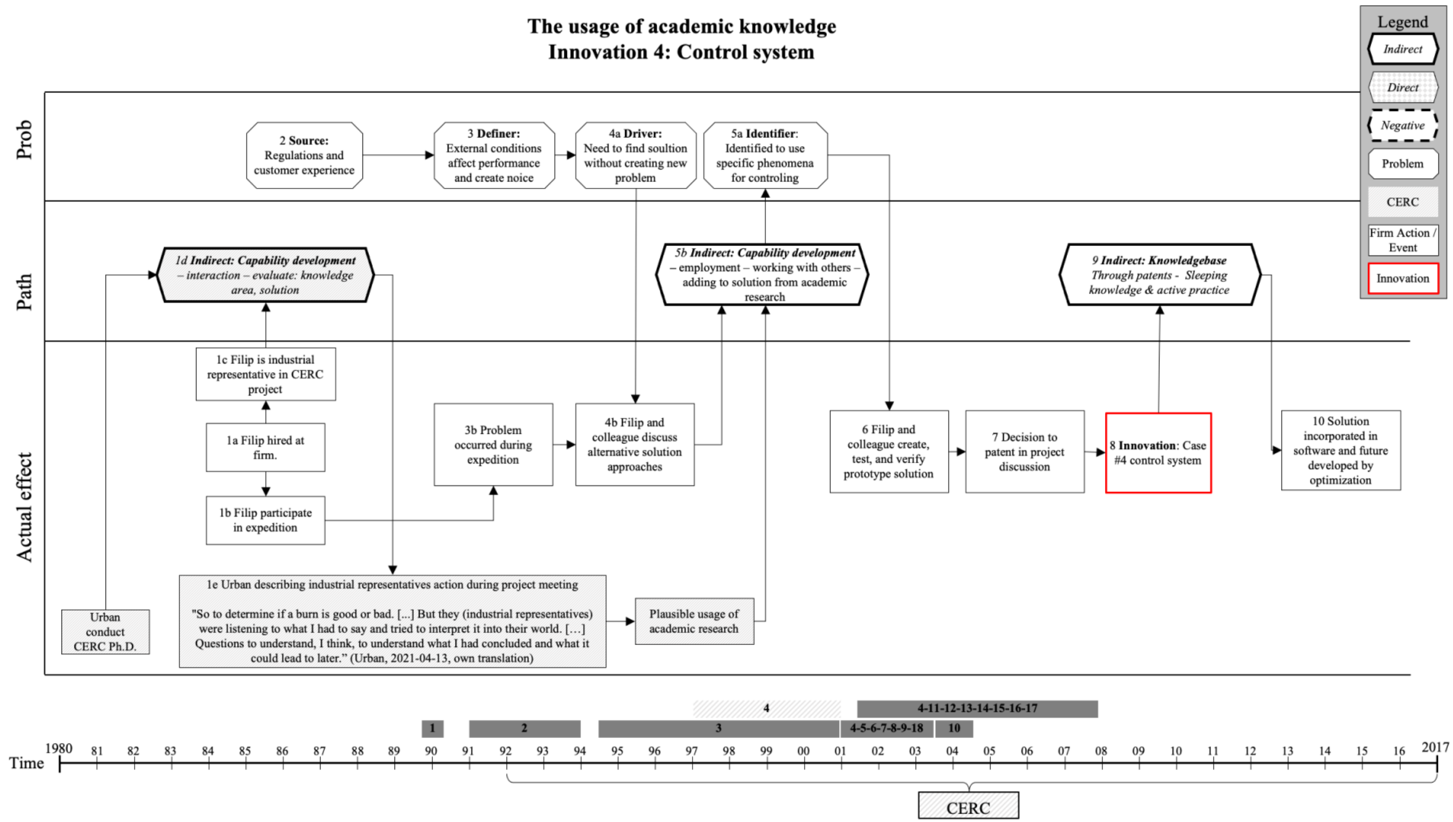
Due to the iterative nature of the data analysis process, some of the respondents were interviewed more than once. In line with case study research and the emergence of themes, the interviews and transcriptions were continuously re-examined and reviewed. Unlike the first round of interviews, all interviews in the second round were conducted by phone or video link. The total length of all interview material was 28 hours for the main study, resulting in a total of 606 pages of transcribed material.

An interview guide ensures a systematic data collection process, and the second round's interview guide centered on the patented inventions that serve as the foundations for the selected innovations. To address the research question and comprehend the overall pattern of relationships between collaboration knowledge and firm innovation, one must examine both the interactions between relevant events and the influence of these interactions. In addition, how interaction at one point in time is related to a later firm outcome is also important to consider. Therefore, inspiration is drawn from organizational scholars and from research on change in organizations. Van de Ven and Poole (2005) argued that organizational change is viewed as either a thing or a process by scholars, distinguishing between variance theory and process theory. In variance theory, change is understood as a dependent variable explained by independent variables (Mohr, 1982). In process theory, change is understood as event driven and explained by order and sequence (Van de Ven and Poole, 2005). The interview guide was inspired by process theory's description of change, and attention was paid to the order and sequence of events. In the context of the second round, this entailed the identification of events preceding the firm innovations and connected to the collaboration knowledge. Here, an event refers to a happening experienced as sufficiently coherent, but allowing for different points of view (Hernes, 2014). The unit of analysis is collaboratively developed knowledge, so the guide is structured around the invention. The interview guide is structured according to four themes: respondent background, before the idea of the invention, after the idea of the invention, and summary. The questions were designed to generate open and descriptive answers, for example: *If we take it from the beginning, how did it start? What happened next?* To mitigate the influence of leading questions and to initiate the conversation, the interviews initially centered on the patents. The rationale for focusing on the patents was primarily to collect information (i.e., the respondents' accounts) about collaboration knowledge usage by drawing the interviewees' attention to their experience of the patenting and related events. Focusing on the individuals' specific actions and rationales for those actions, and on identifying repeated actions, possibly over time and between innovations, helps to reveal how collaboration knowledge is implemented. Despite the challenges of recalling past events (i.e., recall bias), the consistency of reported experiences of similar events across identified innovations was supportive of this research. This rationale derives from the availability heuristic and the ease of recalling subjectively defined relevant instances (Bottom, 2004; Tversky and Kahneman, 1973). In addition, this method also helped to detect other actors who affected the usage of collaboration knowledge and the patenting process; besides the initial inventors, eight other actors were interviewed. Various perspectives were expressed about the progression from idea to patent, but overall, the interviews coherently accounted for how collaboration knowledge was utilized in the firm's innovation development. The complete interview guide for the second round is found in the Appendix B.

As mentioned previously, the anonymity of the patents and respondents included in this study was maintained to ensure a larger pool of participants, despite potential methodological concerns. Specifically, there was a trade-off between two weaknesses, namely: either openly identify the patents and have a reduced number of respondents, or maintain anonymity resulting in methodological criticism. The latter option was chosen because the number of potential informants for comparable innovations was by nature limited. In other words, too few inventors who internalized and applied collaboration knowledge to create an invention would be willing to participate if anonymity were not ensured. Additionally, due to the Covid-19 restrictions prevailing at the time, all interviews were conducted by video link or phone. All interviews were recorded with respondent consent; one respondent did not consent to the recording. The influence of the use of video and phone interviewing on data collection is challenging to determine. One possible systematic limitation could be an inability to read and act on body language. On the other hand, and for the same reason, there may arguably be a decrease in the interviewer effect, since the respondent is limited in reading the interviewer's body language.

In summary, this research interviewed 22 respondents, including patent inventors, industry experts, and decision makers, for the purpose of exploring how knowledge developed in a university–industry collaboration was utilized by the collaborating firm in the development of innovations. The research relied on the respondents' accounts of their experience of patenting and related events, to address this purpose. The research maintained the anonymity of the patents and respondents to ensure a larger pool of participants.

Figure 4: Example of individual innovation description



Cross-case pattern analysis was conducted to identify commonalities and differences between the innovation cases. The search for cross-case patterns between the individual innovations was facilitated by the use of NVivo and, additionally, Excel for summarizing overviews and data triangulation in table format. The patterns were then visualized in PowerPoint, as in the example in Figure 4, above. To enable cross-case comparison, every respondent was treated separately. The predefined AC theory was applied for the comparison categories of similarities and differences between the innovation cases. The summarized overviews in Excel and the table sorting function facilitated the comparison of the quoted excepts from the respondent comments in each AC sub-code. In other words, the coded interview sections were compared separately for each sub-code.

The process of shaping hypotheses in this study utilized a systematic approach to combining and comparing constructs across the innovations. Inspiration was drawn from Seidel and O'Mahony (2014) to combine the developed constructs in collective tables. The triangulation of emergent themes and constructs was progressively iterated by comparing NVivo codes, excerpt tables, visualizations, and notes between the innovations. When a construct emerged in one innovation, an incremental process of gradually expanding and examining similar constructs across the other innovations was employed (Maurer and Ebers, 2006), instead of analyzing all innovations at once. In other words, if a pattern was found in one innovation it was compared with the next innovation. When new constructs emerged, the interviews and transcripts were continuously re-examined and reviewed to discern any logic of replication. This replication logic implies that the cases (here, the innovations) were viewed as experiments in which each case had the potential to support or refute the assumptions. A construct that was replicated and supported across the data was both more relevant and more valuable; this strengthened the relevance of the findings, providing a foundation for the subsequent analysis.

Following the case study method, the analysis and the construct development, from both the within- and cross-case analyses, were then compared with the predefined theories (Eisenhardt, 1989). The literature comparison began at the end of the analysis. The AC framework and its components depicted an internal relationship, extending from the recognition of external knowledge to its exploitation. Therefore, the AC framework was compared with the findings to search for similarities and differences.

In summary, the data analysis involved within-case analysis, cross-case pattern detection, hypothesis shaping, and comparison with existing literature. The within-case analysis allowed for the emergence of unique patterns, while the cross-case pattern analysis identified commonalities and differences between cases. The hypothesis shaping emerged from specific within-case conditions to be compared and generalized across the cases. The result of the analysis is presented in chapter 5, below, and the discussion section in this dissertation expands on the findings of the analysis and of the comparison with supporting and opposing literature.

3.4.3 Archival data

While the primary data for this research were collected through two rounds of interviews, the secondary data were comparable in the two rounds. Here the similarities and differences between the two rounds are described.

Both interview rounds used archival data that included CERC annual reports and scientific publications. The annual reports concern the 1996–2017 period and contain detailed information about: the collaboration knowledge developed during the past year, the participating industry partners, individuals (e.g., their academic titles and research areas), and monetary contributions from industry partners, the Swedish Energy Agency, and the university. Information about the performed research, individuals, and monetary contributions was extracted from the reports and compiled in a separate Excel document. Subsequently, the extracted data were refined and categorized to offer descriptive information about the collaboration. The annual reports enabled the identification of the second archival data source, i.e., the scientific publications, by identifying either individuals or publications listed in the reports. The scientific publications were one form of artifact that contained collaboration knowledge; here, these publications also connected the collaboration knowledge to individual researchers/collaboration participants.

Unique to the first round was field participation in a one-day CERC conference; this entailed observing and taking notes relevant to the research question based on discussions, presentations, and informal conversations. Unique to the second round was the use of patents and VCC press releases to explore how CERC-developed knowledge contributed to the firm's innovation development. Previously, section 3.4.2 detailed the usage of the secondary data in the second round, specifically for the identification of innovations.

Both interview rounds used archival data to build a comprehensive understanding of the university–industry collaboration in CERC, its influence over two decades, and how the firm utilized collaboration knowledge in its internal development of innovations.

3.5 Analysis

This section describes how the analyses were performed in this research in the two rounds of interviews. First, the common structure of the applied analytical process is presented, followed by the unique traits of each interview round. The two interview rounds provide empirical nuances concerning the research question.

Both rounds used qualitative semi-structured interviews as the primary data collection method, with modified interview guides (see Appendix D) and archival data as secondary data. The primary qualitative data were useful for in-depth interpretation of how the collaborating firm internalized collaboration knowledge in the development of innovations and of its underlying reasons and rationale. The archival data could indicate general relationships between collaboration knowledge and firm innovation, and possible trajectories of research. In combination, the quantitative and qualitative data offered a comprehensive understanding of the underlying rationale of the firm's internalization of collaboration knowledge.

The analytical process was incorporated into the interview sessions by means of the summary section added to the interview guides, initiating the analysis after each interview and strengthening the data collection process. This summary section, containing general questions related to the research question, was completed by the researcher immediately after the interview, without respondent involvement. The rationale for incorporating the analytical process into the interview session was to preserve the respondent's narrative and reduce the influence of retrospective constructs. The summary section was the first step toward creating a description of the respondent's account. Then, separately, all interviews were transcribed in the order they were performed, in parallel with the extraction and visualization of notes and comments from the interview sessions using PowerPoint and Excel software. Then NVivo coding was employed, separately for each respondent, to develop initial constructs. The codes used for the first and second rounds focus on nuances of the research question, the first round having a general perspective and the second round a specific intrafirm perspective.

3.5.1 Data analysis, first round of interviews

The analysis of the first round began with initially coding for external knowledge and the AC components recognize value, acquire, assimilate, and exploit; this was followed by additional coding for innovation, biography, and roles. The innovation code identified quotations regarding the type of innovation and, in general, how and where the collaboration knowledge was applied. The biography code identified information about respondent background and the role code was used when indicating an important role or function. In practice, this was done by quoting an extract of the transcribed interview accompanied with a descriptive label (i.e., code), assigned to a main code.

Table 9: Coding table, first round of interviews

Main code	Description	Sub-codes	Mentions
Absorptive capacity	A theoretical code defined as "the firm's ability to identify, assimilate, and exploit knowledge from the environment."[5]	External knowledge	UIC as external knowledge
		Recognize value	Describing or discussing the value of external knowledge
		Acquire	Acquisition of external knowledge
		Assimilate	Internal usage or utilization of external knowledge
			Difficulties associated with external knowledge utilization
		Exploit	Examples of how collaboration knowledge is exploited
Innovation	A theoretical code for product and process innovations following the applied definition.[6]	Innovation type	Types and forms of innovation
		Innovation	General to innovation
Biography	Data regarding key aspects of individuals' life or work experiences, and work-related information.	Background	Professional, practical, knowledge, and educational background
Role	An indication of individuals' roles or functions related to the UIC.	Role	As described

In total, there are four main codes and nine sub-codes (see Table 9, above). The objective of this analytical process was to become familiar with each account and to develop distinguishing stories (Graebner and Eisenhardt, 2004). These codes enabled a process of, first, identifying quotations that describe how the firm approached the collaboration and the knowledge developed through the AC components and, second, comparing the quotations illustrating each code to identify common themes or patterns. Themes that were frequently mentioned by different respondents or included significant information were of particular interest for comparison between the interviews.

[5] Cohen and Levinthal, 1989, p. 569.
[6] OECD/Eurostat, 2018

3.5.2 Data analysis, second round of interviews

The second round of interviews focused on exploring the intrafirm connection between collaboration knowledge and firm innovation by comparing the identified innovations. The data analysis process in the second round was inspired by Eisenhardt's (1989) case study method, including within-case analysis, cross-case pattern identification, hypothesis shaping, and the final comparison of findings with existing literature. In this description of the data analysis in the second round of interviews, the term "case" is used synonymously with the identified innovations. In the second round, the balanced iteration between data collection and analysis, as well as the addition of new collection methods, was performed. This approach is aligned with case study research, which permits the further investigation of emerging themes and features (Eisenhardt, 1989). In the iterative analytical process, respondents were re-interviewed, enabling a more in-depth examination of emerging themes. Incorporating the summary section into the interview guides was the first step in the creation of individual descriptions of each innovation (see example in Figure 4, above, and in the appendix v).

The coding of the transcribed interviews in the second round followed a hierarchical coding structure, presented in Table 10. In the table's left-hand column is the level of the code, with Lvl 1 being directly coded in the transcript and Lvl 4 being an abstract theme derived from the sub-levels. In the second column is the working name, and the last column presents the activity for each level.

Table 10: Analysis coding structure

Level	Name	Activity
Lvl 1	Coding	Assigning raw data essence-capturing and summarizing attributes (Saldaña, 2009); the organization of collected material dependent on relevant abstract features (Locke et al., 2020)
Lvl 2	Sub- and main concept	Collection of codes based on similarities or differences (Rashid et al., 2019)
Lvl 3	Category	Collection of concepts based on similarities or differences (Rashid et al., 2019)
Lvl 4	Theme	

The second round of analysis began by developing initial constructs and constructs for the theoretical concepts: AC, academic engagement, innovation, and collaboration knowledge. Additionally, descriptive coding was performed for action, time, biography, and role. In total, there are seven top-level codes (see Table 11). This within-case analytical process was used to become familiar with each case and to develop case stories (Graebner and Eisenhardt, 2004), allowing the emergence of unique patterns before cross-case pattern comparison.

Table 11: Coding table, second round of interviews

	Main code	Description	Sub-codes	Mentions
Theoretical concepts	Absorptive capacity	A theoretical code defined as "the firm's ability to identify, assimilate, and exploit knowledge from the environment."[7]	External knowledge	UIC as external knowledge
			Recognize value	Describing or discussing the value of external knowledge
			Acquire	Acquisition of external knowledge
			Assimilate	Internal usage or utilization of external knowledge
			Transformation	Difficulties associated with external knowledge utilization
	Academic engagement	A theoretical code defined as "knowledge-related collaboration by academic researchers with non-academic organizations."[8]	Collaboration	Mentions or related mentions of the UIC
			Decision making	That is related to the UIC
			Meetings	Different forms of interactions
	Innovation	A theoretical code for product and process innovations following the applied definition (OECD/Eurostat, 2018).	Firm internal function	Firm internal function for developing innovation
			Innovation type	Types and forms of innovation
			Innovation	General to innovation
	Collaboration knowledge	A theoretical code for the results created through scientific activities at the university.	Collaboration knowledge	When discussing or mentioning the knowledge from UIC
Descriptive	Action	An individual's or group's mental or physical response to a stimulus.	Action	As described
	Time	An indication of time	Time	As described
	Biography	Data regarding key aspects of individuals' life or work experiences, and work-related information.	Background	Professional or practical
			Background knowledge	Education

The first column in Table 11, above, presents the differentiation between the top-level codes for the theoretical concepts (i.e., absorptive capacity, academic engagement, innovation, and collaboration knowledge) and the descriptive codes

[7] Cohen and Levinthal, 1989, p. 569.
[8] Perkmann et al., 2013, p. 424.

(i.e., action, time, biography, and role). The second column presents a description of the code and the third column differentiates between possible sub-codes. The fourth and last column presents mentions to the codes.

Moreover, while case study research allows the participation of multiple investigators (Eisenhardt, 1989), Ph.D. research, for obvious reasons, precludes the full participation of a second investigator throughout the research process. On the other hand, obtaining second opinions from external sources to strengthen the findings is a natural part of the research process. This Ph.D. researcher consulted external industry experts for their perspectives on questions concerning their specific expertise; for example, an industry expert could be consulted to determine whether a general description of a firm's patenting process seems reasonable.

In summary, this research explored the intrafirm connection between collaboration knowledge and firm innovation by comparing the identified innovations, utilizing qualitative data from semi-structured interviews as the primary data, and quantitative data from archival sources as the secondary data.

3.6 Research quality

This section critically evaluates the methodology and quality of the conducted research. This research utilized a single-case design to address the research question, implementing two primarily qualitative interview rounds. The first interview round featured semi-structured interviews, serving as primary data, but also incorporated archival data. The second round was inspired by a case study research approach and compared innovations, with the primary data also obtained from semi-structured interviews. The merits and drawbacks of these approaches are discussed further in the context of validity and reliability, starting with the rationale for the single-case method and the construct validity.

The single-case method was chosen because it allows the in-depth and contextualized exploration of a phenomenon (Eisenhardt, 1989; Yin, 2018), specifically, how collaboration knowledge contributes to the firm's development of innovations within the specific context of the CERC collaboration. The single-case method also allows the application and extension of existing theoretical constructs within the specific context of the case. A construct that is replicated and supported across the data is both more relevant and more valuable; here, this strengthened the relevance of the findings and provided the foundation for the subsequent analysis. To shape hypotheses, the chosen approach combined Humean and neo-Humean views (Parsons, 2007) in the within-case analysis and cross-case pattern search (Eisenhardt, 1989), the former regarding conditions and the latter general regularity. In this context, the term "case" refers to the innovations. The examined cases provide the foundation from which patterns across the cases could emerge. Outlying accounts were revisited and reviewed in contrast to the general pattern. Some obvious issues arise with this method; for example, specific conditions can be overlooked and go unaccounted for in the conclusion. However, there was a limitation of the theoretical and empirical accounts of the role of collaboration knowledge and of the collaborating firm's development of innovations (cf. Jansson et al., 2017; Perkmann et al., 2021; Ramsten and Benner, 2019; Skute et al., 2019). The use of an interview guide, with predefined themes, ensured a structured data-collection process and addressed the possibility of overlooking specific conditions. Moreover, the capacity to detect causal relationships was limited because the primary data sources contained subjective descriptions, resulting in subjective bias. Despite the potential drawbacks, the focus here was to provide accounts that could help illustrate the order of events and the probable causative mechanisms (see "general law" in Parsons, 2007) of a firm's utilization of collaboration knowledge. Consequently, the single-case study, in combination with theoretical expectations, was appropriate to study the main question and increased the construct validity. For the internal validity of findings, data triangulation (Eisenhardt, 1989) plays a crucial role by enhancing robustness and validity. By using multiple data sources—both qualitative and quantitative—and searching for cross-case patterns among the individual innovations, emergent themes and constructs were progressively and iteratively triangulated. In this way, reasonable and rational premises were developed that could help in exploring *how* and *why* constructs are connected. This research and its single-case method constrained the external validity of the findings, i.e., their applicability to other cases or contexts. The aim of this research was to understand how collaboration knowledge was used by a collaborating firm to develop innovations, not to provide findings applicable to all collaborations. However, the findings have implications for the theoretical framework in the context of a university–industry collaboration. These implications need to be verified or rejected by future research. For academic research, the importance of validity and reliability cannot be overstated.

Turning now to the evaluation of research quality, validity and reliability serve as indicators of the appropriateness of the chosen research design and methods, and of the credibility of the findings (Bryman and Bell, 2011). In the context of this dissertation, which seeks to investigate how a collaborating firm utilized collaboration knowledge internally to develop innovations, reliability and validity had to be ensured. This was to bolster the value of the findings' implications for both academic understandings and possible practical applications in firm innovation. To this end, several measures were implemented to ensure the validity and reliability of the research; let us begin by considering validity.

The primary research adopted a qualitative approach, and to ensure the validity of this approach, a structured process was followed. The chosen case, CERC, has significant theoretical value as a representation of the research question and was therefore chosen as a theoretical sample (Eisenhardt, 2021, 1989). The data analysis followed an iterative process employing data triangulation (Eisenhardt, 2021, 1989; Yin, 2018). The emergent findings were scrutinized against prior theoretical constructs, and critical feedback was obtained from supervisors, colleagues, and industry experts (Eisenhardt, 1989; Longino, 1992). The monograph structure employed allows for an in-depth elaboration of the empirical context and the collaboration background (discussed in chapter 4), which is essential in assessing the validity and credibility of the findings (Tracy, 2010).

In the present research, the reliability of the analysis was ensured through use of a rigorous protocol and transparent data collection and analysis, as previously discussed (Goffin et al., 2019), to ensure consistency in the approach. Consistency is a key element of reliability, as it allows for the potential reproduction of the study under similar conditions. Replication in the research process is important, and constructs that are replicated and supported across data are more relevant and valuable, enhancing the reliability of the findings. This has been achieved through an incremental process that gradually expanded and replicated the logic across the cases (Yin, 1984). Furthermore, the research's iterative analysis, alongside data collection and re-interviewing the participants for the in-depth examination of emerging themes, contributed to the reliability of this research. This iterative process enabled consistency checking of the data, refining the theory through constant comparison with the data (Glaser and Strauss, 1967).

Studying past events through interviews can be challenging, largely due to recall bias, or the difficulty respondents face in accurately remembering past events. This issue highlights the necessity of achieving data saturation (Eisenhardt, 1989) and collecting data from multiple sources. In this research, this concern was addressed through cumulative data collection and by including additional respondents until the interviewees' responses converged and started to replicate each other. The interviews focused on individual actions and their rationales, which facilitated the identification of repetitive actions and enabled their comparison between the cases. This approach helped to elucidate how knowledge derived from the collaboration was implemented.

Although recall bias presents challenges, it was also advantageous for this research, as the consistency of similar events and experiences reported across the identified innovations supported the credibility of the research. This rationale derives from the availability heuristic and the ease of recalling subjectively defined relevant instances (Bottom, 2004; Tversky and Kahneman, 1973).

To summarize, the single-case method was chosen due to its capacity for in-depth and contextualized exploration of a given phenomenon. To ensure validity, a theoretically valuable case was used for the research question. The data analysis followed an iterative process and incorporated data triangulation. The reliability of the analysis was ensured through a rigorous protocol and transparent data collection, coupled with consistency in approach and the replication of findings across the data. Considering the issue of studying past events, the necessity of data saturation and multiple data sources to mitigate recall bias is underlined.

3.7 Ethical considerations

This research adheres to the Swedish Research Council's guidelines to ensure ethical conduct. These guidelines describe how research in Sweden should be conducted to avoid ethical problems (Vetenskapsrådet, 2017). Accordingly, respondents were informed of their rights to anonymity, voluntary participation, and to end the interview at any time or to decline to answer certain questions. The respondents were informed that the interviews were going to be recorded; one of the respondents declined to be recorded. As previously stated, the patents identified for the second round of the investigation were parsed and identifying data were deleted to maintain respondent anonymity; the patents were accordingly anonymized using pseudonyms. The data from the public annual reports were also parsed for identifying indicators. Storage of the collected data followed the regulations set forth in the General Data Protection Regulation (GDPR) (Radley-Gardner et al., 2016).

3.8 Method summary

This research employed a single-case study approach, incorporating qualitative and quantitative data, to explore how collaboration knowledge results in firm innovations, as the single-case study allowed the integration and extension of existing theory. The research question was addressed by implementing two primarily qualitative rounds of interviews to probe the identified research question. This single-case study utilized both qualitative and quantitative data, with the former being the primary and the latter the secondary data. The primary data were semi-structured interviews, and in total 37 interviews were conducted with 27 respondents. The secondary data were archival data from CERC annual reports (1996–2017) and corresponding scientific publications, identified patents, and VCC press releases; in addition, data were also gathered from field participation. The ideal case should meet four criteria, involving a firm, a technological university, a knowledge-related collaboration, and an innovation. The CoE is a key instrument to foster university–industry collaboration, because its rationale is to perform industry-relevant research of high scientific quality, generating innovations in the participating companies (Stern et al., 2013). Hence, the CERC collaboration, as a CoE, presented significant theoretical value as a representation of the research question, and was chosen. CERC's long-term partner VCC was ideal for obtaining the firm's perspective due to its consistent involvement in CERC. The first round investigated important roles by conducting semi-structured interviews with individuals engaged in the UIC and by incorporating archival data and field participation. The second round conducted semi-structured interviews with the inventors of the identified innovations, owned by VCC; furthermore, it followed a case study research approach, comparing innovations as individual cases and incorporating archival data. The cases in the second interview round were innovations conceptualized as patents, linked to CERC knowledge through a multi-step process involving interview data analysis, matching knowledge areas and keywords, and comparing publication and patent dates. The identified patents were considered reasonable cases for study, as they displayed similarities in descriptions, relevant individual connections, and knowledge areas linked to CERC knowledge. The data analysis for the first interview round integrated analysis into the interview process by adding post-interview summary sections to the interview guide. The interviews were then transcribed and visualized, and NVivo coding was used to detect common themes or patterns across narratives. The data analysis in the second interview round followed the case study approach, involving the iterative process of data collection and analysis, utilizing within-case analysis, cross-case pattern detection, hypothesis shaping, and comparison with existing literature. Through this summarized process, the validity and reliability of the research were ensured. The research followed the Swedish Research Council's guidelines, ensuring ethical conduct by informing respondents of their rights, maintaining anonymity, and adhering to GDPR regulations for data storage. Following this discussion and clarification of the methodological choices for the thesis, the next chapter of this dissertation is the first of the chapters presenting results.

4 Developing a center of excellence and facilitating collaboration knowledge for firm innovation development

This chapter provides context for the interviewed respondents by outlining the background of the university–industry collaboration and the CoE. This context is essential for comprehending the findings of the two interview rounds. It enables the identification of important actors and knowledge areas relevant to the implementation of collaboration knowledge. The chapter has the following structure: section 4.1 encompasses a presentation of the university–industry collaboration (section 4.1.1) and the specific Combustion Engine Research Center (section 4.1.2) as the case. Section 4.1.3 expands on Chalmers University of Technology as the collaborating university, while section 4.1.4 presents an overview of the collaborating firms. Then section 4.1.5 focuses on VCC as the collaborating case firm. Section 4.1.6 presents a historical description of the CoE. Section 4.2 focuses on the first round of interviews: section 4.2.1 initially assesses the extent to which knowledge originating from the collaboration was integrated into firm innovations; section 4.2.2 explores the dynamics of the collaboration and focuses on the project meetings; section 4.2.3 examines the engagement of industrial representatives in the project meetings; section 4.2.4 summarizes the results and visualizes them in relation to the theoretical framework; section 4.3 then analyzes the dynamics of the influential firm roles; and, lastly, section 4.4 presents the conclusions.

4.1 The case: an overview and the advantages of centers of excellence

To identify a relevant case for the research, the research question and the theoretical orientation provided specifying requirements for the case. These criteria are defined in chapter 0, "Method." A case that fulfills these criteria is a type of publicly funded center involving both academic and industrial actors, namely, the center of excellence (CoE); the following section is a brief historical account of the CoE in the Swedish context.

Research funding councils emerged in the early 20th century as a key policy instrument to strengthen research and innovation in response to the demands imposed by societal complexity and industrialization. Therefore, new state interventions were implemented in areas such as industry, health, and higher education (Stampfer, 2019). Major industrialized countries created a variety of interventions to both strengthen research and incorporate its outcomes into the policy portfolio. One policy instrument was the research funding council, an agency funding various forms of interventions. In 1940, the Swedish government convened a commission led by Gösta Malm to investigate how Swedish engineering could be strengthened. By 1942, the Malm Commission had analyzed the future of Swedish higher education and proposed organizations to support technological change. The most important institutional development was the creation of the Technical Research Council,[9] which was Sweden's first research council (OECD, 2013). Stampfer's (2019) review of the literature on university research funding mechanisms and their impact states that the Malm Commission made a clear decision to "position its universities as the dominant providers of scientific and other research-based knowledge and therefore early on implemented a two-track [research funding council] system" (p. 52). The link between science and its application, through institutions focusing on applied

[9] The Swedish original of this is Statens Tekniska Forskningsråd (Arnold et al., 2008, p. 24).

research and industrial development, was a key finding of the Commission (OECD, 2016). Since the inauguration of the Technical Research Council, different forms of interventions, financial instruments, and additional providing agencies have existed. Stampfer (2019) identified five general types of external funding: (i) individual smaller projects, (ii) investigator projects/large person-centered grants, (iii) strategic and mission-oriented programs, (iv) complex multi-actor programs, and (v) CoEs (2019). Of these various types of external funding, the CoE has emerged as a significant and internationally recognized form.

4.1.1 Swedish centers of excellence as a source of knowledge

In the Swedish innovation system, the center of excellence (CoE) has emerged as a key instrument to foster collaboration between higher education institutions and industrial partners. These centers, popularized in the early 1990s with NUTEK's establishment of the "Center Program," can receive funding from various sources including the Swedish Research Council,[10] Formas,[11] Forte,[12] Vinnova,[13] and the Swedish Energy Agency[14] (Stern et al., 2013). The overall goal of the Center Program was to create a shift in the research and innovation cooperation culture of the Swedish innovation system. The Center Program started out with six goals: performing industrially relevant research; producing high-quality scientific output; developing scientifically qualified human capital with skills in industrially relevant areas; encouraging the development of interdisciplinary critical mass within academia in areas of industrial relevance; changing research culture; and producing

[10] The Swedish Research Council is a government agency within the Ministry of Education and Research that funds research and research infrastructure in all scientific disciplines ("Swedish Research Council—About us," 2020).

[11] Formas describes its work on its website as follows: "Formas is a government research council for sustainable development. … Our areas of activity include the environment, agricultural sciences and spatial planning" (Formas, 2020).

[12] Fortes describes itself and its mission as follows: "Forte is the Swedish Research Council for Health, Working Life and Welfare, [and] is a government agency under the Swedish Ministry of Health and Social Affairs. We promote and support basic and needs-driven research within the areas of health, working life and welfare" (Forsberg, 2019).

[13] Vinnova's objective is to build the nation's innovation capacity, with the vision that "Sweden is an innovative force in a sustainable world" ("Vinnova—About us," 2020).

[14] The Swedish Energy Agency is subordinate to the Ministry of Infrastructure and funds "research on new and renewable energy technologies, smart grids, as well as vehicles and transport fuels of the future" (The Swedish Energy Agency, 2020).

innovations in the participating companies (Stern et al., 2013). Here, three goals are of specific interest: performing industrially relevant research; producing high-quality scientific output; and producing innovations in the participating companies (Stern et al., 2013). These goals indicate that the aim of the CoE is aligned with the named requirements of the population named in chapter 0, “Method”. Moreover, a CoE is a type of research and innovation funding instrument. It is often located at a university campus and involves a consortium of companies that collaborate with more than one academic department in R&D (Stern et al., 2013). In 1995 there were 28 CoEs distributed among eight Swedish universities, six of which were at Chalmers University of Technology in Gothenburg. The Combustion Engine Research Center (CERC) was one of these (Stern et al., 2013). Upon its establishment, Vinnova assumed responsibility for 23 of these CoEs, while the Swedish Energy Agency took responsibility for the remaining ones when they were founded (Stern et al., 2013).

The selection of a Swedish CoE for this research was guided by the critical factors of longitudinal relationships, knowledge utilization, research quality, and geographical location. To choose from the many such centers in Sweden, the longitudinal aspect (as measured in years) of the relationship was critical, in an attempt to optimize the probability of firm-developed innovations based on collaboratively developed knowledge. A CoE is one form of organization that ensures the long-term provision of knowledge through a temporary organization (McKelvey et al., 2021).

The longitudinal aspect was further of importance because the long-term engagement and communication encouraged in collaborations facilitate the utilization of tacit knowledge that is engrained in organizational culture or in individuals (cf. Hermansson et al., 2016; Powell and Grodal, 2006). The quality and aim of the research in the CoE should have industrial impact to ensure that the collaboration knowledge is utilized by the firms. Additionally, the geographical location and accessibility of the CoE can improve the participating firms' access to the collaboration knowledge produced. The same two reasons also affect the possibility of gathering information about how the collaborating firms integrate knowledge derived from the collaboration into the development of innovations. The single case selected for this research, i.e., CERC, located at Chalmers University of Technology in Gothenburg, meets all these criteria and is described in the next section.

4.1.2 The Combustion Engine Research Center: the university–industry collaboration

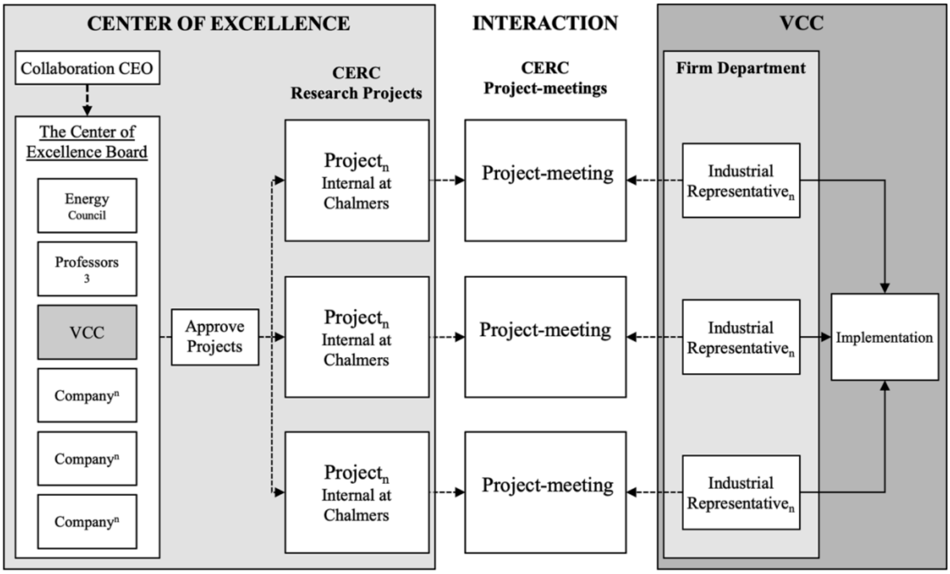
The Combustion Engine Research Center was a CoE emphasizing long-term industry collaboration founded on 1 November 1995 as a three-party agreement between Chalmers University of Technology (Chalmers) in Gothenburg, the Swedish Board for Technical and Industrial Development (NUTEK), and a group of five Swedish industrial companies. It was founded to be a forum for industrial and academic research on internal combustion engines. CERC's goal was to create an interdisciplinary research pool for combustion engine advances, enabling companies to actively participate and derive benefits over time (Karlström, 1997). The Center's fundamental purpose was to build "a concentrated interdisciplinary research pool in which the participating companies can actively take part and benefit from," and its first annual report stated that the long-term objective was to address "fundamental research of high industrial interest" focusing on engines and to "transfer knowledge between the academic community and the industrial members" (Karlström, 1997, p. 2). The report further stated that "strategically important research" would be performed by scientists, focusing on both applied and basic topics (Karlström, 1997). This mirrors the Center Program's fundamental purpose to facilitate industry-relevant research of high scientific quality, generating innovations in the participating companies (Stern et al., 2013).

CERC's focus on basic and transdisciplinary research with industrial relevance has remained consistent over the years. The 1997 report's summary section specifies two aims on which the Center should concentrate, namely "reduction of fuel consumption and engine emissions" (Stern et al., 2013, p. 4). Twenty years later, the 2017 report stresses that the emissions from transportation and greenhouse gases are still a major problem, described as "widely recognized as major challenges facing modern society," and states that there is an "urgent need for more efficient vehicle propulsion systems" (Denbratt, 2018, p. 4). This indicates that from 1995 to 2017, CERC consistently focused on reducing emissions from propulsion systems and addressing related problems. Hence, the problem at hand is the reduction of emissions, which is important for understanding the results and analysis in the subsequent chapter. In 1997, NUTEK's governmental coordination responsibilities were transferred to the Swedish National Energy Administration, which later changed its name to the Swedish Energy Agency[15]. In CERC's annual reports, both "competence center" and "center of excellence" are used with reference to the Center (Denbratt, 2018). In the first half of 2022, CERC ceased operation because the Swedish Energy Agency decided to stop funding it (Johansson, 2022). Ending in 2022, the Center lasted for over 27 years and the outcome of its interdisciplinary and fundamental research of industry relevance was 711 publications. This dissertation concerns the 1995–2017 period.

The organizational structure of the CERC collaboration played a crucial role in facilitating collaboration between researchers and industry partners. To uphold the research quality and ensure the fulfillment of long-term objectives, the collaboration was overseen by a board comprising a board chair as well as members from the university and the five industrial partners. is a conceptual illustration of the collaboration setup.

15 The shift of governmental coordination responsibility from NUTEK to the later created Swedish Energy Agency might explain why both "competence center" and "excellence center" are used for CERC, because of the Swedish Energy Agency's general use of the former and Vinnova's use of the latter.

Figure 5: Collaboration setup

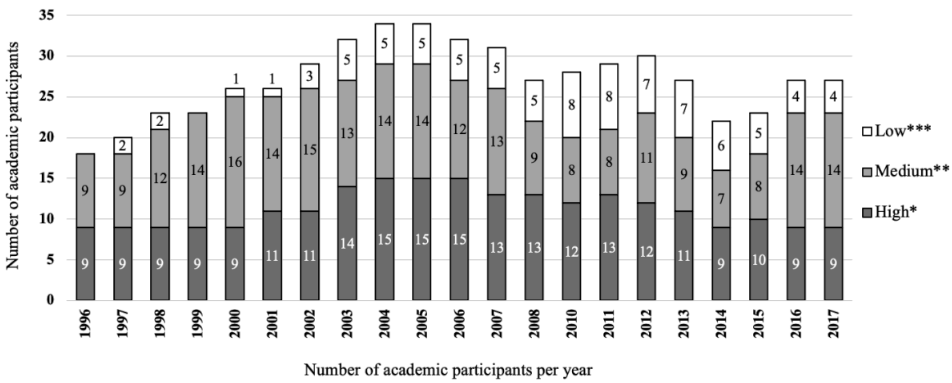


On the left-hand side of is the CERC CoE in the light grey box. Within this box is the CEO of the collaboration on the left side and below that is the board of the Center. The board represents the participating parties: companies, the university, and the Energy Council. The board approves the different research projects that the university will implement, as indicated by the small box in the middle of the light grey box. The approved projects, on the right-hand side within the light grey box, involve various research teams focusing on distinct objectives. The results of the research projects are published in the CERC annual reports. During the year, industrial representatives of the firm have regular meetings with the research project groups. The boxes labeled “Project meeting” between the two larger grey boxes and under the heading “Interaction” indicate these. In the project meetings, the university researchers present, to the representatives, their new research findings and progress since the last regular meeting. The representatives can discuss the results with the university researchers and provide feedback to the project. On the right-hand side of the figure is a dark grey box representing the collaborating firm, VCC. Within this box is the firm department to which the industrial representatives belong, indicated by the light grey box within the dark grey VCC box. In general, this department focuses on advanced engineering, including R&D. The next section describes the problem on which CERC focused.

4.1.3 Chalmers University of Technology: the collaborating university

Chalmers University of Technology, the university in the collaboration, has a rich history of academic excellence and interdisciplinary research, which has contributed to CERC's research. Chalmers was founded over 150 years ago, became a university in 1937, and has awarded Ph.D. degrees since 1940. Chalmers' personnel have so far conducted research on technology and natural science, among other areas. Different university departments participated in the CERC collaboration after its inception (in total 16 participating departments), creating an interdisciplinary research pool. However, these departments may not be distinct entities, as changes in the university's organizational structure have led to alterations in department names. From the university, over 70 individuals have participated in the collaboration. They have been assistant professors, engineers, industrial doctoral students, master's students, professors, project students, research engineers, researchers, senior engineers, senior lecturers, senior researchers, senior scientists, technicians, visiting professors, and visiting researchers. These participants are categorized into three groups in Figure 6.

Figure 6: Number of academics participating in CERC between 1996 to 2017 in three categories



*	Higher level of education: Adjunct Professor, Assistant Professor, Associate Professor, Professor, Professor Director, Professor Emeritus, and Visiting Professor.
**	Medium level of education: Industrial Ph.D. Student, Ph.D., Ph.D. Applied, Ph.D. Student, Researcher, Senior Lecturer, Senior Researcher, Senior Scientist, and Visiting Researcher.
***	Lower level of education: Engineer Lic., Engineer M.Sc., Project Student, Research Engineer, Senior Engineer, and Technician.

To provide an overview of the university's involvement in the collaboration, Figure 6 shows the number of participants per year from Chalmers between 1996 and 2017. The *y*-axis represents the number of participants, while the *x*-axis indicates the years. There are three color-coded categories: dark grey, white, and light grey. The dark grey represents the academics with higher education, i.e., with "professor" in their title. The white represents those with a medium level of education, i.e., either researchers or those with Ph.D. in their title. The light grey represents those with a lower level of education, i.e., those with M.Sc., engineer, or technician in their title. The figure shows that, over time, the collaboration has included more individuals from the lower-educated category. The data were collected from the CERC annual reports, except for 2009: the 2009 report could not be found either by CERC personnel or online, so this year is excluded. The data also exclude the director of the collaboration and the administrative personnel.

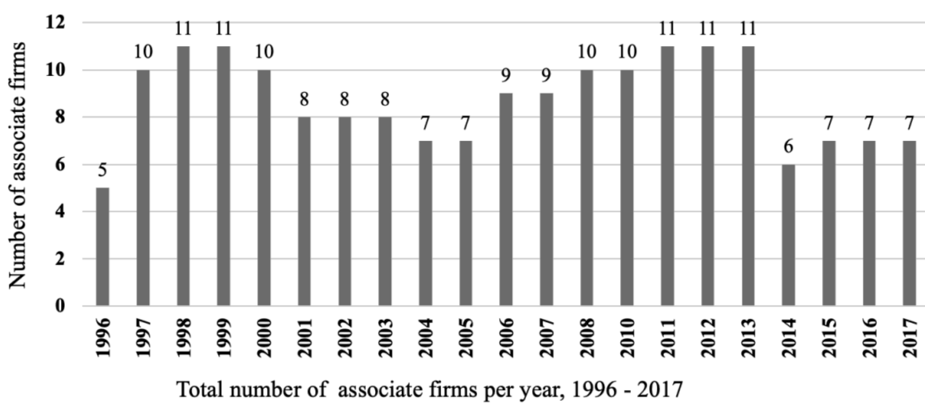
4.1.4 An overview of collaborating firms between 1995 and 2017

Between 1995 and 2017 numerous firms participated in the CERC collaboration, the shared interest being the need for the academic research performed in the collaboration. For example, the CERC annual report from 2002 states some general challenging aspects identified during an industry conference earlier that same year. These challenges concern how industry can decrease its effect on the climate. The following passage is from the report:

> Fulfilling legislation and global environmental issues such as CO2 will require major research into … concepts and … processes. The required changes for … industry will be the guidelines for the future research projects at [CERC]. (Annual report, 2002)

The above quotation underlines the associated firms' valuation of the academic research that the collaboration performed. Figure 7 shows the number of firms associated with the collaboration.

Figure 7: Number of associated participants in the collaboration



An associated firm is a firm contributing resources to the collaboration. These resources can be monetary, technical (e.g., tools or machinery), consulting, or personnel (e.g., industrial doctoral students). In the annual reports, the "in-kind" contributions are converted into their monetary value. Figure 8 shows the total in-kind contributions of the associated firms per year between 1996 and 2017.

Figure 8: In-kind contributions of associated firms between 1996 and 2017

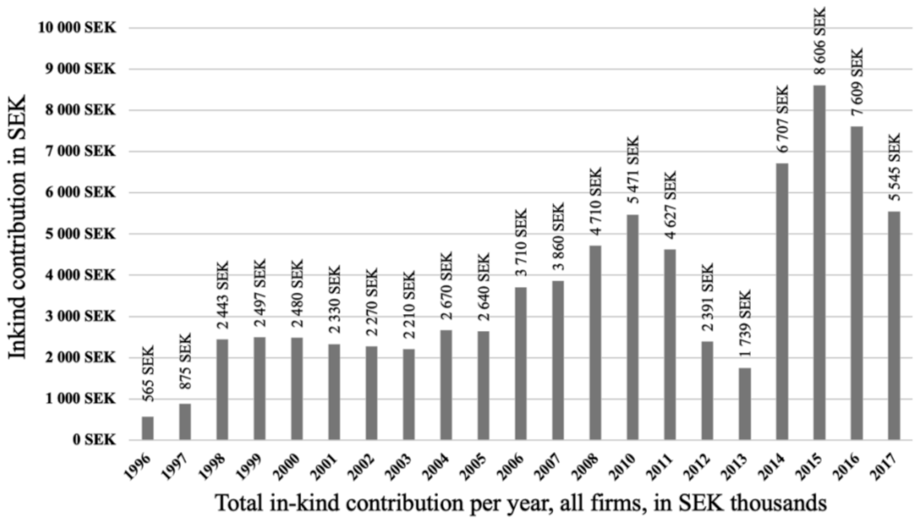


Figure 8 shows that the in-kind contributions changed over the period, having their lowest monetary value in 1996 and their highest in 2015. In-kind contributions for 2012 and 2013 diverged from an increasing pattern because three associated firms could not continue in the collaboration because of emergent circumstances.

Over time, the number of participating Swedish industrial firms has fluctuated, with three companies emerging as long-term partners of and contributors to CERC. Throughout the 1995–2022 period, VCC, Scania CV AB, and Volvo Group Truck Technologies AB have remained consistent full-member partners of CERC, making them ideal companies for studying how the collaborating firms utilized the collaboration knowledge for innovation development. Studying how the collaborating firms utilize the collaboration knowledge presupposes the participation of committed firms, because extended participation is critical for facilitating knowledge usage. Of the firms, VCC has been specifically addressed because its headquarters and a significant portion of its R&D activities are located in Gothenburg, Sweden. The presence of a local R&D organization is important for innovation development (i.e., product or process development), as evident from its central role in the AC literature (e.g., Lane et al., 2006). In the present research, VCC employed individuals who has engaged in CERC can account for how this collaboration knowledge contributed to the firm's innovation development, and will therefore be the objects of later cross-comparison.

4.1.5 Volvo Car Corporation: the specific collaborating firm

Volvo Car Corporation (VCC) is a well-recognized international company in the automotive industry. VCC controls the design, development, manufacturing, sales, distribution, and aftermarket service of the vehicles it produces. The firm has been credited with successfully branding itself and is known for its commitment to incorporating advanced technology in its products. VCC is regarded as an attractive employer and an innovative firm. Several innovations have been developed to facilitate and improve the user experience and demonstrate the company's dedication to continuous improvement. For example, VCC is behind innovations such as the three-point safety belt (1959), the rearward-facing child seat (1972), the whiplash protection system (1998), the blind spot information system (2003), and oncoming threat mitigation by braking (2018) ("Safety innovations," 2023-05-04). Its vehicles contain numerous high-tech components and are used in everyday life worldwide. Since VCC's foundation in the 20th century, additional products and services have been developed by the firm. VCC's vehicles are sold to different customer segments. VCC maintained a consistent presence in the collaboration between 1996 and 2022. During this period, the firm was a full member of the collaboration with defined responsibilities and access to the academic research results, as defined in the annual reports. Focusing on the 1996–2017 period, VCC was also part of the board governing the CERC collaboration. The board consisted of voting members representing the academic community and industry, plus the board chair. VCC has production sites in Europe, Asia, North America, and several locations in southern Sweden. Figure 9 shows VCCs in-kind contributions between 1996 and 2017.

Figure 9: VCC's in-kind contributions

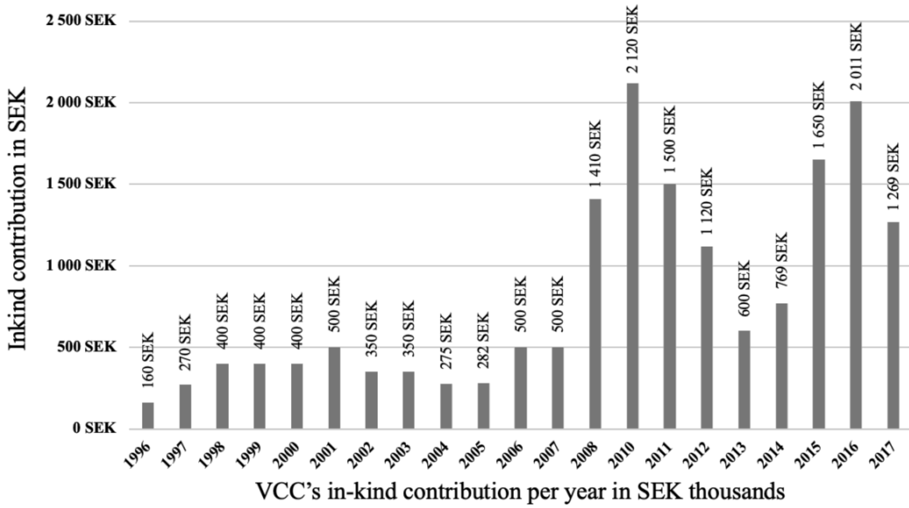


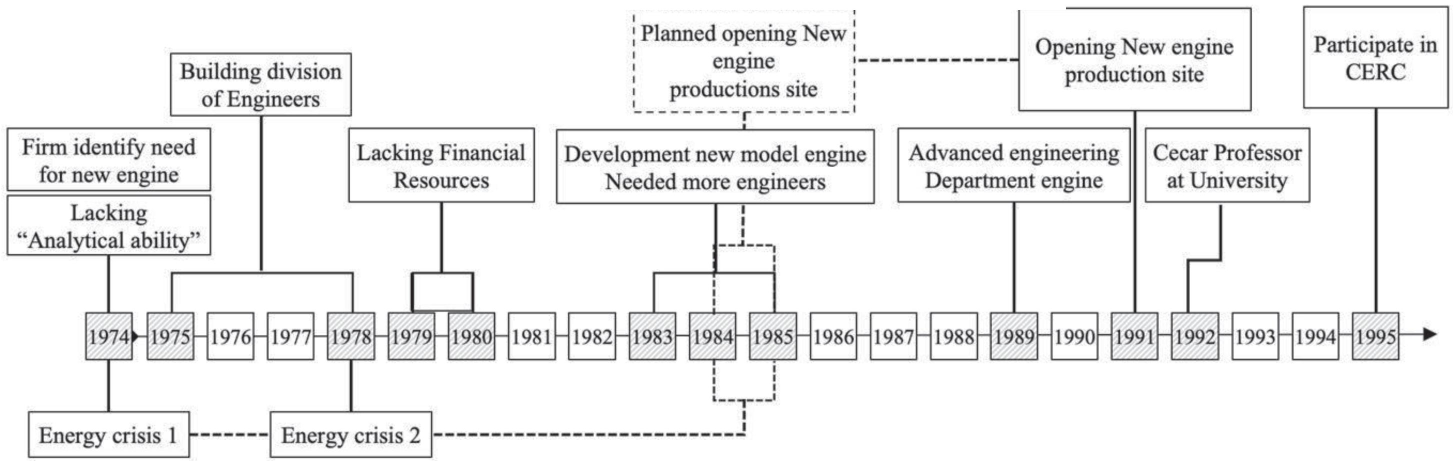
Figure 9 shows that VCC's contributions have been continual over the period. In 2008 the firm decided to increase its contributions, and the 2013 and 2014 contributions were influenced by the 2008 financial crisis. The increase in VCC's in-kind contributions to the collaboration signals that VCC perceived the collaboration as valuable. This is evidenced by VCC's continued participation over time and increase in in-kind contributions. This perceived value was supported by the respondents; for example, Cecar stated: "I think if you had no use for the results, you would not have been interested in investing time or money in this" (Cecar, 2020-07-29, own translation). Given VCC's specific role in the creation of CERC as a UIC, the historical background and rationale of the firm's participation it examined next.

4.1.6 A historical description of the collaboration

Two key individuals, Olle and Cecar, with notable expertise and relationships within both the firm and the university, played significant roles in the collaboration.

To understand the rationale behind the initiative to collaborate with the university, several respondents emphasized the role of these two individuals in the decision-making process. The first individual, Olle, had long-term experience of working at the firm in a managing position and had two degrees from the higher education system. Other respondents described Olle’s role in both the firm and the firm’s decision to participate in the collaboration as very influential. For instance, Martin characterized Olle as “knowledgeable” and “very competent.” Olle had extensive experience and influence within the firm, particularly in engine development, which was the focus of the CERC collaboration. The second individual, Cecar, was identified by all respondents as an influential individual in the collaboration. Cecar also had a degree from the higher education system. In the early 1990s, Cecar worked for Olle at VCC and later Cecar became a professor at Chalmers. Although the firm’s decision to participate in the UIC cannot be attributed solely to Olle and Cecar, their contributions were crucial in shaping the collaboration. Before moving on, Figure 10 presents a timeline of engine development showing the progression from 1974 to 1995, followed by a historical description of influential events that culminated in the UIC.

Figure 10: Timeline of engine development leading to CERC collaboration



Between 1974 and 1995, external factors and the firm's internal developments significantly influenced the evolution of the engine department. The timeline consists of white and grey boxes, with the grey boxes representing the years when important developments occurred in the engine department. Above the timeline are the explanations of these years, all connected to the firm. Below the timeline are the two mentioned circumstances that drove the firm's engine development: first was the 1974 energy crisis, which led to the firm's decision to build a lighter engine; second were stricter legislative demands that increased the urgency of engine development.

Olle was headhunted to VCC by the director of engine development and became a manager of a subgroup within the same division. In the mid-1970s, Olle was promoted to be the new director of engine development. Because of the energy crises in 1974 and 1978, VCC had identified a need for a new generation of engines, made of a new lighter material, and estimated that a new production site for these engines could begin operation in the early 1980s. The decision to change the engine material put more requirements on the development team of the engine division. During this period, local legislation in various markets where VCC operated imposed restrictions on the engine's environmental impact. As a director of engine development and its new generation, Olle compiled an inventory of the employees to map available competence, concluding that the firm lacked the "analytical ability" to meet the technical demands of creating the new engine. In the interview, Olle said that one employee had the required engineering background at the time; however, this employee left the firm to move closer to home. As a result, in 1975, the firm entrusted Olle with the task of creating a new division of engineers, which later evolved into the advanced Engine Engineering Division in 1989.

Despite facing financial difficulties in the late 1970s, VCC was able to recover and continue its engine development in the 1980s, thanks to currency fluctuations and a revived product line. At the end of the 1970s, VCC had financial problems and postponed the development of the new production site. With the American dollar's increase in value and the relaunch of an old product, the firm regained market share in the mid-1980s. In the same period, the forces of the previous energy crises had changed, and the firm now had the financial resources to develop new engine models. The previously postponed production site was now estimated to be ready at the beginning of the 1990s. Olle's division, and Cecar, worked on the expansion and on evaluating new techniques for the new engine, but it was difficult to find and recruit engineers. Olle described this period as follows:

> Everything had actually changed in five years, from the feeling of being almost outnumbered and that we could not access any financial resources. We had so much money, so the problem was to find and hire engineers to do the expansion we wanted to do [in engines] … So at that time, the firm even started to look outside the company to buy a competitor. (Olle, 2019-03-12, own translation)

This quotation highlights an issue that pervaded all interviews, namely, the challenge of finding suitably educated employees. Olle said that this was an early observation, and noted that the employee inventory had identified only one engineer. Even though there were no financial constraints at the firm, it was still difficult to locate and attract educated personnel. In the interview, Olle described how the firm resolved the issue with a mix of buying consultancies and hiring employees.

In the early 1990s, VCC decided to open its new production site and to produce all models of the engine in house, driven by the need for innovation and market expansion. Previously VCC had bought some engine models from competitors, which Olle described thus: "It's never good, to buy something. Then you always get relatively old technology at a high price" (Olle, 2019-03-12). The new production site was originally planned to open in 1984–1985, because the 1974 and 1978 energy crises had made the old engine outdated. The in-house production was intended to introduce different versions of engine that could be produced at the site, to expand VCC's position in existing markets. The market expansion was hindered by local regulatory concerns, which put high constraints on the engine. In response to these demands, VCC had to ensure that its vehicles met environmental requirements to maintain sales in the regulated markets.

During the early 1990s, the firm's central R&D unit functioned separately from the engine division, but collaborated with it through a reference group. The engine division was connected to the R&D unit through inclusion in a reference group. The R&D unit worked on problems and projects that were not directly related to the products of the firm, although their knowledge could be useful. The engine division used both the R&D unit's projects and its employee competences in their projects. Furthermore, the engine division started to outsource the evaluation of different techniques to the R&D unit.

The increasing demand for engine research and appropriately educated individuals, driven by environmental legislation, strengthened the relationship between the university and VCC. The combination of the new series of engines, the engine development, and environmental legislation was described as a "devilish combination" that no one knew how to resolve. The only way was to build in-house knowledge competence in areas related to engines. Educated individuals with the right competence could be recruited from the university. Olle described this situation:

> To my understanding, there were forces within the university that argued that engine technology research was too applied. In their eyes, it could be canceled, and investments could be made elsewhere. … the industry pushed them, they [i.e., the industry] had a high demand for professors of engine technology research, because it was here that one

> [i.e., the industry] recruited the powers that drove the real engine development. (Olle, 2019-03-12, own translation)

There was a stronger demand for educated individuals within the industry in general, and this demand was attributed to the environmental legislation that affected technologies such as the combustion engine. VCC had educated employees, but not enough of them. The Swedish government also acknowledged the industrial need for engine research. Consequently, the government was interested in partly financing collaboration between university and industry. VCC also wanted the collaborating university to be local, based on the assumption that graduates were more likely to remain in the city where they had completed their education. As the 1980s transitioned into the 1990s, an opening at Chalmers University provided an opportunity.

During the decadal transition, a series of events involving key individuals at Chalmers University and VCC were influential for the establishment of the collaboration. In the late 1980s, the departure from Chalmers of a professor whose research was connected to engines created a vacancy. This departure left a "vacuum" and the position remained unfilled until early 1990. VCC encouraged Olle to apply for the vacant position. Although Olle's application was denied in early 1990, his employee Cecar later applied for a similar position and was accepted. Olle stated:

> When he left, it created a vacuum. At the university there were those who were of the opinion that this practical function should be shut down, so can we put the resources into other areas. I do not want to point out who said that, even if I could. So, the university searched for a new professor. I was also encouraged by the firm to apply for that professorship, and I applied. It must have been 1992, 1993, some time, that I sent in my papers, and the most incredible thing was that I was declared incompetent. … Instead, they [i.e., the university] got a very

> talented theorist whose name is [Prof. T]. … At that time, [person X] came in, who came from us, and that was a very good balance, because [Prof. T] was not so close to the product, for obvious reasons. But very skilled in theory, chemical reactions—and those things he built up, started a very good function. And so came [Cecar], who had worked a lot with engines and who also was a very skilled mathematician, and started important work at the university. (Olle, 2019-03-12, own translation)

Cecar’s experience in the engine division and his involvement in identifying new technical requirements for the new engine made him a leading figure in the creation of the collaboration. All interviewed respondents acknowledged Cecar as an influential individual in the ongoing collaborative work and research. Cecar worked in the engine division, where he was involved in identifying the new technical requirements for the engine to be produced at the new production site that opened in the early 1990s. Between 1984 and 1992, Cecar had a role in the team that developed the technical specifications for the new engine. This combination of technical expertise and industry experience positioned Cecar to bridge the gap between Chalmers and VCC.

The driving forces behind the collaboration can be attributed to both Chalmers University’s goals and the involvement of key individuals such as Cecar, as evidenced by differing perspectives among respondents. Viktor, the first respondent, also named Cecar but argued that Chalmers University was the driving partner initiating the collaboration. Chalmers wanted to build knowledge in the engine area comparable to that of another Swedish university geographically distant from VCC. Viktor suggested that Chalmers might have wanted access to industry money and also noted that VCC, at the time, had other collaborations with Chalmers. In the 1994–1995 period, VCC decided to participate in a collaboration with the university and with other industrial partners.

In summary, the period between 1975 and 1995 saw growing legislative demands regarding engine technology as well as the need to satisfy customer expectations, illuminating the necessity for further knowledge in specific research areas and for a skilled workforce. The source of educated individuals was identified to be the university. In the late 1980s, a position in a research area connected to engines became vacant at Chalmers; this position was awarded to Prof. T and, in the same period, Cecar was appointed to a different professorship at Chalmers. In 1995, Cecar and Prof. T were involved in the start of the CERC collaboration, and VCC decided to join in the same year. Having focused on the history of the CERC collaboration and VCC's participation, the following briefly describes why VCC eventually decided to leave the collaboration.

In the spring of 2019, CERC organized its annual conference, which featured presentations of research from the previous year. Attending the conference were both Olle and Zäta. During the conference, it was announced that VCC would exit from the collaboration, with 2019 as the last year. According to Zäta and Olle, VCC decided to cancel its participation because the firm's educated decision was that meeting the demands of increasingly stringent regulations would require a shift in technology focus. VCC had opted to pursue a different technology based on the knowledge it had gained about engine technology, in part through the CERC partnership. While it was declared that 2019 would be the last year of VCC participation, the CERC annual reports for 2020 and 2021 still addressed VCC as a member of the Center. It can thus be assumed that VCC announced that it had decided to leave CERC in 2019, a decision that only became effective at the end of 2021. The year 2021 was also the final year of CERC, because the Swedish Energy Agency decided to withdraw its funding of the center, with the justification that the area of research was mature (Johansson, 2022).

With the history of the collaboration and the rationale behind VCC's initiative to collaborate with the university having been described, the next section addresses the results of the first round of interviews.

4.2 First round of interviews: identified firm roles

The primary aim of this section is to present the results of the first round of interviews in relation to the research question, followed by analysis of these findings and the presentation of conclusions. To investigate the research question, the results presented here concentrate on the initially identified firm innovations, the collaboration approach, and the individuals and identified roles that influenced the firm's utilization of collaboration knowledge in developing innovations. A comprehensive understanding of these influential roles requires the exploration and examination of their interconnections. We now turn to the first section, examining innovations linked to knowledge from the collaboration.

4.2.1 Firm innovations from collaboration knowledge

First, we will assess the extent to which VCC integrated knowledge from the university–industry collaboration into its innovations since 1995, as a measure of its absorptive capacity. The firm participated in the CERC collaboration from 1995, so a natural question is whether knowledge from the collaboration was implemented in the development of innovations at the firm. Firm innovations that contain or build on knowledge gained from the UIC would indicate that VCC had recognized the value of, acquired, assimilated, and exploited the collaboration knowledge. In other words, such innovations would be a hallmark of the firm's AC. Following the aforementioned definition of innovation (see OECD/Eurostat, 2019, p. 60), 19 distinct innovations connected to collaboration knowledge were identified using the interview data. These innovations fall into both the product and process innovation categories, and are presented in Table 12.

Table 12: Innovations connected to collaboratively developed knowledge

No.	Type	Application	Description of provided advantage
1	Product	Control systems	Collaboration knowledge controls different functions in product
2	Product	Design of product	More efficient
3	Product	Design of product	Collaboration knowledge used to develop new model
4	Product	Design of product	Changed product to use other types of technology
5	Product	Design of product	Decreasing emissions
6	Product	Technical portfolio	Collaboration knowledge contributes to scope of technical portfolio
7	Process	Calibration and optimization	Collaboration knowledge applied for calibration and optimization
8	Process	Faster decisions	Collaboration knowledge helps make faster decisions
9	Process	Supplier interaction knowledge	Collaboration knowledge provides knowledge to better negotiate with supplier
10	Process	Model development	Faster development (less trial and error testing)
11	Process	Model development	Used in products
12	Process	Model development	Collaboration knowledge (from other UIC) used to increase reliability of predictions
13	Process	Modeling	Model knowledge applicable in another internal department of firm
14	Process	Testing	Gain knowledge of better testing
15	Process	Faster industrialization	Collaboration knowledge helps accelerate industrialization by increasing calculation development efficiency
16	Process	Knowledge base	Gained a better position to interact and negotiate with sub-contractor
17	Process	Knowledge base	Knowledge base development increases pace of decision making
18	Process	Strategic	Knowledge of limitations used in choice of firm strategy
19	Process	Knowledge base	Collaboration knowledge functions as knowledge base for future model (not used in years)

The second column from the left in the table categorizes the types of innovations according to the definitions of six product innovations and twelve process innovations. The third column from the left briefly describes the application of the collaboration knowledge. For example, knowledge from the UIC has been applied to change the design of the engine that the firm produced. The competitive advantage produced by the collaboration knowledge is summarized in the fourth column. Using examples 2–5 from Table 12 shows that application of the knowledge in the engine design led to a more efficient engine, lower emissions from the engine, the application of other types of technology in the engine, and development of a new model of engine. The competitive advantage was created by incremental knowledge development by university employees in the collaboration, but the application of this knowledge was time consuming. Respondents Martin and Viktor described the application of this knowledge as follows:

> So, you see, the results are used, but you cannot take anything directly and say "now we shall implement this." Instead, you adapt the results

> [in line] with other experiences you have with them [i.e., the university] in the project. And then we could see knowledge development toward an applied implementation. (Martin, 2019-01-22, own translation)

> No, because you do not know when something is happening … but with some regularity, you have exchange meetings. And it is at those meetings that they [i.e., collaboration results] are communicated. It is not like there is a major breakthrough that turns the entire world upside down. Sadly, we do not have that kind of development here. Instead, it is small refinements, hard work, and development. I think that suits [the collaboration] well. Then we can proceed like this with quarterly feedback. (Viktor, 2018-12-13, own translation)

What is being said here is that the collaboration research findings were not immediately used in innovations and were not anticipated to be immediately applied either. The firm expected the development of its knowledge base within specific knowledge areas that, in the long term, might be applied in innovations. This was the case for most of the collaboration research focusing on specific natural phenomena of which the industrial partners need a better understanding. In this example, there was fundamental inquiry into how and why a certain natural phenomenon operated the way it did. The respondents argued that the development of fundamental knowledge was important in order to meet increasing regulations. At the same time, research on the specific natural phenomenon was associated with high risk, high cost, uncertainty, and considerable investment of time. Therefore, research on this natural phenomenon was in the interest of all the industrial partners in the collaboration. On the other hand, there was a general exception in the data, namely, mathematical models and modulations (henceforth, "models").

Models are computational models and mathematical calculations that, for example, can describe and predict natural phenomena. Models can be more quickly absorbed and applied by the firm because it has pre-existing, but less precise, models that describe these phenomena. Knowledge from the collaboration, in the form of models, can be added to the firm's models and combined to provide better predictions or computational testing. Superior predictions and computational testing decrease development time by reducing the necessity for physical trial-and-error testing. Knowledge originating from the collaboration could be exploited by the firm in innovations and therefore indicate the firm's AC. The next section outlines the formal approach to collaboration that was important for accessing the knowledge.

4.2.2 A formalized approach to collaboration: project meetings and industrial representatives

This section explores the dynamics of the university–industry collaboration, focusing on the project meetings in which different stakeholders actively participated in sharing collaboration knowledge and ideas. The data describe the general setup of the university–industry collaboration. The board of the collaboration contained professors from the university, representatives of the firms providing substantial support (in 2017 the mandated minimum financial support was SEK 600,000), and a representative of the Swedish Energy Agency. The board discussed and approved relevant research projects that the university should implement. The research in these projects was usually performed internally at the university by a supervising project leader and doctoral students. The conclusions of the research were reported to the collaboration's board of directors.

The respondents referred to two sources where valuable collaboration knowledge could be identified: different types of meetings and written content. These types of meetings were board meetings, seminars, presentations, and project meetings. The written content comprised short reports, presentation material, CERC annual reports, and Ph.D. dissertations. The data show that the project meetings were recurrent events in which valuable collaboration knowledge was recognized, acquired, assimilated, and later exploited.

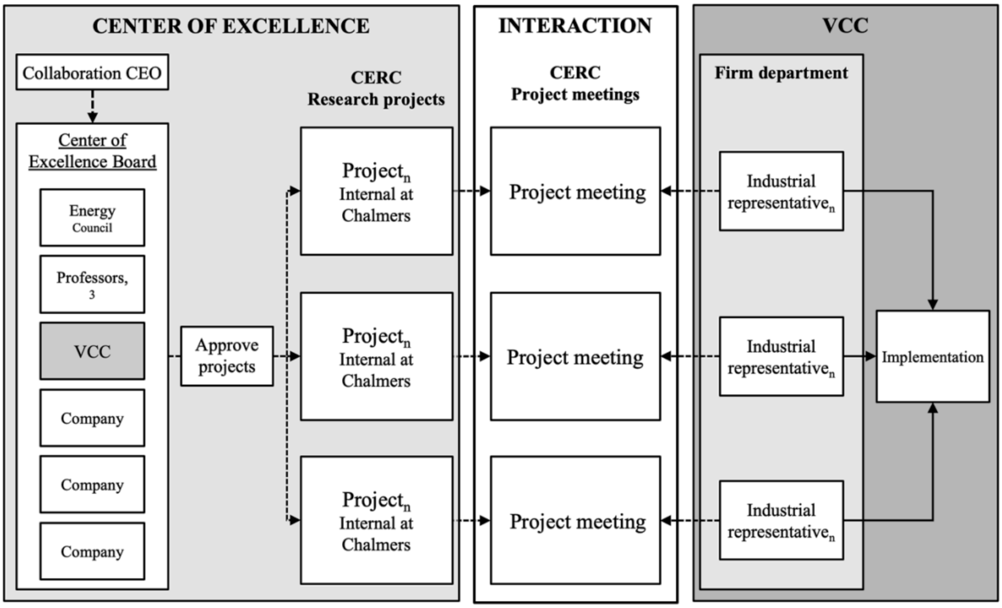
The project meeting was a half-day meeting occurring three to four times per year. Attending the meeting were industrial representatives of the firms providing substantial support, doctoral students participating in the project, and the project manager. The project meeting's agenda called for the doctoral students to present research results (i.e., collaboration knowledge) obtained since the last meeting to the industrial representatives. The industrial representative of VCC specialized in the research area of the specific project. The respondents argued that their industrial representative needed a research background and a Ph.D. education to effectively participate in the project meeting. One respondent described the requirement that the representative should be "qualified to understand these people [i.e., university researchers]" (Yngve, 2019-01-29). A research background was needed because the research area in which the doctoral students worked in the project was considered "highly complex." Before attending the meeting, the industrial representatives had to prepare for the meeting to ensure a productive discussion. This was because project meetings enabled the firm to establish ongoing awareness of the research field and to manage the collaboration's research goals. The following quotation describes this:

> So, I know that I was a sounding board for the doctoral students when they were going to perform measurements, about how one could use the equipment and present the results. So, it was the Ph.D.s we supported. Anyhow, I was also steering the alignment of the research, and what they [i.e., the project researchers] should do, which hardware needed to be investigated or which process. (Viktor, 2018-12-13, own translation)

Viktor's remark shows why the project meetings were important for the firm and illustrates the role of the firm's industrial representative in these meetings.

In the project meetings, the industrial representative gained access to findings in a delimited research area, which the firm itself was active in initiating. The respondents described how the industrial representative monitored the firm's interests in order to ensure that the results of the collaboration research met the firm's expectations; accordingly, the representative would pilot the scope of the project's research. The effect the firm had on the research content of the projects was described by the respondents in terms of "forcing" (Qvintus, 2018-12-20, own translation), "steering" (Willhelm, 2019-01-1, own translation), "influencing" (Xerxes, 2019-01-25, own translation), and "pointing out" (Zäta, 2019-01-31, own translation). The industrial representative was responsible for ensuring that the financed research was aligned with the interests of the firm. Martin, a former CERC board member, credited the collaboration with a different perspective, by saying that it was an "extension of our own research," while Yngve added that "those who participate from the industry have to understand how the academic world works." The industrial representative's influence on the collaboration was why their background knowledge was often on a Ph.D. level. Figure 11 illustrates the project meetings and the flow of the collaboration knowledge.

Figure 11: Project meetings and the flow of collaboration research



In Figure 11, the dashed lines (--) between the "CERC research projects" located in the "Center of Excellence" box, the thick-outlined "Interaction" box, and the "Firm Department" box within the "VCC" box represent how the results of collaboration research are presented to the firm's industrial representative. The subscript indicate that the projects and industrial representatives were not limited to three As mentioned above, the representative evaluated the findings and provided feedback on the project during the meetings. In the "case-firm" box on the right-hand side are solid lines (—) that lead to the "Implementation" box. These lines represent the integration of valuable findings by the firm.

The university and industry were generally described as two separate entities in the data, having different agendas and languages. In one interview, the respondent implied that the researchers did not understand industry and the industrial perspective. Zäta summarized this as follows:

> That is the point of our work, to get the most competitive product possible. While the university's function is to understand the underlying phenomena, what is behind the technical solutions, building theoretical knowledge within the area. So that is how they are separated. (Zäta, 2019-01-31, own translation)

This quotation is one expression of the view that the agendas of the firm and the university were incongruous and needed to be monitored. On the other hand, the firm seemed to understand the potential value of knowledge developed in the collaboration, both the research and knowledge itself and the monetary benefits it could bring. For example, one respondent said that "they [i.e., the project group] need to have a chance to work by themselves." The next section further describes the industrial representative's interaction in the project meetings.

4.2.3 The industrial representatives' project meeting engagement and industrial monitoring of collaboration research

In the CERC project meetings, which focus on addressing complex research problems and enhancing knowledge development driven by international environmental regulations, the industrial representative has an important role. The research problems on which the university–industry collaboration's different projects focus are complex phenomena about which more knowledge is needed, due to increasing regulatory pressure. This pressure is international and puts increased demands on engines to be more environmentally friendly. To comply with international regulations, the firm had to improve its knowledge in specific research areas. Knowledge development in these areas is required in order to understand complex phenomena and their combined effects on the environment. This research was performed by the project's students in the collaboration and presented to the industrial representatives at the project meetings.

The data show that, at these project meetings, the industrial representative monitored the project's research, as mentioned above, and identified collaboration knowledge valuable to the firm. The identified knowledge was often connected to the work tasks the industrial representative was performing at the firm. Distribution of the research, within the firm, depended on the representative. Some respondents strove to share the knowledge from the collaboration internally at the firm by holding seminars or through face-to-face interactions with colleagues at the firm. But a majority of the respondents argued that the knowledge from the collaboration was too specific and only valuable to a limited number of individuals to be distributed widely within the firm. Willhelm stated, "One could maybe use it [i.e., collaboration knowledge], but I doubt that it has happened—it is too specific," in response to questioning as to whether other departments at the firm had applied research from the collaboration. On the other hand, Viktor pointed out that the calculations modeling a physical phenomenon had been used in another department. This knowledge had spread when individuals from two departments were working on the same computer. Moreover, the collaboration knowledge was not only useful for the firm as a source of knowledge for new innovations; rather, the collaboration knowledge also guided the firm away from research areas considered not to merit ongoing investigation. One such example was a technology that the UIC was attempting to advance on the research agenda. Tests of the technology at the university had produced promising results both in theory and in experiments. Ultimately, however, this technology was rejected for industrial implementation because it was concluded that further investigation of it was a "dead end." However, in 2019, a competitor of VCC introduced an engine with a technology based on the same theoretical principles.

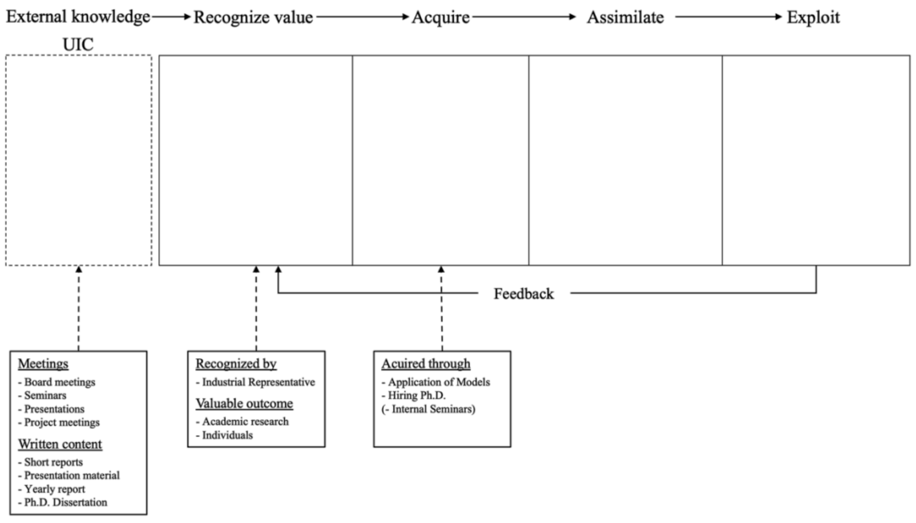
The project meetings were also an opportunity for the industrial representative to identify another valuable resource. There was unanimous agreement among the respondents that one of the most substantial outcomes of participation in the collaboration was the possibility of identifying competent individuals among the doctoral students participating in the different projects. Participation in the UIC enabled ongoing interaction with individuals from the university who later could be employed at the firm. The doctoral students were frequently mentioned in the interviews and credited as a source of “specific knowledge that is very hard to find” (Willhelm), of “competence” (Xerxes), and of “knowledge” (Åke). The firm could hire the doctoral students to transfer their knowledge from the university to the firm. The firm was interested in individuals who were aligned with its research strategy and could apply the university knowledge at the firm. The two quotations below exemplify this:

> [The] Ph.D.s have learned a great deal about [a specific technology] … So they bring it with them in their head, and work for several years. Then, later, they apply it in products that [the firm] has, and fine tune it and develop it. (Willhelm, 2019-01-14, own translation)

> These are very interesting individuals to hire. I think that this is one of the main reasons why we should have this type of collaboration project—that in the long term we can hire individuals with developed specialized skills. (Viktor, 2018-12-13, own translation)

The remarks show that the knowledge the doctoral students developed during their education was valuable to the firm. The full value of that knowledge cannot be condensed, or limited, in a report or a Ph.D. thesis that can simply be read and absorbed. To fully access that knowledge, the firm’s intention was to hire the identified doctoral students.

Figure 12: Absorptive capacity and findings of first round of interviews



The meetings, written content, and valuable outcomes described in this section can be positioned within the theoretical framework of AC. On the left-hand side of is the "External knowledge" component of AC, here the UIC. The external knowledge, i.e., the knowledge from the UIC, was accessed through meetings and written content. In the above figure this is the box below the "External knowledge" box. Following it is the "Recognize value" box, showing the industrial representative identifying valuable outcomes. The next component "Acquire" describes how the valuable outcome was acquired through applying the research or hiring CERC Ph.D. students.

4.2.4 Summary of first round of interviews

The firm wanted to collaborate with the university to investigate specific research areas of interest. The outcome of the university's research was accessed by the firm through meetings in different forms (e.g., board meetings, seminars, presentations, and project meetings) and through written content (e.g., shorter reports, presentation material, CERC annual reports, and Ph.D. dissertations). In the data, the project meetings were frequently mentioned regarding accessing knowledge from the collaboration.

The respondents described how, in the project meetings, the firm monitored and influenced the performed research. In addition, the industrial representative received ongoing updates on the project's research results and could also identify interesting and competent individuals. Collaboratively developed knowledge, valuable for the representative's daily work, was assimilated and could be directly applied or spread within the firm. The spread of knowledge was dependent on the representative, and while some respondents strove to spread the knowledge, others considered it too specific to be of any value for others at the firm. The firm hired CERC doctoral students to access a dimension of collaboration knowledge that could not be gained through explicit content. The collaboration's research and knowledge development on specific natural phenomena were both important and valuable for all the industrial partners, but the research outcome, i.e., collaboration knowledge, was considered neither immediately useful nor immediately applicable. The exception was findings regarding the researched phenomena expressed in computational models.

The interviews indicated that the adjunct professor (called Cecar in the historical description) and the industrial representative were of importance for the firm and its access to collaboration research and knowledge. The following analysis shows how these two parties can be described in terms of three firm roles that influenced the internal implementation of knowledge developed in the UIC.

4.3 Understanding the dynamics of the influential firm roles

The data compiled in this section demonstrate a formalized pattern of interaction that indicates the existence of a systematic approach to collaboration and the strategic assignment of individuals possessing pertinent knowledge backgrounds. This approach ensured the effective absorption and exploitation of collaboration knowledge. For example, Figure 11, above, illustrates how this systematic approach can be described: the firm delegated an employee equipped with appropriate knowledge background to be its industrial representative. The consistent participation of this representative in the recurrent meetings provided access to collaboration knowledge and influenced the trajectory of future research.

Specific positions within a firm had a significant impact on its ability to absorb and exploit collaboration knowledge, as supported by the compiled data. The positions of the adjunct professor and the industrial representative have been identified as particularly influential for the firm's AC. These positions were central to various key aspects, such as initiating the collaboration itself, formulating the rationale for VCC's participation, and fostering the firm's ongoing recognition, acquisition, and assimilation of collaboration knowledge when collaborating. The analysis of these positions distinguishes between three roles, namely: translator, interpreter, and assimilator. Figure 13, below, visualizes the three roles, their relationships to absorptive capacity, and the findings presented in , above; this figure is followed by a summary of each role's individual functions.

Figure 13: Influential firm roles and absorptive capacity

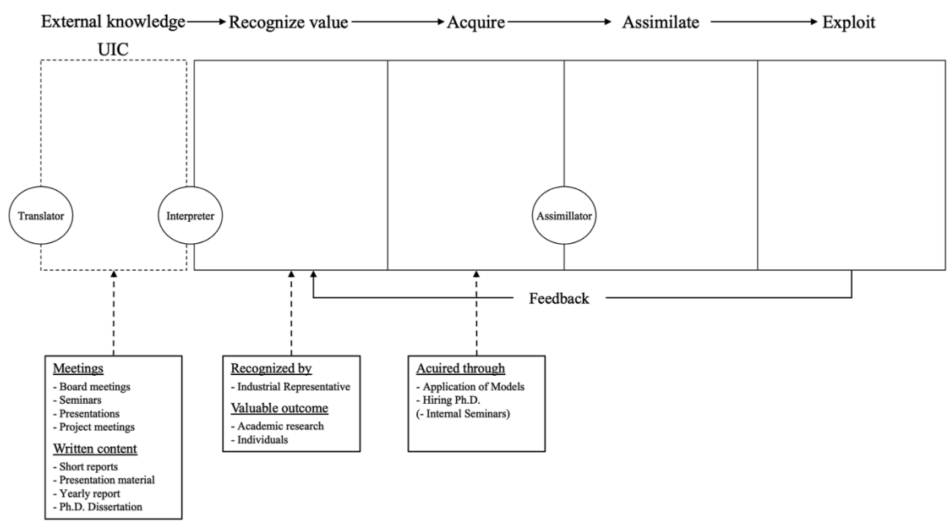


Figure 13 illustrates the three roles and includes the findings presented in section 4.2.3. In the middle of the figure are the roles and their titles inside the circles. What follows is an analysis of these roles, beginning with the translator.

Translator—this is an informal role that requires considerable overlap of knowledge domains and that is comparable to Cohen and Levinthal's (1990) notion of the boundary spanner, who "monitors the environment and translates the technical information into a form which is understandable" (p. 132). The translator identifies solutions from the external knowledge domain and translates them into the context of firm problems. In the context of UIC, the translator is important for initiating the interaction.

Interpreter—this is a formal role assigned to the structured interactions that require specific knowledge domain overlap between the domain of the external knowledge and the knowledge base of the receiving firm unit. The interpreter decodes the external knowledge source information and selects information depending on its applicability to the agent's own problems within their role at the firm. In the context of UIC, the interpreter is important for the recognition of valuable knowledge presented in the structured interactions.

Assimilator—this is an informal role that requires knowledge of the firm's prior problems and solutions regarding specific technologies as well as knowledge of the structured interaction's selected collaboration knowledge. The assimilator translates the information from the external knowledge source in light of firm-specific conditions and applies these conditions to determine the usefulness of the knowledge. In the context of UIC, the assimilator's actions take place inside the firm. The assimilator's actions are both practical and theoretical. They are practical in terms of applying ideas, methods, and approaches originating from the collaboration research and as outcomes of the structured interaction. They are theoretical in terms of applying the selected collaboration knowledge in internal interactions as hypothetical or as ideas for solutions to firm problems.

The *continuous comparison* of problems is manifested in the occurrence of structured interactions in which an interpreter is established and formalized. These interacting agents, i.e., interpreters, appear due to a company's commitment to organized interaction, which is a strategic choice with an aim. The firm's aim is to allocate valuable collaboration knowledge within a domain of knowledge. In the UIC, the first knowledge receiver is the formalized interpreter, specifically appointed due to their position at the firm. In structured interactions, the interpreter recognizes collaboration knowledge as valuable by means of continuous comparison with the firm's problems. The interpreter compares the incoming knowledge by interpreting it in the context of the firm's conditions (i.e., "What does this mean for the firm?"). The same phenomenon is present, except more subtly, when the translator identifies a solution in a non-structured interaction with the university as an external knowledge source. Similar to the interpreter, the translator also compares external knowledge with the firm's problems. What seems to be the difference between the two is their prior knowledge and the external knowledge source. For the translator as a knowledge receiver, the prior knowledge is more distant from the external knowledge, thereby requiring translation and interpretation. The knowledge needs to be understandable and aligned with the firm's conditions. For the interpreter as a knowledge receiver, the prior knowledge is similar to the external knowledge, so translation is not required and interpretation can take place instantaneously. There are similarities between this argument and prior research. Knowledge similarity, or overlapping knowledge bases, supports the exchange and integration of knowledge (Dyer and Singh, 1998; Lane and Lubatkin, 1998; Szulanski, 1996; Volberda et al., 2010). Where there is similarity of knowledge and its successful integration, this is suggested to be the outcome of an aligned comparison. A consequence of the problem perspective is that the continuous comparison of the firm's problem with external knowledge sources should influence the comparer to develop a bias in favor of the firm's view. This logic was supported by Todorova et al. (2007), who claimed that valuing is biased and needs fostering. By means of the continuous comparison between problems and external knowledge, one could say that collaboration knowledge progresses through the AC components as a solution to a problem.

In summary, the three delineated roles each uniquely contribute to the firm's AC ability and exploitation of collaboration knowledge. The translator, an informal role, leverages a broad knowledge domain to translate external solutions into firm-specific contexts; the interpreter, a formal role, interprets and selects external information based on its applicability within the firm; and the assimilator, an informal role, uses and applies the collaboration knowledge in firm-specific conditions.

4.4 Conclusion

The first round of interviews, conducted in 2019, examined and explored the firm roles that were influential for the integration of collaboratively developed knowledge and its influence on firm innovations. This round employed a qualitative method of semi-structured interviews with individuals who had been active in the firm and directly involved in the CERC collaboration. The analysis of nine semi-structured interviews and 21 years of archival data showed that product and process innovations can be connected to knowledge developed in the collaboration. Below are the three major findings:

1. Three roles - translator, interpreter, and assimilator
2. Individual decisions - the identification of valuable knowledge is subjective
3. Systematic approach - to ensure systematic knowledge integration

The first finding is that the three roles, i.e., translator, interpreter, and assimilator, each have a significant and unique impact on the firm's ability to recognize, acquire, and assimilate valuable knowledge from the collaboration. The second finding is that the individual who represents the firm in the collaboration project meetings has a subjective effect on the identification and integration of valuable knowledge. The third finding is the existence of a systematic approach to ensure the efficient generation of new knowledge, identification of valuable collaboration knowledge, and knowledge transfer to and integration in the firm. The firm's collaboration structure follows a pattern that engages multiple interacting individuals. Thereby, the project meetings are the events in which collaboration knowledge is recognized and acquired.

Now we turn to the research question concerning how a collaborating firm recognizes, acquires, and assimilates knowledge from a university–industry collaboration to develop firm innovations. It is found that three roles—translator, interpreter, and assimilator—have significant parts in this process. An in-depth discussion of this matter will be presented in chapter 0. Despite the established link between knowledge from the CERC collaboration and firm innovations, further exploration of this association is necessary. The previous finding, namely, that individual decisions influence the linkage between the collaboration knowledge and the process of innovation, also has implications for the AC framework, from value recognition to value exploitation. Hence, the present findings suggest that firm innovations stemming from the collaboration knowledge are likely to be influenced by both individual and organizational aspects. To explore how knowledge developed within the collaboration contributes to the collaborating firm's development of innovations, a comparison of innovation cases connected to CERC knowledge is proposed, which involves interviewing the inventors. The next chapter concerns this comparison and is the last of the chapters presenting the research results.

5 Recognizing and implementing collaboration knowledge

The purpose of this chapter is to understand how knowledge developed in a university–industry collaboration is recognized, acquired, and then assimilated in firm innovations, and to detail the mechanisms and routes involved. It presents the results of the second round of interviews investigating a firm's utilization of knowledge derived from a UIC. The results are anchored in the perspective of the participation of a firm, i.e., VCC, in the CERC collaboration. Building on the previous chapter's findings, which highlighted a systematic approach to integrating collaboration knowledge in the firm, this chapter provides further elaboration. The chapter is structured as follows. Initially, the research question is reiterated with analytical clarifications to provide context for this chapter. The first major sections present the results of the second round of interviews, focusing on the recognition (section 5.1) and implementation (section 5.2) of collaboration knowledge, summarized in section 5.3. This is followed by the analytical section 5.4, which examines the problem as well as its functions and implementation paths, and then provides an analytical summary. Finally, section 5.5 presents the conclusions of the second round of interviews. With the structure of the chapter outlined, the research question is restated below:

RQ

How does a collaborating firm recognize, acquire, and assimilate knowledge from a university–industry collaboration to develop firm innovations?

This chapter identifies a connection between collaboratively developed knowledge and firm problems (with sources and functions depictured in Figure 14) and, in turn, these problems' connection to the AC framework. The focal interest in the second round of interviews was the usage of collaboration knowledge created through scientific activities at the university. The aim is to advance our understanding of how the collaborating firm internally develops innovations using collaboration-derived knowledge, by means of empirical descriptions of the AC components. Simply stated, this chapter considers how knowledge from the collaboration is used internally.

A firm's usage of collaboration knowledge does not necessarily lead to innovation. The rationale behind this assertion is that innovation has its own set of specific criteria (see section 2.1.1), and it is plausible for a firm to make unsuccessful attempts to use collaboration knowledge, thereby falling short of meeting these criteria. While innovation as an outcome is interesting, the main focus of this chapter is on the recognition, acquisition, and assimilation of collaboration knowledge—briefly stated, the usage of collaboration knowledge. An innovation linked to collaboration-derived knowledge serves as a significant source of insight into the connection between this knowledge and the AC components recognition, acquisition, and assimilation. In the following section, the results of the innovation comparison are presented, beginning with recognizing collaboration knowledge as valuable.

5.1 Recognizing collaboration knowledge as valuable through the relationship to a problem

What follows is a description and exploration of the various ways in which collaboration knowledge is valuable, and of the connection of this knowledge to a problem, that emerged in the data analysis. The collected and transcribed interviews suggest a nuanced understanding of the value of collaboration knowledge. These nuances are evident in the transcripts when sorting out passages that refer to the university (as an entity in itself, via an individual representing the university, or as a collaboration partner) and its association with value. Participants indicated the value of collaboration knowledge in diverse ways, for example, noting its role in advancing technology, providing comprehensive understanding, enabling diverse scenario testing, and developing methodological skills. For example, Bertil (2020-07-02, own translation) mentioned that collaboration knowledge "push[es] the technological front forward" and "has some form of application"; similarly, David (2020-08-06, own translation) emphasized that the collaboration provides an opportunity to "truly understand something." Collaboration knowledge is valuable because it can be used in testing multiple scenarios through the scientific method and because, for example, by using the resources at the university, "one can get different exhaust gases and compare their differences," which illuminates "what the effects of their production are in a new type of engine" (Ivar, 2021-02-10, own translation). Collaboration knowledge is made valuable by trained and employed Ph.D. candidates who have the knowledge needed to apply methodological skills developed at the university: "in that situation, we had the benefit of being able to execute calculations" (Niklas, 2021-03-23, own translation). Beyond individual perspectives, collaboration knowledge was also understood as valuable in the research process. This concerns both the process itself—"they [i.e., the participating firms] can derive much value from our way of thinking" (Qvintus, 2021-02-24, own translation)—and the later application of the research process in the firm by former Ph.D. candidates: "we proved that my hypothesis worked" (Johan, 2021-03-15, own translation); "much of the research methodology is general and can be applied in many different applications" (Kalle, 2021-02-16, own translation); "if you successfully define the problem in a good way then it is easier to find a solution … after the problem definition, I start to analyze how it can be broken down into smaller problems" " (Helge, 2021-03-10, own translation) The above quotations illustrate how collaboratively developed knowledge is understood as valuable. These quotations highlight a range of value aspects associated with collaboration knowledge, extending beyond explicit representations (e.g., the value of the research process is inherent in the individual) and remaining valuable and useful. The following section will explore the relationship between values and problems.

In relation to a problem, value can be perceived as an attribute of a solution; more specifically, it can be regarded as a more valuable solution. When collaboratively developed knowledge is associated with a valuable solution, it is in response to an identified problem. As David (2020-08-06, own translation) noted, collaboration knowledge constitutes a valuable solution because it provides the opportunity to "truly understand something," since the known problem is that it is difficult to truly understand something. In this way, valuable collaboration knowledge is an attribute of a solution to a known problem. Both the problem and the valuable collaboration knowledge, as an attribute of a solution, are connected to the AC framework and its component *recognition of value*. This is because of the possibility that a solution can be recognized as valuable, and thereby indirectly connected to a problem. A problem, as indicated in the interviews, presupposes a problem source and has three functions (i.e., the identifier, definer, and driver). The problem, together with its source and functions, will be further addressed below.

Value, as determined by the firm, is intricately connected, as a subjective evaluation, to individual work tasks, indicating that a solution is valuable when it effectively addresses an individual's specific problem. This finding adds to the first round's finding regarding the subjective nature of value recognition, but also links the problem to the firm, influencing the definition of value. This phenomenon is illustrated by Filip's remark: "Usually, if you get ideas that do not carry [value] in the project … those ideas do not go so deep" (Filip, 2021-03-31, own translation). In this quotation, Filip expounded on the nature of ideas that emerge during a project, particularly those intended to solve a current problem. If the ideas fail to *carry* value to the project, then Filip argued that they are neglected and not seen as potential patent material. The problem addressed in the project thus supersedes the potential value of the idea. Filip's comment accentuates the constant yet subtle presence of problems, a topic that will be discussed further in the analysis section, while the next section considers the results of the use of collaboration knowledge.

5.2 Identifying when collaboration knowledge is implemented

This section describes and accounts for the findings, derived from interviews with inventors and decision makers, pertaining to the implementation of collaboration knowledge in the context of patented inventions. The term “implementation” employed here accentuates the act or process of implementing or of making something active or effective. As stated previously, the inventors of the patents were sources of information for addressing the research question. The main objective of concentrating on patents was to collect information on collaboration knowledge usage, by redirecting the interviewees’ attention toward their patenting experience and related events. The interviews with the inventors and the additionally identified decision makers provided numerous accounts that, in some instances, connected the collaboration knowledge to the patents. These accounts were identified through a methodical coding process that filtered interview excerpts depicting or linked to the usage of collaboration knowledge, labeling such instances as “implementation.” In line with the case study method, the first-round interviews were revisited and analyzed when the categories had emerged (Eisenhardt, 1989). Additionally, new interviews were performed either with new respondents who had become significant in the second round or with previous respondents for clarification or to confirm details. This process continued until data saturation was reached.

The implementation of collaboration knowledge in the firm was manifested through a variety of explicit and implicit cross-referential mentions captured in the coded data. The excerpts coded for the implementation of collaboration knowledge include directly mentioning, for example, “then you see something”(Willhelm, 2019-01-14, own translation); indirectly mentioning, for example, “I was the first at Volvo” (Bertil, 2020-07-02, own translation); and cross-referencing, for example, “Anyhow, we carried on and we worked a lot with CFD [computational fluid dynamics], and both Erik and Niklas are calculation engineers.” (Cecar, 2020-07-29, own translation) In the cross-referencing example, Cecar was referring to the firm’s development of the CFD calculation method in early 1990 and specifically to Erik, who was hired because his dissertation focused on this specific method. Table 13 presents the number of references to the implementation of collaboratively developed knowledge from the two rounds of interviews.

Table 13: Mentions of implementation of collaboration knowledge

Interview round	Interviews	Interviews/pages	References
First	9	173 p	24
Second	23	656 p	466
Total:	32	829 p	486

In Table 13 the first column specifies the associated interview round. The second and third columns respectively delineate the number of interviews and the corresponding number of transcribed pages for both rounds of interviews. The final column presents the number of references coded as "implementation." The compilation of the interview data, when summarized in the bottom row, shows that 32 interviews transcribed in 829 pages were analyzed and coded, resulting in 486 implementation references. This elucidates the recurrent mentioning of collaboratively developed knowledge within the data, manifested as direct or indirect mentions or cross-references.

5.3 Summary of the results

Taken together, the presented results suggest that university–industry collaboration knowledge had value to the firm and to the individuals who interacted with the university. The value of this knowledge was evident in many ways, appearing in contexts ranging from explicit reports and publications to embedded nuances carried by individuals. The value of this knowledge was entangled with the problems faced by the firm, as well as with the individuals who interacted with the university and who encountered the corporate environment. The problems had broad characteristics, encompassing the sources of the problems, the implications of those problems for the individual, and how the problems furthered the search for solutions. Excerpts from the interviews related to the usage of collaboration knowledge illustrated the breadth and depth of the knowledge contributions. The excerpts showed that the knowledge had been used mainly through the direct, indirect, and negative paths. The next section presents the analysis of the second round of interviews.

5.4 Analysis: emergent themes—problem, path, effect, and phases

The integration of collaboration knowledge in firm innovations was characterized by a distinct combination of the following three themes: problem, implementation path, and effect. This tripartite pattern emerged during the analysis and was strengthened through the revisiting and recoding of all innovations, by gradually adding one innovation at a time (Eisenhardt, 1989). The result was formulated as a synthesized theoretical model (depicted in Figure 14) that encapsulates the implementation of knowledge developed in the collaboration within the firm and outlines the intricate relationship among the themes. This analysis section first introduces the analysis and coding from which the themes emerged; the theoretical model is then elaborated on, along with the explanation of each phase. The problem and path themes are separately presented in sections 5.4.1 and 5.4.2, respectively. Initially, in the second round of interviews, four patents

were identified as reasonable innovations that connected collaboration knowledge to the innovations. The inventors of these patents served as prominent sources of information. Adhering to opportunistic data collection (Eisenhardt, 1989), two additional patents were identified during the data collection process. In total, six patents and 14 inventor interviews were analyzed and coded; the results of this coding and the identified themes are shown in Table 14.

Table 14: Coding table: problem, path, and effect among the innovations

Theme	Category	Definition \ Innovation	1	2	3	4	5	6	Total
Problem	Source	The source of a problem is the origin, or originator, of a specific problem and can be physical or non-physical.	5	8	7	18	14	4	56
	Definer	The problem is a definer when it describes what needs to be solved.	23	27	16	21	26	10	123
	Driver	The problem is a driver when it is used to motivate action.	7	7	11	37	18	3	83
	Identifier	The problem is an identifier when it filters information signaling a solution.	20	21	43	7	5	9	105
Path	Direct	Direct implementation is when the collaboration knowledge is a source of knowledge based on which decisions or actions are made.	7	28	19	0	13	2	69
	Indirect	Indirect implementation is when the collaboration knowledge is used as a source of knowledge based on which decisions or actions are made at a later time.	57	89	29	23	32	15	245
	Negative	Negative implementation is when the collaboration knowledge informs the receiver of the limitations or boundaries of a certain thing or phenomenon and causes an action not to be executed.	0	7	0	0	2	0	9
Effect	Event/ action	The effect is an indication of a firm's action or event due to the implementation of collaboration knowledge.	11	34	20	3	27	6	101

As detailed in Table 14, three distinct themes emerge, i.e., *problem*, *path*, and *effect*, each quantified through various categories and defined in subsequent columns. The first column presents the three themes and the second column presents their categories, which are defined in the third column. Columns four to nine provide the number of mentions (i.e., coded interview segments) for each theme's category for Innovations 1 to 6. For example, for Innovation 1 (column four) there are 5 interview references coded to the category "source" and the theme *problem*. The last column contains the total number of references for each category. A notable pattern is visible in the table for the *path* theme, for which the "indirect" category contains more than three times the references (245) as does the "direct" category (69), and twenty-four time more than the "negative" category (9). The same pattern cannot be discerned for the theme *problem*, for which the references are more uniformly distributed among the categories, with the "definer" category standing out as noteworthy with its 123 references. Below is a quotation including all three themes and illustrating their coding. In the excerpt, Kalle described the common tasks and responsibilities of an industrial representative participating in a CERC collaboration project meeting:

> If you look at their perspective, they obviously want to meet the emissions legislation in as cheap a way as possible. Then the question is, is this the right way to go? Are there other alternative ways to achieve the same thing without having to, for example, put more hardware in the car? That was part of what we were looking at. (Kalle, 2021-02-16, own translation)

This excerpt encodes the themes and their corresponding categories in a practical context, illustrating the real-life relevance of the CERC research and the collaboration knowledge. In the excerpt, the "emission legislation" and "cheap" have been coded to the theme *problem* and the category "source," the problem is further elaborated on in section 5.4.1, below. "Is this the right way to go?" has been coded to the theme *effect*, due to its indication of firm action. The last sentence in the excerpt is coded to *path* because the "we" Kalle refers to includes himself as a CERC doctoral student and to the category "direct" because the context concerns the industrial representatives' problems that the doctoral students' research was investigating. Details of the three paths of implementation are discussed in section 5.4.2. This excerpt is from an exchange describing the application of collaboration knowledge, thereby demonstrating the three themes. The result of the innovation comparison is visually represented in Figure 14.

Figure 14: Theoretical model of usage of academic research

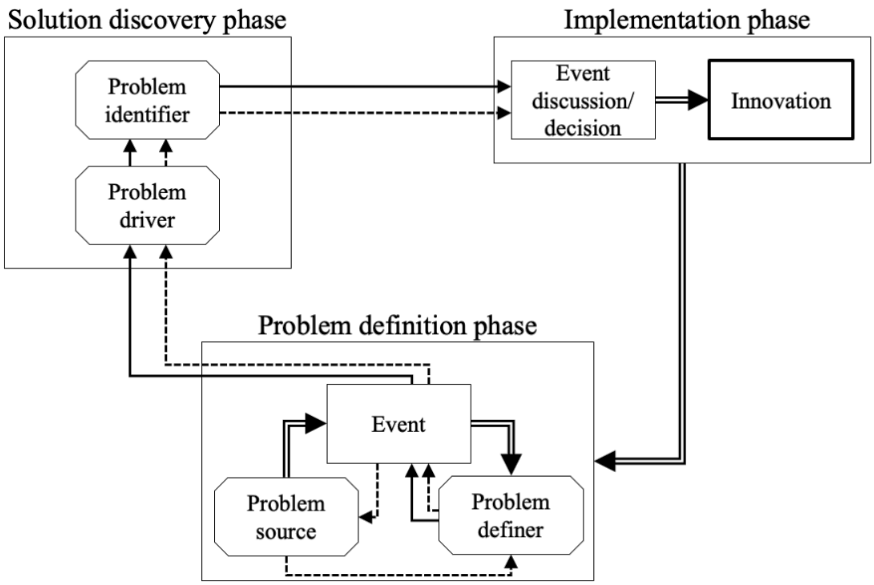


Figure 14 is a theoretical model of the analysis illustrating the implementation of collaboration knowledge within a firm and the interconnectedness of the themes problem, path (three categories), and effect with regard to firm events. Further visualization of each innovation can be found in Appendix E, while Figure 16 elaborates on the model's connection to the theoretical framework. The model in Figure 14 encapsulates three central phases, namely: problem definition, solution discovery, and implementation. The term "phase" here denotes that the components were bundled together by the relationships indicated in the interviews; an indicated relationship can be expressed in terms of "then we," pointing to its temporal nature. Each phase incorporates multiple components, and in total there are six key components, representing the distinct themes and their categories within the process of implementing collaboration knowledge. The three categories of the *path* theme are represented by the dotted and solid lines, with the former referring to the "indirect" category and the latter to both the "direct" and "negative" categories. The four categories of the *problem* theme are shown by the rectangles with snipped corners containing category labels. The two categories of the *effect* theme are visualized by the double line for the "firm action" category and the regular rectangle for the "firm event" category. The rectangle with a thick outline represents the two types of innovation (i.e., product or process). The arrowheads of dotted, solid, and double lines indicate the components' relationships with each other. This clarification is essential for the following analysis, concerning the first phase of the model.

The problem definition phase, outlined at the bottom of Figure 14, pivots around the events and actions that systematically drive the formulation of the problem definition, forming the central argument of this phase. For the *direct/negative path*, this phase is initiated by a *problem source* (i.e., regulation, cost, or customer) that leads to a *firm event* and culminates in the first problem function, i.e., the problem *definer*. These three components are interlinked by the *firm action* arrow, signifying the firm's internal awareness of the problem at hand. For the *indirect path*, this phase is initiated by a *firm event* (e.g., the collaborating firm employ a collaboration Ph.D. student) that leads to the *problem source* and then to the problem *definer*. These three components are interlinked by the dotted line. Both the *direct/negative* and the *indirect* arrow then return to the *firm event*, for the *indirect* arrow the *firm event* regards a new event compared to the *direct/negative* where the *firm event* can be the same event. Then both the *direct/negative* and the *indirect* progresses to the next phase.

In the second, solution discovery phase (in the top left of Figure 14), the main subject is the identification of a solution to the previously established and defined problem; this illustrates a cognitive aspect of the problem-solving logic, accounted for across the innovations, which incorporates collaboration knowledge. The term "cognitive aspect" refers to subjective associations or conclusions derived by individuals in their pursuit of a solution (e.g., "then you see something," Willhelm, 2019-01-14). The first component of this phase is the problem's function as a *driver* that accentuates awareness of, and amplifies the necessity of solving, the defined problem. In other words, the problem is important to solve. Following the driver function is the third problem function, *identifier*, indicating that collaboration knowledge has been recognized in either a *direct* (solid arrow) or *indirect* (dotted arrow) way as a solution to or as part of a solution to the defined and important problem. Knowledge from the collaboration is recognized as a solution *directly* through accessing explicit collaboration knowledge (e.g., scientific publications and software) or *indirectly* through an individual's tacit collaboration knowledge (e.g., experiences and meaning structures). The identification of a solution to the problem then leads to the third phase of the model, the implementation phase.

The third and last central phase of the model, implementation (top right in Figure 14), explores the practical application of collaboration knowledge. In this phase are *firm events* that revolve around the discussions and decisions regarding the problem, with the identified knowledge to some degree being part of the solution. The result of the firm event is a decisive *firm action* (double arrow) to implement collaboration knowledge as a solution to the problem. The firm action to implement the knowledge then leads to the *innovation* component, as a new, or improved, product or process that is available to the users or brought in for the firm to use.

The innovation can create *firm action* and initiate new *firm events* in the first phase, i.e., problem definition. This is exemplified in the second Innovation (Figure 15, below), where the new collaboration with a supplier is a *process innovation* (box 11b), preceded by the *firm event* "Erik hired at firm" (box 7). The innovation affects the expansion of the firm's simulation team and simulation knowledge (boxes 13, 14, and 15), and is further interlinked to both the product innovation in box 19 and the process innovation in box 20.

In addition to the above-described progression is an alternative account beginning with a *firm event*. When a problem has been *defined* and returned to the event box, the indirect path can progress through the problem's source and functions (i.e., definer, driver, and identifier), culminating in the implementation phase and the *event discussion/decision*. The path progresses through the dotted arrows beginning with the *event* in the problem definition phase. In these cases, a recently employed individual (*event*) gains access to the problems the firm intends to solve. With knowledge of the problem, the individual adds the collaboration-gained knowledge and thereby specifies the problem *source* and *definer*. With the defined problem and its need to be solved, the individual then *identifies* a solution to the problem based on the collaboration knowledge. For example, this occurs in innovations 1 and 2 (see Appendix E). The emphasis in this alternative account is on access to the problem that the firm needs to solve.

In summary, the analysis shows that usage of knowledge from the collaboration is preceded by the firm's problem and its defined meaning for the firm before a solution can be identified. In other words, collaboration knowledge is used as a solution to a firm's specific problem. The analysis synthesizes the three themes in a theoretical model (depicted in Figure 14) that encapsulates the integration of collaboration knowledge within a firm through three central phases, namely: problem definition, solution discovery, and implementation. The problem definition phase pivots around the events and actions that systematically drive the formulation of the problem definition. In the solution discovery phase, a solution to the defined problem is identified, incorporating the collaboration knowledge. The implementation phase applies the identified the knowledge in a practical setting, leading to firm actions, discussions, and decisions, culminating in innovation. The alternative account highlights the importance of access to firm-specific problems. Having discussed the phases of the theoretical model, the next section addresses the theme *problem*.

5.4.1 The problem: its functions and its sources

The *problem* theme has a pivotal role in integrating collaboration knowledge in firm innovations, as repeatedly pointed out in the interviews. From the interviews, it can be discerned that a problem refers to a source (the problems origin or originator) and has three functions: definer, driver, and identifier. The term "problem" is used here as a subject, verb, and noun (see the literature review and Landry, 1995): as a subject concerning information about the source (e.g., thing, place, or person) of the problem; as a verb (i.e., what the subject does or is) concerning the condition of the subject; and as a noun by informing about who "owns" the problem. The following sentence exemplifies this: "It is emissions and CO_2 that govern what we need to develop, what we need to get better at" (Viktor, 2018-12-13, own translation). In that sentence, the problem's source (subject) is both the emissions and CO_2, while the condition (verb) is "govern," which provides information about what the problem is or does. The problem owner (noun) in the quotation is "we" and refers to the department where Viktor is working.

An in-depth exploration of the problem's three functions—definer, driver, and identifier—reveals their roles in shaping the understanding of a problem. The problem's three functions are on the categorical level and emerged in the analysis through the search for commonalities between concepts. An overview of the preliminary analysis of these three functions is presented in Table 15. In the table, the first column contains the three functions, defined in the second column and each illustrated by quotations in the third column; the frequency of references appears in the fourth column, and the last column presents the primary concept with correlating references in.

Table 15: The three functions of a problem

Function	Definition	Excerpt	Mentions
Definer	The problem is a definer when it describes "what" needs to be solved.	"At a certain point in time, they [i.e., the participating firm] knew that they needed to meet certain emission requirements in their cars. I think they are attacking it from a perspective and as if it were driving a line from Volvo's direction." (Kalle, 2021-02-16, own translation)	123
Driver	The problem is a driver when it is used to motivate action.	"But I saw here that you needed both experiments, which we ourselves were quite decent at anyway, but then you also needed calculation. Above all, you needed calculation in the early phases before there was any hardware, so you could at least get a little clear on how to do it." (Cecar, 2020-07-29, own translation)	83
Identifier	The problem is an identifier when it filters information, signaling a solution.	"Yes absolutely. He was also then the project manager for pre-development projects. So, he was aware of what other things they were working on at this time—so, the issues in a way that I was not aware of as a doctoral student. So, he actually saw that connection, I must say." (Johan, 2021-03-15, own translation)	105

First, the problem functions as a *definer* by distinctly addressing and describing what needs to be solved, or by delineating the problem area for the problem owner. The quotation from Kalle, coded as definer in Table 15, elucidates the firm's "challenge" that requires a solution, specified as "emission requirements." Therefore, the problem (i.e., emission requirements) functions as a definer by delineating the area where a problem needs to be solved. Others described the definer and what needs to be solved as follows: "it has to be fully vaporized for it to actually work properly" (David, 2020-08-06); "what kind of problem do we have out there on the market" (Adam, 2020-06-30, own translation); "the liquid must evaporate" (Ivar, 2021-02-10, own translation); and "the engine knocks" (Filip, 2021-03-31, own translation). Others specified the problem area as follows: "only at very high temperatures does the deposit get removed" (David, 2020-08-06) and "it concerns the after-treatment system" (Filip, 2021-03-31, own translation). Moving on, the problem not only serves as a definer but also operates as a driver, stimulating the creation of solutions.

Second, the problem functions as a driver by its motivational usage in creating action, i.e., the problem drives consideration of why a solution is needed. In the example in the table, Cecar insisted that calculations were "needed" (in the two sentences, "need" is used three times) to solve a problem. Here, the problem is the uncertainty in the early stages of the product development process. In the same quotation, the problem's functionality as a driver is further stressed when Cecar explained that "so you could at least get," implicitly motivating action by referring to a problem. Other respondents described the driver as follows: "and then a way to avoid this was needed" (Filip, 2021-01-19, own translation); "obviously, in the end we shall deliver that this system is so or so good" (Peter, 2021-02-04, own translation); "so we took a closer look at how to help vehicles" (Helge, 2021-02-09, own translation); or as Kalle put it, "as we all know, emissions and CO_2 emissions from internal combustion engines are something that you want to get rid of and try to find new combustion concepts" (2021-02-16, own translation). The problem functions as a driver that stimulates action by illuminating the necessity of a solution, thereby constituting the underlying motivation for the ensuing process.

The final function of the problem lies in its capacity to identify valuable information and solutions, by filtering and drawing attention to received information that signals a solution to a defined problem. In other words, it enhances awareness of information that indicates a solution to an acknowledged problem. The identifier is unique as it is the only function including two main concepts: valuable information and valuable solutions. Valuable information includes references that describe how information has been compared to a known problem and then identified as valuable. For example, information about a problem's boundary conditions was used by Adam: "It was the pressure change in the intake manifold and that was what I concluded. So, I made sure not to make any pressure change and then it was peace and joy" (Adam, 2021-03-25, own translation). In a similar way, Johan's research as a doctoral student became valuable when he gained knowledge of a specific problem: "I could use and apply the research I have been involved in, and done, directly [in the work]. Because of the problems that had arisen in the engine, I had tried a method for them" (Johan, 2021-02-12, own translation). The latter includes references to information about potentially valuable solutions to a problem. One example was Cecar's identification of a method as a valuable solution to a known problem: “[We] understood that this was an area that would grow in importance in the future” (Cecar, 2020-07-29, own translation). The filtering of and attention to received information were not only inclusive, but also exclusive by identifying information that was insufficiently valuable. Filip described how an idea was excluded due to its limited connection to a project and its problems, saying “[such ideas] don’t settle that deeply, you don’t work with them that much” (Filip, 2021-03-31, own translation). In summary, the three problem functions help to define the problem, motivate action, and identify a solution, and these are important for the usage of knowledge developed in the collaboration.

For the implementation of collaboration knowledge, the three problem functions offer insights into “why” and “what” collaboration knowledge is assimilated, particularly through the definer function. Frequently, the defined problem is firm specific and not a matter of public interest. Those who have access to the defined problem can also determine a solution. Innovation 2 provides an illustration of this, with the problem being known by Cecar, who identified the method while working at the university. A similar instance is seen in Innovation 3, with David knowing about the specific boundary conditions of the problem and identifying a solution when reading the literature. Another example is Ivar’s assertion that a collaboration is evaluated based on the possible beneficial outcomes for the firm, citing an example in which the firm could gain knowledge of the boundary conditions that influenced its product. The problem definition’s relationship to the usage of collaboration knowledge was probably best summarized by Adam: “Research at universities is often more generic, so they are, like, not so acutely concretely focused on solving the problems that exist. It is also an information problem, as universities do not have access to corporate problems” (2021-03-25, own translation). In relation to the problem, the respondents commented on sources of the specific problems and repeatedly mentioned three sources.

The source of a problem is the origin, or originator, of a specific problem and can be physical or non-physical. The analysis identified three recurrent sources considered by the respondents when taking action: costs, customer value, and regulations. The phrase "taken into consideration" refers to the premises of the respondents' reasoning about the action taken, about the rationale for the action. Following this logic of action causation and the case study methodology's search for commonalities, an excerpt is coded as referring to a problem source at the categorical level when addressing a frequently considered concern—i.e., a root cause. Table 16 provides a detailed breakdown of the three identified problem sources.

Table 16: Problem sources identified from interviews

Sources	Definition	Excerpt	Mentions
Costs	A problem source when capital or monetary reasons are identified as root causes of action or non-action.	"But it is probably not used very much. But CFD has survived, then, [but] this other experimental activity it is far too expensive for the company to engage in. Expensive and staff intensive, so it is happy to send them to universities." (Cecar, 2021-06-07, own translation)	10
Customer value	A problem source when the customer's previous or expected experience is identified as the root cause of action or non-action.	"In my personal experience, this is not so common. Usually, if you get an idea it is not carried out in the project. … So those ideas do not go so deep. You do not work so much with them—now I say "you" but I really mean "I." So it has been relevant to write a patent application on them. Without the things that have led to patent applications, they have also entered the projects." (Filip, 2021-03-31, own translation)	11
Regulations	A problem source when national or international regulations or laws are identified as root causes of action or non-action.	"And at that time, it was exhaust emissions, that is, HC and C and things like that, that the United States constantly introduced hard, hard limits for, they lowered them. So, we needed to solve it. So, we saw then that we had problems with throttling and cold starting and stuff like that. Then it will be huge. So, I chose it as a subject and started researching, and then you end up with wall film on intake manifolds. It's what sets everything apart." (Adam, 2021-03-25, own translation)	49

The table outlines three problem sources, defined in the second column and illustrated by quotations in the third; the frequencies of references to the problem sources are indicated in the fourth column. With the first problem source, *cost*, capital or financial constraints are premises for particular actions or non-actions. In the excerpt, Cecar explained that, due to the expense of experiments, the firm took the action of utilizing the university for this activity. What Cecar pointed out was the mutual value and necessity of experimentation for both the firm and university, but that, due to resource constraints, the firm saw more value in having the university perform this activity. Similarly, another respondent discussed cost, describing it in more general terms:

> It is often a matter of our having a car, and in this car we have limited space. We have limited money and so on. So that we want to have a flexible, cheap solution, of course. (Ivar, 2021-02-10, own translation)

Ivar's comment reflects the commonly held view that cost is a considerable factor when taking action.

The second problem source, *customer value*, is when previous or expected customer experience is the premise for action or non-action. Filip's quotation sheds light on this, detailing which ideas progress to become patent objects and elucidating the necessity of an idea being "carried out in the project." The project here refers to an advanced stage of the product development process involving the development of an engine function to manage torque and mitigate spark jerks and thereby enhance the customer experience. The second part of Filip's quotation concerns desired functional traits, with the driver experience (i.e., customer value) being the premise to be fulfilled to file a patent. Moreover, some interviewees pointed out how customer value is a frequently recurrent aspect of their product development work (see quotation from Erik, below) and of their superior's work (see quotation from Johan, below):

> There's a lot of work you have to put into that part when you develop an engine, because, yes, the customer should perceive it as a good engine. (Erik, 2020-08-12, own translation)

> The manager did not think it was important for the customers. And unfortunately, I think that was right. Customers say they care about the price, but they do not act that way. (Johan, 2021-02-12, own translation)

These accounts describe how customer value is a problem source that is thought of in the respondents' profession.

The third problem source, *regulations*, is when national or international regulations or laws are the premise for action or non-action. This problem source is the most-cited root cause motivating action. Adam's quotation describes how international regulations created the need for a solution and were the root cause of his decision to engage in research. Adam was an industrial Ph.D., and the firm and the university both had major roles in his education. Further emphasizing the impact of regulations as a problem source is Kalle's comment:

> But I think the interest for them is that they have a challenge that they need to solve in the long run from their product perspective. At a certain point in time, they know that they need to meet certain emission requirements in their cars. (Kalle, 2021-02-16, own translation)

In the quotation, Kalle argued that the emission regulations must be considered by the firm in the engine design, directly creating a premise for the firm to participate in the UIC.

This section has presented the findings related to the problem sources and their three functions: definer, driver, and identifier. The next section examines the three paths of implementation.

5.4.2 Three paths of implementation

The interviews emphasized that knowledge developed in the collaboration had been implemented through the theme *path* and its three distinct categories, namely, direct, indirect, and negative. The three paths are on a categorical level, representing diverse ways in which collaboration knowledge is incorporated and applied in various contexts. Table 17 provides an overview of the three paths of collaboration knowledge implementation.

Table 17: The three paths of collaboration knowledge implementation

Path	Definition	Excerpt	Mentions	Main and sub-concepts
Direct	Direct implementation is when the collaboration knowledge is a source of knowledge based on which decisions or actions are taken.	"So, they can physically also look into materials. What happens when you have aged these, and the things clump together or change their structure? Changing properties? Because they are interested in that, because they are trying to make new materials that should be better, then, in terms of both durability and function." (Ivar, 2021-02-10, own translation)	69	Use research output: articles, conferences, in firm code, project meeting
Indirect	Indirect implementation is when the collaboration knowledge is a source of knowledge based on which decisions or actions are taken at a later time.	"It can still be said that it somehow gave rise to the modeling business that has since been started at Volvo PV. So, in that way we had collaboration." (Cecar, 2021-06-07, own translation) "So that was really what we were interested in being able to study, what happens during a stroke inside the cylinder with calculations." (Erik, 2020-08-12, own translation)	245	Capability development: know how to, evaluate or understand, employment, interaction Through: patents, problem rehearsal, solution portfolio, testing Knowledge base
Negative	Negative implementation is when the collaboration knowledge informs the receiver of the limitations or boundaries of a certain phenomenon, causing an action not to be executed.	"So the knowledge was in Swedish industry, but they did not introduce it because they saw restrictions. But all that knowledge, I must say, came through this applied research, and that's just one example. And then there were probably theoretical models, what the air vortices look like and everything in the combustion chamber." (Martin, 2019-01-22, own translation)	9	What not to do

Table 17 presents an overview of the three distinct paths of collaboration knowledge implementation. The table is divided into six columns: the first lists the paths, the second defines each path, the third contains quotations exemplifying each respective path, the fourth enumerates the number of mentions of each path, and the fifth denotes each path's main concept(s) with the associated number of mentions in parentheses and the sub-concepts indented. It can be seen in Table 17 that the indirect path contains significantly more codes than the other two paths. Apparently, this also affects the following number of main and sub-concepts (fifth column). The table shows the main characteristics of each implementation path to the main- and sub-concept level (see Appendix D for all sub-concepts).

The *direct* path is when collaboration knowledge is attributed as a source of knowledge based on which decisions or actions are taken. The knowledge is explicitly acknowledged as the source or basis of the actions taken. Accounts of the direct path include individual experiences referring to collaboration knowledge as generating action; the excerpt in Table 17 is one example of this. The direct path involves using collaboration knowledge from conference presentations, published papers, and project meeting presentations as a source of ideas for solutions to known problems. One example, from the first round, is Wilhelm's narrative of the industrial representative's role in project meetings and the potential to identify a possible solution: "then you see something … this looks interesting" (Willhelm, 2019-01-14, own translation). The word "something" refers to an intriguing element of the presentation that triggered an idea for a solution, the "this looks interesting" in the excerpt. Other examples of mentions of collaboration knowledge serving as an information source for decision making is the sub-concepts (fifth column) articles and conferences, for example when reading an article provide information that is acknowledged as the source for the actions taken.

The *indirect* path refers to the delayed use of collaboration knowledge at a later time. This path includes individual knowledge procured from advanced university studies, for example, Ph.D.-level courses, specifically designed courses for the UIC, and information obtained by firm representatives through interaction with the university or by employing collaboration Ph.D. students. This knowledge or information is later used at the firm. For an account to qualify as referring to the indirect path there must be a linkage between collaboration knowledge and its usage; this quotation from Erik is one such example:

> So that was really what we were interested in being able to study, what happens during a stroke inside the cylinder, through calculations. (Erik, 2020-08-12, own translation)

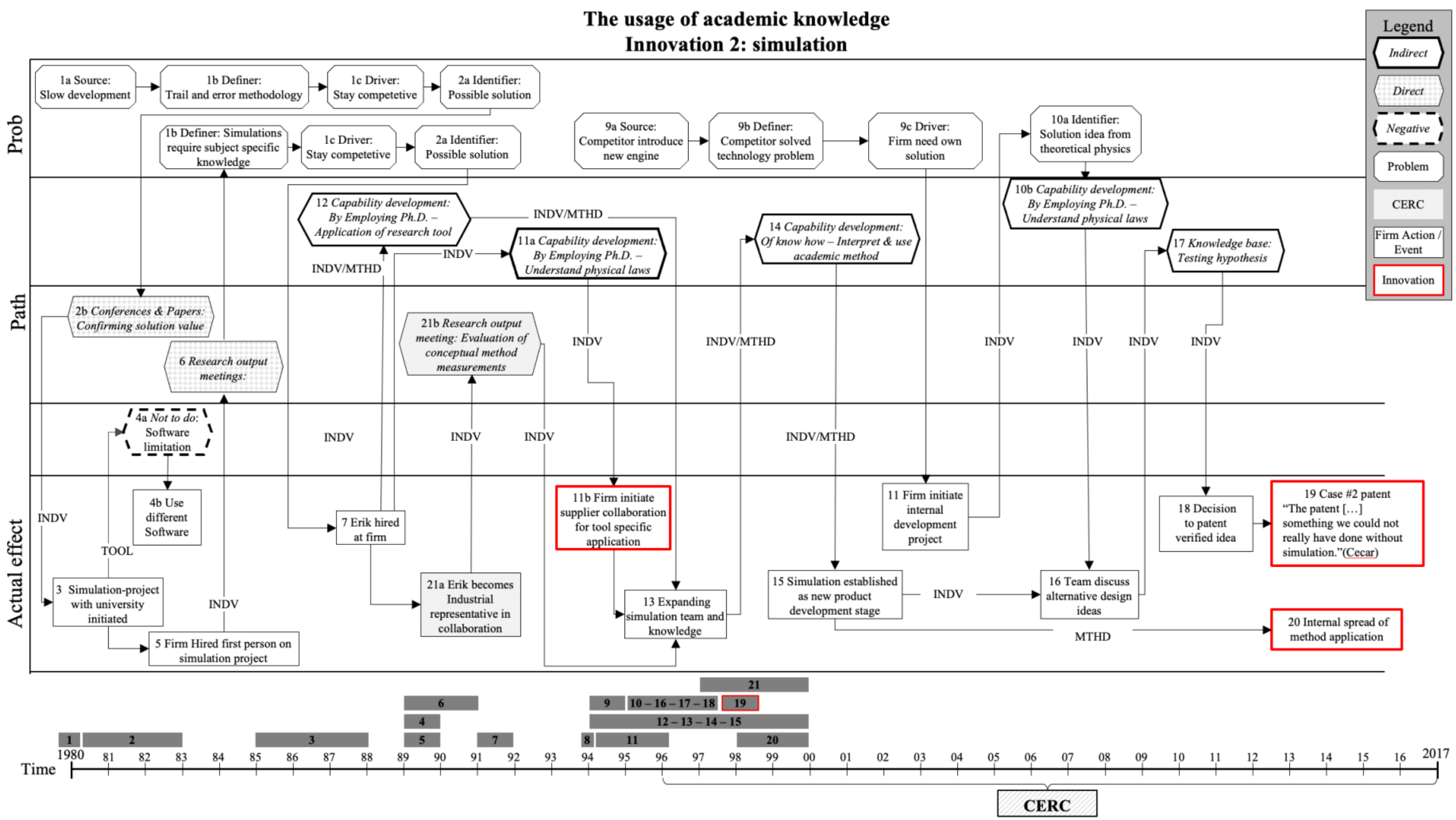
In the above quotation, Erik described how “they” as a group at VCC wanted to understand how to study the phenomena occurring during a cylinder stroke via calculations. concern computational fluid dynamics, whose possibilities VCC had wanted to explore and develop prior to hiring Erik. Shortly before Erik started working at VCC, he finished Ph.D. studies at Chalmers in which this method was a significant component. This prior practical knowledge was one reason for Erik’s recruitment. Therefore, the above quotation fulfills the criteria for exemplifying the indirect path, as Erik’s prior collaboration knowledge was implemented at the firm. A parallel instance can be observed for Innovation 1 regarding Johan, another recruit from CERC, whose academic experience of a new technology was used as a suggested solution to a theoretically predicted problem (box 6 in Innovation 1, see Appendix E). The indirect path is connected to capability and knowledge base development. For example, collaboration knowledge was indirectly used for the internal development of the knowledge required to solve a problem (described in , below) or for a process to explore a scientific or technological knowledge domain (boxes 3, 6, and 7a in Innovation 5, see Appendix E). This knowledge can later be used to solve problems for which the solutions can be innovations. The indirect path represents a less immediate but nonetheless important way that collaboration knowledge contributes to the firm’s decision making and actions, contrasting with the more immediate negative path to be discussed next.

The *negative* path is when collaboration knowledge is acknowledged as a source of knowledge that reduces the room for possible action. An account coded to the negative path describes how collaboration knowledge has informed the receiver of the limitations of, or restrictions on, a subject of interest. In the illustrative quotation in Table 17, Martin recalled how “they” (i.e., the Swedish automotive industry in general) chose not to introduce a certain technology due to restrictions that could be understood by the theoretical models developed by the university. The negative path thus essentially represents how collaboration knowledge can provide the receiver with an understanding of what actions not to take, acting as a form of cautionary guidance.

In regard to the research question, most interviews indicated that usage of collaboration knowledge occurs most often through the indirect path, followed by the direct path and then the negative path. These three paths can be understood as different paths within the AC framework, but relate primarily to the AC assimilation component, through which knowledge from a UIC can be implemented. These three paths provide insights into the varied applications of collaboration knowledge. They help elucidate the nuanced ways that this knowledge is implemented in different contexts to inform action and decision making, either immediately or later, or to provide guidance about what actions not to take.

The three paths are contextualized in Figure 15, below, which illustrates how collaboration knowledge of a simulation method was identified and used by VCC over the 1980–2000 period. In the top row of the model are the problem *source* and the three problem functions: *definer*, *driver*, and *identifier*. The three rows below the problem are the three paths, *indirect*, *direct*, and *negative*. In each row are hexagonal boxes that describe the usage of the collaboration knowledge, and the italic text presents the specific codes used during the coding process. The last row, “Actual effect,” contains rectangular boxes representing firm events or actions. Hexagonal boxes with striped shading contain matters related to the UIC. At the bottom is a timeline from 1980 to 2017, with grey boxes indicating the extent of an event or action. The numbers in the model show the chronological order. The arrows in the model are either thick and represent the patent-related impact of collaboration knowledge or dashed and represent the patent-unrelated impact of collaboration knowledge. Lastly, the red-outlined boxes highlight the patents.

Figure 15: Innovation 2—simulation patent



The numbered boxes in Figure 15 above, help guide our understanding of how an academic method became a new stage in product development.

Box 1. a–c. In 1980, the problem was identified and addressed in an imprecise product development effort using a trial-and-error process. *Box 2. a–b*. In 1983–1985, Cecar identified the simulation method as a possible solution to the above problem; the identification happened through participation in conferences, reading academic articles, and interacting with a professor at a university. At this time, Cecar was working both for VCC and as a teacher at the university. *Box 3*. In 1985–1989, Cecar initiated collaboration between VCC and Chalmers, in which one project focused on the development of the simulation methodology. In this period, VCC and specifically Cecar participated in meetings with the simulation project's doctoral student and received information about its progress. In this period, the respondents described the simulation method as mostly an academic method that was rarely used at VCC; internationally, simulations had started to become accepted outside the university. *Box 4. a–b.* In 1989–1990, Cecar and VCC obtained information about the simulation method's limitations and possibilities, using the method in an internal decision to change to different software; this was because the doctoral student in the initiated simulation projects experienced difficulties with the project's specific software. *Box 5*. In 1989–1990, the information from the simulation was the foundation of VCC's decision to internally assign its own simulation employee to develop the ability to apply this method. *Box 6*. In 1989–1993, the internally assigned employee struggled to apply the simulation method; in parallel, the results of the simulation project meetings indicated that experience with the sub-models used in performing the simulation method was required. At the time, this experience was identified as found among individuals at the Ph.D. level. *Box 7*. In 1991–1992, Erik finished his Ph.D. studies at the same university unit responsible for the simulation project mentioned in point 3, above, and started working at VCC. In Erik's Ph.D. studies, the simulation method had been a significant component. *Box 12*. Starting in

1991, through the hiring of Erik, the firm was able to deploy and develop the usage of the simulation method (i.e., apply the research tool). *Box 13.* Starting in 1995, the simulation team and the simulation knowledge were expanding, and in mid-1990, Niklas was hired. *Box 14*. Starting in 1995, the usage of the simulation method increased through the experience Erik and Niklas had gained at the university and were cultivating at VCC. Their university experience enabled them to use simulations and to interpret the simulation results. *Box 15*. In 1996–1997, simulations became established as a new stage in product development in which the effects of different designs could be simulated and compared before a physical prototype was created.

Returning now to *Box 9*. a–c, in the early 1990s, a competitor of VCC announced the introduction of a new engine including the new technology. By introducing a new engine, the competitor had developed a solution to a technological problem. In the same period and arguably related to the competitor's engine introduction, VCC initiated a project to develop a similar technological solution. Cecar, Erik, and Niklas worked on this project. *Box 10. a–b.* In mid-1990, Cecar was on a field trip and saw an alternative solution to the mentioned problem and concluded that specific physical laws had been drawn upon in its creation. Through this realization, Cecar came up with his own idea to solve the problem. *Box 16*. Starting in 1996, Erik, Niklas, Cecar, and Bertil discussed Cecar's idea and alternative design ideas, and decided on some more promising options. *Box 17.* Starting in 1996, Niklas and Erik simulated and tested the promising options. *Box 18.* In 1997, the team of Bertil, Cecar, Niklas, and Erik decided to apply for a patent for one verified idea. *Box 19.* In 1998, the patent was approved both by VCC and the Swedish patent office.

Regarding the non-specific impact of collaboration knowledge, we return to *Box 11. a–b.* Through the employment of Erik and his understanding of the physical laws affecting the simulation method, VCC had the ability to develop closer collaboration with the supplier of the simulation model. Erik's interaction with the supplier enabled the specification of a basic problem, expressed in the software, specifically for VCC's conditions. Erik described how they discussed the matter in meetings with the supplier: "I was taking over, and then when we changed geometries and then different parts, valves maybe, so we started from this basic problem that they had set up for us" (Erik, 2020-08-12, own translation). *Box 21a–b*. Due to Erik's research experience, he was assigned to represent the firm at different CERC project meetings. Erik described how the project meeting content was valuable because it contained information on methodological approaches that related to his work. Erik described the value of the project meeting content as follows: "They could study the concept but also maybe look a little closer at how to access and to measure in a sensible way and such things even then" (Erik, 2020-08-12, own translation). *Box 21b*. This hexagonal box also impacted the expanding simulation team and knowledge (*Box 13*). *Box 20*. In the late 1990s, simulation was established as a product development resource for engine development through Cecar, Bertil, Erik, and Niklas' work and later the patent. Erik told of how a team, working in the same physical area and on a related part of the engine, had created an opportunity to note the simulation's usefulness and limitations. Sometime around the turn of the millennium, the simulation method was used by another team.

5.4.3 Analytical summary

The analysis of the data shows that a distinct combination of the themes *problem* and implementation *path* characterize the use of collaboratively developed knowledge in firm innovations. As mentioned in the introduction, the purpose of this dissertation is to explore how knowledge developed in a university–industry collaboration is utilized by the collaborating firm in the development of innovations. AC is adopted as a theoretical framework, extending from external knowledge source to internal firm exploitation, to explore how collaboratively developed knowledge is used by a collaborating firm. The data presented in this chapter show that collaboratively developed knowledge is used by the firm and that its usefulness is connected to value. This shows that the knowledge developed in the UIC (CERC) was understood as valuable to both the collaborating firm (VCC) and the receiving individuals, and that its value had a range of associated aspects.

The data analysis synthesized a theoretical model, including three phases, encapsulating the implementation of collaboration knowledge within a firm and outlining the intricate relationships among the three analytical themes: problem, path, and effect. In the model, the firm's problems and the path's categories further specify the relationships. The data analysis illustrates that collaboration knowledge is understood as valuable by being associated with a solution to a firm problem.

The analysis of the problem distinguishes between categories of problem sources and the problem functions definer, driver, and identifier. The problem functions mainly have implications for the recognition and assimilation of collaboratively developed knowledge. The three functions are summarized below.

The definer	–	*The problem is a definer when it describes "what" needs to be solved.*
The driver	–	*The problem is a driver when used to motivate action.*
The identifier	–	*The problem is an identifier when it filters information signaling a solution.*

The results presented here indicate that the firm's utilization of valuable knowledge originating from the collaboration takes place via three paths, i.e., the indirect, direct, and negative paths, which are summarized below. While both the direct and indirect paths lead to the creation of action, the negative path does not.

The direct path	–	*Direct implementation is when the collaboration knowledge is a source of knowledge based on which decisions or actions are taken. The direct path seems to use collaboration knowledge of an explicit nature (e.g., publications) or that is immediately applicable (e.g., configuration of calculation model).*
The indirect path	–	*Indirect implementation is when the collaboration knowledge is a source of knowledge based on which decisions or actions are taken at a later time. The indirect path uses collaboration knowledge that is embedded in the carrier (e.g., by hiring a Ph.D.) or in intellectual property.*
The negative path	–	*Negative implementation is when the collaboration knowledge informs the receiver of the limitations or boundaries of a certain technology or phenomena and causes inaction.*

Within the absorptive capacity theoretical framework, the three *paths* of implementation are here mainly detailed descriptions of the assimilation component of the studied UIC case. Similarly, the three *functions* of a problem have implications for the recognition of the value component. Figure 16, below, illustrates the relationship between the theoretical framework by incorporating these findings.

Figure 16: Theoretical modification of absorptive capacity framework

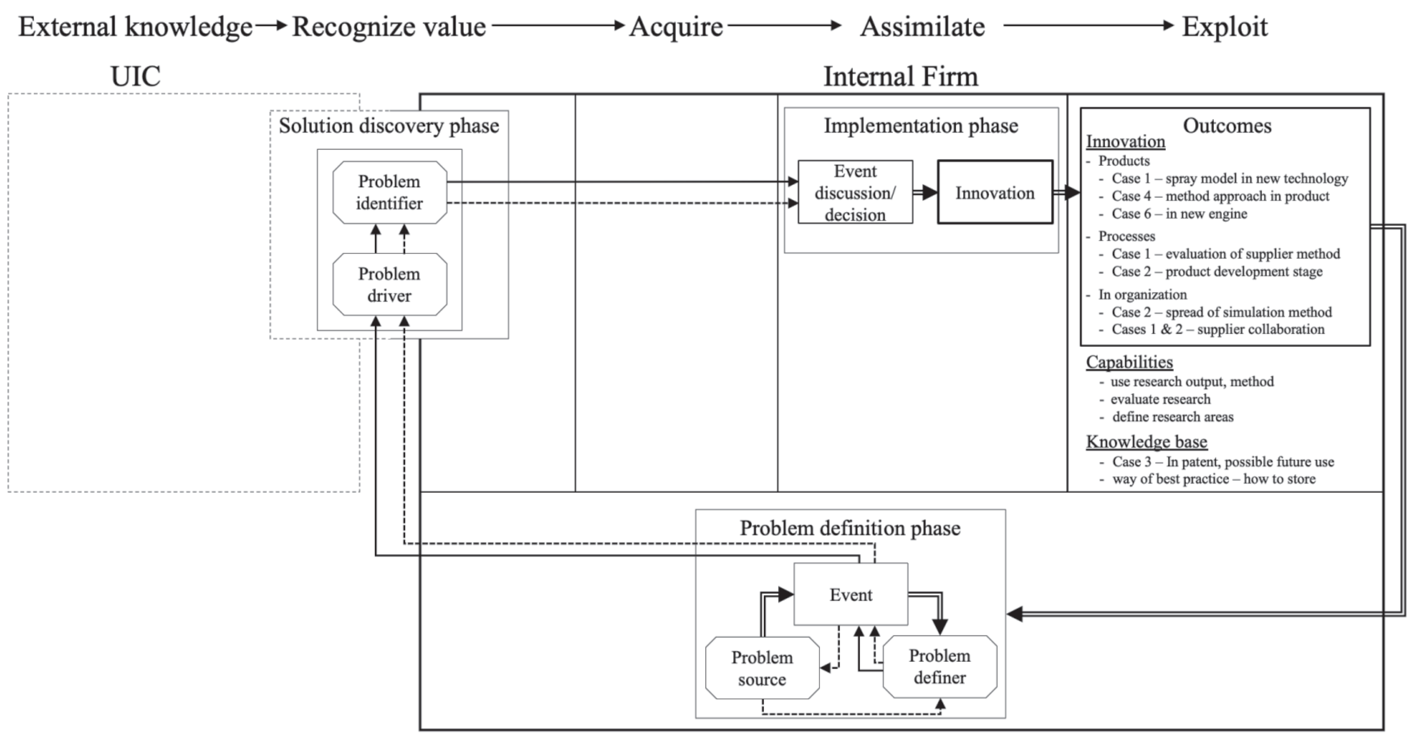


Figure 16 presents the absorptive capacity framework, listing its components and external knowledge horizontally from left to right and including the three phases of the model from the analysis. The first phase, *problem definition phase*, positioned at the bottom of the figure, is conceptually occurring outside the AC framework. This phase contains the *source* of the problem and the problem's *definer* function. This phase is connected to the AC component *recognize value* and the solution discovery phase through two arrows: a dotted arrow symbolizing the *indirect path*, and a solid arrow representing the *direct path*. The *recognize value* component intersects with the *solution discovery phase*, recognizing collaboratively developed knowledge as a potential solution to a firm's known problem. In the solution discovery phase, the *problem driver* function creates the need for a solution and the *problem identifier* function associates the collaboration knowledge with the firm's defined problem from the prior phase. The solution discovery phase in turn leads to the *implementation phase* located within the AC component *assimilation*. This phase contains the firm *event* box, representing actions such as internal discussions of the applicability of the collaboration knowledge. The outcome of such discussions could lead to the decision to implement collaboration knowledge, leading to *innovation*, the thick-outlined box inside the implementation phase. The last AC component, *exploitation*, presents the outcome of the firm's implementation of collaboration knowledge as innovations (i.e., product and process innovations), firm capabilities, and firm knowledge base development. The usage of knowledge developed in the collaboration is connected to two innovation types: product innovations (e.g., simulation models used in new technological and methodological approaches in new products) and process innovations (e.g., methods to evaluate suppliers and the new production development stage, and organizational innovations through new supplier collaborations and simulation method spread). The elements of the figure illustrate the implementation of collaboration knowledge through the three paths and the role of the problem's functions.

The concept of "use" offers nuanced perspectives on the utilization of collaboration knowledge, as indicated by the three implementation paths and the values derived from the data. The research question allows the term "use" to be interpreted more expansively in relation to knowledge, because "use" helps us understand "how" questions. A broad interpretation of the term is needed to capture the complete picture of the intricacies accounted for by the respondents referring to the value of collaboratively developed knowledge. The term "use" is best contextualized in terms of the three paths and their respective roles in creating action. All three paths require knowledge from the collaboration as a premise for taking action, either to act or not to act, but from different time perspectives. Whereas the direct path immediately takes action, the indirect delays taking action and the negative path immediately creates *inaction*. The use of collaboration knowledge does not necessitate a physical or explicit outcome; rather, the outcome can be tacit. For example, a methodological approach learned at the Ph.D. level can be applied by an individual without specifically attributing an explicit outcome. This idea is further exemplified by the negative path, in which knowledge of the limitations of a certain object or phenomenon can lead to a conscious choice not to act, similar to precautions in everyday life, for example, when we tell someone not to put their hand on a hot surface. The implication of this understanding of the "use" of collaboratively developed knowledge is connected to the development of capabilities in the next section.

This analysis indicates that collaboration knowledge is used to develop capabilities over time. The firm is prescient about the knowledge gap that it needs to overcome and about what it wants to learn about. This influences the firm's participation in the collaboration and the problems on which the collaboration project focuses. The desired outcome is knowledge from the collaboration research (often codified) and learning about a phenomenon's characteristics (e.g., flame development and soot), about or specifying the development of a method (e.g., a simulation or algorithm), or about a physical object's characteristics (e.g., sensor evaluation). Over time, the firm's capabilities and knowledge base develop and can become the premises for taking or not taking action. Moreover, the firm can hire collaboration doctoral students to secure the knowledge they gain (i.e., experience) during their education, knowledge that is problem specific. The employment of these students is a way to access more of the collaboration knowledge than just the codified outcomes; if the entire range of the collaboratively developed knowledge could be expressed in codified outcomes, then it would be unnecessary to employ doctoral students. Note that hiring these individuals is one of the reasons for the firm's participation in UIC most frequently cited by respondents.

5.5 Conclusion of the second round of interviews

In the second round of interviews, conducted during 2020 and 2021, the research question was investigated using a qualitative method and semi-structured interviews with patent inventors and individuals who had been identified as important actors in VCC's usage of knowledge developed in the CERC collaboration. The analysis of the 28 semi-structured interviews and patent data shows that a problem's functions influence how collaboratively developed knowledge is recognized as valuable, acquired, and assimilated to develop firm innovations. The results show that the implementation of collaboration knowledge occurs through the *direct*, *indirect*, and *negative* paths. In summary, the analysis of the second round of interviews resulted in two major findings:

1. Problem functions - connected to the recognition of value
2. Three paths - implementation of collaboration knowledge via three paths

The three *problem functions* influence the recognition, acquisition, and assimilation of collaboratively developed knowledge. The term "problem" is here used as a subject, verb, and noun: as a subject concerning information about the source (i.e., thing, place, or person) of the problem, as a verb regarding the condition of the subject (i.e., what it does or is), and as a noun by informing about the "owner" of the problem. First, the problem functions as a *definer* that addresses and describes what needs to be solved. Second, the problem functions as a *driver* motivating actions by showing why a solution is needed. Third, the problem functions as an *identifier* creating awareness of received information that signals a solution to the defined problem. While the first function is performed at the firm, the last two functions are performed in conjunction with the collaboration and are connected to the AC component *recognize value*.

The three *implementation paths* represent three diverse ways in which knowledge developed in the collaboration is incorporated and applied in various contexts. The *direct* path is when the collaboration knowledge is used as a source of knowledge based on which decisions or actions are made. The *indirect* path is when the collaboration knowledge is used a source of knowledge based on which decisions or actions are made at a later time. On the other hand, the *negative* path is when the collaboration knowledge is used as a source of knowledge that limits the scope of possible action, a motivator for why decisions or actions should *not* be taken. In all three paths, knowledge from the collaboration is a premise for either acting or not acting, within different time perspectives. Whereas the direct and negative paths have an immediate nature, the indirect has a delayed nature when it comes to taking action. As mentioned in the literature review, previous research on transferring collaboratively developed knowledge has not yet fully addressed how the effects and values generated in a university–industry collaboration come into existence. The present research provides a detailed description, and its results help to bridge a previously unexplored gap in which some of the findings are more unexpected than others.

6 Discussion and conclusions

This chapter will address and discuss the findings, followed by the theoretical, managerial, and policy implications. The structure of this final chapter is as follows: section 6.1 presents the answer to and discussion of the dissertation's research question. This section presents a concluding theoretical conceptualization that integrates the findings and guides the discussion of the sub-sections. Section 6.2 delves into the theoretical, managerial, and policy implications, and section 6.3 explores potential avenues for future research. The chapter ends in section 6.4 by presenting the final conclusions.

The phenomenon studied here is how cooperatively developed knowledge, resulting from knowledge-related interaction in a UIC, is internally utilized by a firm. The purpose underlying this dissertation is delineated as follows:

Purpose

The purpose of this research is to explore how knowledge developed in a university–industry collaboration is utilized by the collaborating firm in the development of innovations.

This purpose formulation centers on the firm perspective and on the intrafirm functions and practices that facilitate the firm's utilization of knowledge derived from the collaboration. The aim is, by means of empirical descriptions, to contribute to and improve our understanding of how the collaborating firm internally develops innovations using knowledge derived from collaboration. This dissertation applies a firm perspective and a qualitative single-case study design to address the research question. The university–industry collaboration is selected as the type of interaction and the CoE is the selected form of collaboration in which the firm and university engage in knowledge-related interactions. The CERC collaboration as a CoE is the studied case, thereby providing the context of this dissertation. The CERC collaboration is a prominent case because, as a CoE, its initial rationale was to foster and perform industry-relevant research of high scientific quality, generating innovations in the participating companies. CERC was founded to be a forum for industrial and academic research on internal combustion engines, with the purpose of building a concentrated interdisciplinary research pool in which the participating firms could actively take part and benefit from the long-term perspective. The long-term objective was to “carry out fundamental research of high industrial interest” (Karlström, 1997, p. 2). The Center’s focus on basic and transdisciplinary research of industrial relevance remained consistent over the years.

6.1 Leveraging collaboration knowledge for firm innovation

The research question was addressed through a qualitative approach and a single-case study research design focusing on the comparison of innovations. The research employed semi-structured interviews with 27 respondents as the primary data, conducted in two interview rounds, for a total of 37 interviews. The primary data encompassed individuals with practical experience of the CERC collaboration, such as patent inventors, industry experts, and influential decision makers. As secondary data, CERC annual reports, scientific publications, patents, VCC press releases, and participant observations were used to substantiate the analysis.

This research employs absorptive capacity (AC) as the theoretical framework to elucidate the collaborating firm’s ability to recognize the value of, acquire, assimilate, and exploit external knowledge, with knowledge developed in the CERC collaboration being conceptualized as external knowledge. To understand the firm’s internal utilization of collaboration knowledge, this research accentuates the absorptive capacity components *recognize value*, *acquire*, and *assimilate*. The two interview rounds focused on the identification of influential firm roles, the firm’s problems, and the implementation of collaboration knowledge in relation to the AC components. The findings show that three roles are important for the firm's integration of collaboratively developed knowledge, influencing the firm's internal development of innovation. These roles are: the *translator*, a role central to initiating the collaboration; the *interpreter*, a role essential to the recognition component; and the *assimilator*, a role important for the assimilation component. The firm's problem and functions are important for defining what needs to be solved, for justifying why a solution is needed, and for identifying a solution. Defined firm problems are important for the AC recognition component. The three implementation paths elucidate how collaboration knowledge is used to inform action and decision making, either directly or at a later time, or to indicate what actions not to take. Having presented this short summary, I now turn to the research question of this dissertation, which is stated as follows:

RQ

How does a collaborating firm recognize, acquire, and assimilate knowledge from a university–industry collaboration to develop firm innovations?

In response to the research question and, it was found that a distinct problem configuration of the firm, including sources and functions, three implementation paths, and three different roles, characterized how collaboration knowledge was utilized to develop firm innovations. The collaborating firm recognized the knowledge as valuable by means of its capacity to address a defined firm problem and through the role of the interpreter. The collaboration knowledge was acquired as an idea for a solution through the interpreter. The collaborating firm assimilated the knowledge by internally applying it in existing or new processes through the role of the assimilator. Table 18 presents an overview of how the collaborating firm recognized, acquired, assimilated, and exploited knowledge from the collaboration.

Table 18: Overview of how knowledge from the collaboration was recognized, acquired, assimilated, and exploited in firm innovations.

	Recognize	Acquire	Assimilate	Exploit
What	Knowledge was recognized as valuable by its capacity to address a defined firm problem	Knowledge was acquired as an idea for a solution to a problem	Knowledge was internally used and applied in existing or new processes	Knowledge was embedded in product or process innovations or in the knowledge base
Why	Because the interpreter had and iterated knowledge of firm problems	Because of the expected capacity of the knowledge to solve a defined problem	The assimilator applied the knowledge to evaluate its potential as a solution to a defined problem	Because the knowledge was evaluated as a whole or partial valuable solution to a defined problem
When	When receiving knowledge from the collaboration	When the knowledge matched a known problem but had not been used and verified as a solution	When the knowledge was used in existing or new processes	When the product or process was available to the intended user
Where	The formalized UIC meetings	The formalized UIC meetings	Internally and under firm-specific conditions	Internally in firm operations or processes Externally as all or part of a new product
Role	The interpreter	The interpreter	The assimilator	The firm

Table 18 presents a detailed exploration of knowledge processes within a collaborating firm, focusing specifically on the AC stages of *recognize*, *acquire*, *assimilate*, and *exploit* knowledge. Each column represents one of these processes, with each row providing insights into the characteristics, rationale, timing, location, and key role associated with each process. Below is a presentation of each component. In Figure 17 the problem, paths, and roles are synthesized in a theoretical model encapsulating how the firm developed innovations from collaboration knowledge. The figure integrates the findings within the AC framework.

Figure 17: Concluding theoretical conceptualization of absorptive capacity framework.

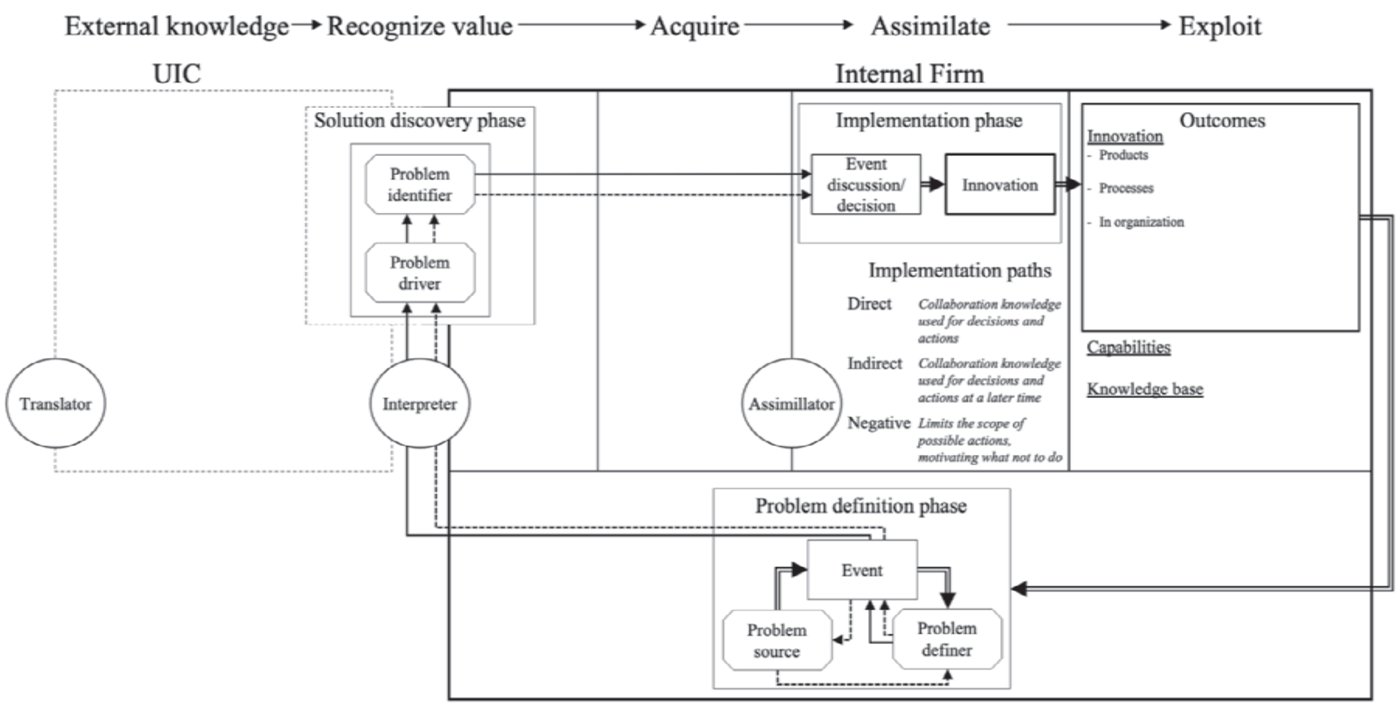


Figure 17 is a concluding conceptualization, encapsulating the identified phases, roles, and paths. Detailed elaborations of Figure 17 including examples and discussion follow in the subsequent sections. At the top of Figure 17 on the left is the external knowledge source, here the UIC, followed by the AC components recognize value, acquire, assimilate, and exploit. The firm's problem is defined in the problem definition phase, which comprises the problem source, the problem definer function, and the event. The collaboration knowledge is recognized as valuable in the solution discovery phase, which comprises the problem driver and problem identifier functions. The knowledge is assimilated in the implementation phase, which comprises the event and innovation. The outcomes of implementing the collaboration knowledge are presented within the AC component exploit, here comprising innovation (i.e., product, process, and organizational innovations), capabilities, and the knowledge base. The three implementation paths represent diverse ways in which collaboration knowledge is incorporated and used by the collaborating firm. Lastly, the three identified roles (i.e., translator, interpreter, and assimilator) are illustrated in circles.

The following three sections present and discuss the findings referring to Figure 17 above, with section 6.1.1 addressing the external knowledge source, the two AC components recognition of value and acquisition, the two phases problem definition and solution discovery, and the identified translator and interpreter roles. Section 6.1.2 concerns the AC components assimilation and exploitation, the implementation phase, the three paths, and the identified assimilator role. Section 6.1.3 concerns the identified roles and centers on the translator role.

6.1.1 The recognition and acquisition of collaboration knowledge

While the absorptive capacity literature presents a broad understanding of the recognize value component (the first solid-outlined component in Figure 17), the details of why and how external knowledge from a UIC is recognized as valuable require further clarification. Here two levels, the individual and firm levels, of value recognition will be discussed. Individuals are active in the recognition of the value component (cf. Matusik and Heeley, 2005; Volberda et al., 2010). The firm's prior knowledge allows it to recognize value in new information (Cohen and Levinthal, 1990) and that its prior knowledge is embedded in the individual level (Lane et al., 2006). The discussion also connects how organizational routines enable a firm to recognize complex knowledge from external sources as valuable (Galunic and Rodan, 1998; Lane et al., 2006; Van den Bosch et al., 1999).

From the present findings, the process of value recognition at the individual level is initiated in the problem definition phase and subsequently the solution discovery phase, primarily by the translator and interpreter. Simultaneously, the firm-level AC value recognition occurs through routines and iterative practice. The firm's problem is defined in the problem definition phase that pivots around the events and actions driving the formulation of the problem definition, i.e., describing the specifics of the challenge at hand. This phase thus creates the foundation for discovering possible solutions, later to be recognized as valuable in the subsequent solution discovery phase. In Figure 17, the problem definition phase incorporates the components problem source and problem definer, shown by the labeled rectangles with snipped corners. The problem source provides the origin, or originator, of a specific problem (whether physical or non-physical), and in the context of the UIC, the three sources' regulations (national and international), the customer value (customers' experience of the product), and the costs are identified as problem origins. The definer function helps to address and describe what needs to be solved, defining the problem within the UIC in terms of the specifics the engine must fulfill to meet the environmental regulations. Both the source and the definer functions are vital for the possibility of finding a solution. Additionally, the problem phase has an event component, the regular rectangle, which represents an effect of implementing the collaboration knowledge or a firm action.

Here, the translator is observed to have had a central role in the initiation of the UIC by recognizing the university as a valuable external source of knowledge with which to address the firm's unsolved problems. For the initiation of the collaboration, the unsolved problem was of a general non-specific character, such as decreasing the combustion engine's carbon footprint. Collaboration with the university was a potent avenue for solving the problem by enabling access to knowledge that the firm could learn and innovate from. The translator often had irregular interaction with the university requiring general understanding of the university's knowledge domains to determine its usefulness for the solving the firm's problems. One example is a translator suggesting computer modeling for engine simulation (external knowledge domain) to reduce the time burden of the trial-and-error process; however, as a function of their role, they cannot perform the technical aspects (specific knowledge domain) of model development themselves. In other words, before the UIC was formalized, the translator identified computational modeling as one of the university's knowledge domains to include in the collaboration. The value of collaboratively developed knowledge depends on its capacity to address a firm's defined problem. Therefore, defining the problem occurs prior to the recognition of value and internally in the firm, in the problem definition phase.

The next phase, the solution discovery phase, is located within the AC recognize value component that in the UIC context interconnects collaboration as the external knowledge source and the internal firm perspective. In this phase, the main subject is the identification of a solution to the previously established and defined problem. This phase illustrates the cognitive aspect of the problem-solving logic, accounted for across the innovations, and incorporates collaboration knowledge. For example, "it is only by producing knowledge that a problem can be solved" (Landry, 1988, p. 318)—in other words, solving a problem requires a combination of the necessary information (about the problem) and problem-solving abilities (Von Hippel, 1994). In the UIC context, this combination is suggested to occur in the solution discovery phase and by the driver and identifier functions. The problem's driver function motivates actions to determine why a solution is needed and to search for a solution. The identifier function creates awareness of received information, signaling a solution (cf. Autio et al., 2013). These two functions are performed in conjunction with the UIC and the formalized meetings, illustrated in Figure 17 by the rectangle with both dotted- and solid-line borders. The driver and identifier functions can be correlated to previous findings of Nickerson and Zenger (2004), who found that managers must choose valuable problems (value depending on the number of possible solutions and the cost of their discovery) and search for knowledge of the solutions, which is a question of searching. This helps us understand how external knowledge can be interpreted as a valuable solution to a valuable problem. Davenport and Prusak (2000) claimed that value was an integral part of knowledge, determining how conclusions are drawn from observations. In the context of the UIC, the solution discovery phase involves individuals in the recognition of value and may provide insights into how recognition can be fostered by its connection to the prior problem definition phase, in which the problem's functions point to a sequential relationship between the firm's definition of a problem and later solution discovery.

When the UIC is formalized, the recognition of value shifts from the translator role to the interpreter role. The interpreter role is a formal role assigned to the structured and formalized UIC meetings and requiring specific knowledge within the same domain as the external knowledge source and the knowledge base of the receiving firm unit. An example is when the translator has general knowledge of the external domain (i.e., computer modeling) and the firm's knowledge base (i.e., combustion engines) and identifies the university as a valuable source of knowledge with which to solve the problem (i.e., to decrease the carbon footprint of the combustion engine). When the UIC is formalized, the interpreter has specific knowledge of both the external domain (i.e., how to perform computer modeling) and the firm's knowledge base (i.e., combustion engines), and can interpret when a collaborative specific domain research outcome (i.e., computer modeling), presented in the meetings, is valuable to solve the firm's problems. In other words, the interpreter receives and interprets the collaboration knowledge depending on its potential applicability to the problems at the firm. The incorporation of the translator and interpreter roles further elaborates on the actions of individuals in the AC recognition of the value component (cf. Matusik and Heeley, 2005; Volberda et al., 2010). Additionally, the incorporation of these roles demonstrates how prior knowledge (i.e., the translator's general knowledge and the interpreter's specific knowledge) is connected to the firm's recognition of value (Cohen and Levinthal, 1990), or explorative outcome (Lane et al., 2006), in a UIC context. The roles as they pertain to the problem definition and solution discovery phases may also illustrate how knowledge similarity influences the firm's AC (Dyer and Singh, 1998; Lane and Lubatkin, 1998; Sancho-Zamora et al., 2022). Hence, the knowledge developed in the university–industry collaboration is recognized as valuable at the individual level by the translator and interpreter, who are connected to the AC recognize value component.

Furthermore, AC recognition of the value component occurs at the firm level through routines and iterative practice. The relationship between the firm and the individual is vital in understanding how value recognition occurs within the UIC. Prior AC researchers such as Todorova and Durisin (2007) claimed that valuing is not automatic and needs to be fostered for absorption to begin at all. Fostering is here a firm-level function. Other scholars have drawn connections to organizational routines and to the fact that they enable a firm to recognize more complex knowledge from external sources (Galunic and Rodan, 1998; Lane et al., 2006; Van den Bosch et al., 1999). In relation to this literature, one aspect of the problem's identifier function can illustrate a synergistic relationship between two levels of analysis, i.e., the firm level and individual level, with the firm level providing and defining the problem, thereby constructing boundaries for the individual level. Here, the aforementioned connection between the AC recognize value component, routine formation (Galunic and Rodan, 1998; Lane et al., 2006; Van den Bosch et al., 1999), and fostering (Todorova and Durisin, 2007) has several implications.

Feldman and Pentland conceptualized the organizational routine as incorporating two aspects, the ostensive and the performative. The routine's ostensive aspect is its ideal outcome or what the result of the routine should be, i.e., the firm-level aspect. The routine's performative aspect here focuses on its iterative practice and the performance of the routine, i.e., what is done at the individual level. This aspect can hypothetically foster awareness when the practitioner of the routine considers that the ideal outcome has been achieved. In the UIC, the CERC project meetings (formalized) can be defined as an organizational routine that included both actors and routine aspects. The project meeting's ostensive aspect and ideal outcome was, from the firm perspective, to allocate valuable collaboration knowledge addressing a defined problem. The performative aspect was the firm representative's participation in the meeting, the interaction, and when the meeting participants understood/judged that the ideal outcome had been achieved. In the UIC the representative is the interpreter. When valuable knowledge was recognized in the project meetings, the present findings argue that the solution discovery phase and the problem's two functions, i.e., driver and identifier, had been performed. These functions were performed on the individual level by the interpreter, emphasizing why the external knowledge was recognized as valuable. As stated earlier, this knowledge has the capacity to address a defined firm problem, and the preceding problem definition phase drives the definition of the problem at hand. The problem definition phase's problem source and definer function are determined at the firm level, whereas the solution discovery phase is performed on the individual level. Through distinguishing between the problem's functions and allocating them to either the individual level or the firm level, it is argued that the firm primarily impacts the problem's source and definition (in the problem definition phase), and that the individual primarily impacts the driver and identifier functions (in the solution discovery phase). Together, they interact to achieve the AC recognition of value component, because in the routines' performative aspect, achieving the ideal outcome is an individual-level evaluation performed by the interpreter. In the meetings, the interpreter recognizes collaboration knowledge as valuable depending on the solution's capacity and thereby achieving the routine's ideal outcome—allocating valuable collaboration knowledge. Moreover, the problem's identifying function can clarify "how" the AC recognition of the value component is executed through the interpreter's prior developed knowledge of firm-defined problems (with value as an integral part, see Davenport and Prusak, 2000) that has created awareness of a solution—the identification function. "Why" the collaboration knowledge is recognized as valuable would then follow as the solution to a repeated problem.

6.1.2 The assimilation and exploitation of collaboration knowledge and three paths of implementation

When the collaboration knowledge was recognized as valuable in the meetings, it was obtained through the AC acquire component and by the interpreter. In the UIC, the knowledge was acquired as an idea for a solution to a problem when the interpreter had matched the collaboration knowledge to a known problem but not applied and verified it as a solution. The interpreter acquired the knowledge because of its expected capacity to solve a defined problem. The collaboration knowledge was then used in the implementation phase, occurring in the AC assimilation component in Figure 17.

This phase explores the assimilation and practical application of collaboration knowledge. The assimilation of collaboration knowledge takes place when the knowledge is internally used or applied in existing or new processes, and under firm-specific conditions, by the identified assimilator role. Through internally using the knowledge, the assimilator evaluates its potential as a solution to a known problem. The assimilator's use of collaboration knowledge is both practical and theoretical:

practical by applying ideas, methods, or approaches that originate from the collaboration knowledge; theoretical by applying the selected knowledge in internal interactions as hypothetical, or ideas for, solutions to firm problems. The usefulness of the collaboration knowledge is the subject of the "Event discussion/decision" phase rectangle in Figure 17, which revolves around discussions and decisions regarding the problem. The result of this discussion is the possible action to implement a solution when the identified knowledge is to some degree part of the solution, i.e., the "Innovation" phase rectangle outlined in a thick solid line. In this way, the collaboration knowledge is exploited, which is the last AC component. The collaboration knowledge that has been evaluated as a valuable solution to a problem is embedded in product or process innovations and contributes to enhancing the firm's knowledge base. The exploitation of collaboration knowledge takes place internally in firm operations or processes, and externally as a new product or as part of a product. It is initiated when the product or process becomes available to the intended user. The identification of an influential role for the AC exploitation component has not been within the purpose of this dissertation. Thereby, a specific role has not been identified.

In the implementation phase, both the interpreter and assimilator roles are important. The assimilator role requires knowledge of the firm's prior problems and solutions for a specific technology as well as knowledge selected in the formalized meetings by the interpreter. These two roles can be filled by a single individual simultaneously, suggesting a potential overlap in functions. This means that the individual recognizing the collaboration knowledge as valuable is also applying and evaluating the knowledge as a solution. This can describe why knowledge similarity is found to increase the assimilation component (Puranam et al., 2009). This makes the border between the AC components acquire and assimilate somewhat vague, so the assimilator is placed on the border between these components.

Prior research has described how collaborative research can lead to firm innovations through two routes, the indirect and direct routes (McKelvey and Ljungberg, 2017). The direct route (i.e., commercialization) involves the tangible research results being directly transferred to the collaborating firm and then commercialized. The indirect route (i.e., academic engagement) accounts for how an intangible outcome of university collaboration can indirectly foster innovations when knowledge, from the collaboration, in various ways is transferred to the collaborating firm for possible use and development, enhancing the firm's internal capabilities to innovate. The here-identified three *paths* of implementation (i.e., direct, indirect, and negative) contribute to McKelvey and Ljungberg's (2017) conceptual framework of how the *indirect route* impacts firm innovation. The important difference between the terms "route" and "path" is scale, as the former addresses the collaboration-level and the latter the firm-level processes of how research leads to firm innovation. A path describes how collaboration knowledge is used in practice by the firm as a premise that motivates immediate internal action (the direct path), immediate inaction (the negative path), or delayed action (the indirect path). Specifically, all implementation paths describe how the firm's innovation capabilities are developed, through the indirect route, by increasing the firm's knowledge base so that an innovation can subsequently be realized.

In the UIC context, and in the formalized meetings, the direct and negative paths use the collaboration knowledge as a premise arguing for action. For example, the interpreter receives collaboration knowledge regarding a method (i.e., computer modeling) in the meeting and recognizes it as a valuable idea that can be directly tested in firm conditions by the assimilator. Here, the collaboration knowledge is an argument for action to test the method. Negative usage, on the other hand, is when the interpreter receives collaboration knowledge regarding a specific condition of an essential physical phenomenon, for example, the limited possibility to modularly express how the flame, inside an engine cylinder, develops during the ignition cycle.

Such collaboration knowledge can be recognized as a valuable idea for a solution that argues for not taking action. In this case, the firm can use the collaboration knowledge as the deciding premise to wait until the knowledge domain has developed. Therefore, the collaboration knowledge, and the specific condition, can reveal the limitations of a method and thereby serve as an argument for not taking action.

Not specific to the formalized meeting, the collaboration knowledge can, via the indirect path, be subsequently recognized as valuable through individuals who gain access to firm-defined problems. The present findings show that the firm's employment of collaborative Ph.D. students contributed to its capability development by means of the application of research tools and methods, the interpretation and use of academic methods, hypothesis testing, knowledge of physical laws, and knowledge sharing by working with others. The indirect route was further investigated by Berg and McKelvey (2020). Their research explores a similar context, i.e., collaboration between the firm and university, but in contrast to the present research, Berg and McKelvey's (2020) industrial Ph.D. student was a firm employee, as opposed to the aforementioned collaborative Ph.D. student, who was first employed by the university. Hence, industrial Ph.D. students have access to firm-defined problems prior to firm employment, whereas the collaborative Ph.D. students gain access to firm-defined problems after completing graduate studies. Therefore, one could argue that industrial Ph.D. students could contribute to the direct and negative path due to their immediate access to firm-defined problems, whereas collaborative Ph.D. students could contribute to the indirect path due to their delayed problem access and recognition of collaboration knowledge as valuable. Moreover, the individual case visualizations (see Appendix E) show how the accumulation of collaboration knowledge, through the three paths, contributes to the firm's internal knowledge base and, by extension, to solving firm-identified problems through solutions classified as innovations.

It is thus suggested that the direct, negative, and indirect paths describe firm-level functions that elaborate on how collaboration knowledge is applied, and how the firm's knowledge base, and thereby the firm's innovative capability, develops.

While discussing the paths, the negative path of implementation is a result that merits elaboration, because the findings suggest that the negative application of knowledge may be the most frequent implementation path. This means that when the content of received external knowledge supports not taking action (i.e., research reveals limitations of a phenomenon, rendering it irrelevant), this gives rise to the dilemma of how to measure negative use. In this research, the negative path is a conscious decision to use knowledge, separating it from scholarly concepts such as de-adaptation and non-innovation included under the umbrella term "Novation" (Godin and Vinck, 2017). In NOvation, dominant ideology and theory affect new processes and phenomena by making them appear mindless, sub-rational, and difficult to regard as common goods (Godin and Vinck, 2017). The negative path is a conscious and deliberate decision, versus NOvation, which concerns neglect. The negative path is closer to the types of research use referred to as conceptual and symbolic. The conceptual use of research is for general enlightenment with indirect effects, and the symbolic use of research is to legitimate or sustain an existing position (Amara et al., 2004). In practice, the negative path is similar to Fleming and Sorenson's (2004) notion of the modest role that science plays in ruling out unfruitful directions. Initially, the negative path, by motivating action, seems to be a symbolic use because it legitimizes action. However, from a time viewpoint, knowledge from the collaboration might be exploited later and more indirectly to motivate action. This opens up a possible sub-path of implementation, i.e., the negative indirect path.

6.1.3 The influential firm roles

This research notes that the three roles translator, interpreter, and assimilator are connected to the AC framework and the firm's internal use of knowledge, originating from the collaboration, in its innovation development. The relationship of these roles to the AC framework is shown in Figure 17 and depicted by the circled labels. The translator is an informal role, located on the left-hand border of the external knowledge source. The interpreter is a formal role, located on the border between the external knowledge source and the recognize value component. The assimilator is a formal role, located on the border between the acquire and assimilate components. While the translator role is comparable to Cohen and Levinthal's (1990) boundary spanner, this research identifies two additional roles (i.e., the interpreter and assimilator) that also influence the firm's AC. In this research, these two roles were usually filled by a single individual, suggesting a potential overlap in function. In contrast, in the studied case, the translator role was filled by one individual who informally interacted with the university and identified it as a source of knowledge for possible solutions to known firm problems. The translator was a supportive actor, valuable for initiating the UIC, but was not further involved in the formalized processes of facilitating the firm's integration of collaboration knowledge. These findings contribute to the AC literature by adding the two roles and elaborating on the relationship between individual-level roles and a firm's AC within the context of UIC.

Cohen and Levinthal (1990) identified the boundary spanner as an informal role with an interface function, monitoring and translating external information to be understandable to the layperson, and conducting an intentional search for solutions. Rohenkohl et al.'s (2021) depiction of the boundary spanner mirrors Cohen and Levinthal's (1990), but they further highlighted the efficiency of this role's influence on the firm's AC. Rohenkohl et al.'s (2021) concept of efficiency, derived from Penrose (2009), encapsulates the firm's structures and activities that form how the boundary spanner views and incorporates opportunities. The theoretical framing of the boundary spanner by both Cohen and Levinthal (1990) and Rohenkohl et al. (2021) is similar to the translator described in the analysis in chapter 4. The boundary spanner's position in a network can be understood in terms of Lissoni's (2010) "gatekeeper"[16] analysis of academic inventors who can assume the boundary spanner role. Lissoni's boundary spanner is positioned as a node between the two industrial researcher and academic researcher nodes. In contrast to Lissoni's characterization of the boundary spanner as a third node in a network, the translator role identified here incorporates both the boundary spanner and industrial researcher nodes. Thereby, the translator role places particular emphasis on industrial research.

In contrast to prior research, the present results suggest a difference between theory and practice regarding the translator's intentional search for solutions, compared with Cohen and Levinthal's (1990) boundary spanner. The translator described in the current study also undertakes the interface function; however, the translator differs in that the search for a solution is found to be unintentional and the recognition of value coincidental. The translator's identification of the university as a valuable source of knowledge with which to address known firm problems can be understood from its interface function, here positioned between the firm and the university. Autio et al. (2013) argued that an individual's opportunity evaluation ability is enhanced by two technological information factors: lead user attributes (e.g., awareness of bottlenecks and seeking solutions create heightened solution sensitivity) and technological probing (i.e., access to technological developments). The term "opportunity evaluation" means discerning whether external opportunities are aligned with feasible and desirable first-person entrepreneurial aspirations. The translator's interface with the university provides insight into both technological developments and bottlenecks, so the role is aligned with opportunity evaluation

[16] When elaborating on the term "gatekeeper," Lissoni (2010) referred to Tushman and Scalan (1981), who used the term "boundary spanner," so the gatekeeper is here comparable to the boundary spanner.

even though the search remains unintentional. Instead, the intentional search for a solution is executed by the interpreter role in the UIC. The interpreter differs from the AC literature's boundary spanner by being a formalized role that identifies and selects external knowledge. The interpreter has specific domain knowledge and is therefore assigned to a specific UIC project as a formal representative of the firm. These two roles have a similar function in evaluating and identifying the value of external knowledge, and it seems to be the case that the translator is a UIC role with informal knowledge-related interaction and that the interpreter is a firm role with formal interactions. Differentiating the roles is that the interpreter's search scope is narrower, solution oriented, and intentional, versus the translator's search scope, which is wider and somewhat more unintentional. The interpreter's narrower orientation is linked to the role's formal interactions and to the interpretation and selection of information depending on its applicability. This is comparable to the AC boundary spanners, who view and incorporate opportunities formed by the firm's structures and activities (Rohenkohl et al., 2021). Therefore, it is reasonable that the individual who intentionally identifies the collaboration knowledge as valuable should also apply and use the knowledge, as does the assimilator role in this research. This offers a perspective from which to understand the relationship between high-level AC and innovation performance in the UIC context. The interpreter's specific knowledge is comparable to employee know-how, a conceptualization of high-level AC that positively moderates the firm's innovation performance (Biedenbach et al., 2018; Kobarg et al., 2018). In this research, the interpreter and assimilator roles can be performed by one individual, thereby interlinking the AC components and the innovative outcome. The above discussion of the identified translator role is grounded on limited data and need further empirical investigation for confirmation.

In the context of university–industry collaborations and firms' absorptive capacity, three distinct roles have emerged, expanding on the singular role of the boundary spanner as outlined in previous literature. These roles encompass the translator, interpreter, and assimilator as influencing the firm's absorptive capacity and its internal utilization of collaboration knowledge in the development of innovations. The three roles and their features help conceptually illustrate how individual agents impact (Matusik and Heeley, 2005; Volberda et al., 2010) the firm's AC. In the UIC context and the AC framework, the translator and interpreter are the roles that recognize the collaboration knowledge as valuable and acquire it, whereas the assimilator facilitates the integration of this knowledge. The distinction between the three roles, as accounted for here, has to the author's knowledge not been identified in prior literature on UIC and AC.

6.2 Theoretical contributions, and managerial and policy implications.

In this section, the theoretical contributions and the managerial and policy implications of this dissertation are presented, beginning with the theoretical contributions that concern absorptive capacity and academic engagement, followed by the managerial and policy implications.

In the context of a UIC and from the firm-level perspective, the interpreter and the assimilator are two conceptual roles that influence the firm's AC. These two firm roles are different from the prior conceptual role of the boundary spanner in the AC theoretical framework, which is similar to the translator role identified here. The distinctions between the translator, interpreter, and assimilator describe in greater detail how external knowledge from a UIC is recognized, acquired, and assimilated by the collaborating firm. The here-accounted-for interpreter and assimilator roles help us understand how and why collaboration knowledge is recognized as valuable in the formalized meeting, acquired, and assimilated. In the same way, the translator role contributes by describing the characteristics of a UIC-initiating individual who recognizes the university as a valuable knowledge source and understands why that source is identified as valuable. The translator role expands our understanding of how firms identify valuable external knowledge sources and denotes the option of unintentional discovery. The interpreter role provides insight into how firms formally engage with external knowledge sources, identify valuable knowledge, and emphasize domain-specific knowledge in the innovation process. The assimilator role sheds light on how firms assimilate and apply collaboration knowledge in their innovation processes and highlights the role of individual agents in this process. These findings merit further investigation to explore their impact.

For absorptive capacity, the results address the question of how value recognition and assimilation occur (Fabrizio, 2009) and cast light on their connection to the receiver's prior related knowledge (Volberda et al., 2010). The results indicate that the recognition of value component is connected to the solution discovery phase, which is tied to the knowledge receiver and the firm's problems in which the receiver is engaged. For the knowledge receivers, the translator, and the interpreter, the prior related knowledge constitutes both the external knowledge domain and the firm's problems that, when combined, affect the recognition of value. This combination takes account of the nature of the external knowledge (Vega-Jurado et al., 2008), with the similarity of knowledge domains being related to the firm's AC and, specifically, to the recognition of value (Fabrizio, 2009). This is the case for both the interpreter and value recognition in the project meetings and for the translator and value recognition during informal university interactions. While the prior literature has considered aspects of the nature of external knowledge, such as the complexity of knowledge (Hansen, 1999), type of knowledge (basic and applied, Mangematin and Nesta, 1999), and applicability of knowledge (Vega-Jurado et al., 2008), the combination of knowledge domain overlap and firm problem helps reveal how prior knowledge affects AC.

The results also indicate a relationship between the individual level and the firm level and how their interaction can be understood from a problem-centric perspective in which individual recognition of value is connected to role-specific problems. This is the case when the role includes iterations of tasks anchored to a specific firm role and often specified in a work description. For example, the role of development engineer in the department of combustion engines includes the performance of tasks to solve problems in order to enhance engines. The problems connected to these tasks are provided by the individual who designates the roles in the work description, here conceptualized as the organization.

Regarding academic engagement and the formal interaction occurring in university–industry collaboration, the findings indicate that the firm's problems exert a substantial effect on its usage of collaboration knowledge. The problem sources and functions have effects on the formal interactions by affecting the agenda of the project meetings and the interpreter's recognition of value. The problem also affects informal interactions and the translator's recognition of value. This result contributes to McKelvey and Ljungberg's (2017) conceptual framework and the indirect route to innovation, in which the three implementation paths show how a firm collects and uses collaboration knowledge. Within this route, the three implementation paths, and their entanglement, can help describe how the firm's capabilities emerge by using collaboration knowledge.

With regard to managerial implications, the findings argue that the use of collaboration-derived knowledge incrementally contributes to the firm's knowledge base by means of the individual absorption of the interpreter and the utilization of the assimilator. This stresses the importance of defining problems and discovering solutions in the process of knowledge absorption. A manager of these roles should take into consideration the repeated unsolved problems of these roles and that the implementation of collaboration knowledge can also be expressed indirectly and negatively. When the firm formally collaborates with a university, it is also suggested that managers should encourage problem solving and emphasize problem definition.

The three identified roles—translator, interpreter, and assimilator—are, in the UIC context, crucial to the process of knowledge absorption and innovation development. Managers should ensure that these roles are clearly defined and filled in the organization when participating in a UIC, because the identified roles have different functions and are connected to different AC components. Managers should also ensure that the individuals in these roles understand the functions of the roles and are able to carry them out effectively.

Regarding policy implications, the present findings argue that publicly funded university–industry collaborations should devote resources to ensuring that the collaborating parties have shared knowledge of the problem that the cooperation is attempting to solve. Ensuring a shared understanding of the problem at hand can mitigate communication concerns by guiding the agenda for formal interaction. Additionally, by applying a problem focus, it is possible to detect research areas for collaboration where both the industry and higher education parties gain valuable outcomes.

6.3 Future research

The research highlights the interplay between firm-level and individual-level analysis in problem identification and solution discovery. Future research could delve deeper into this dynamic, exploring how different organizational structures and cultures might influence this relationship. The present findings suggest that the definition of value used in the absorptive capacity component recognizing value is affected by the subject performing the identification, namely, the individual recognizing value. The individual's recognition of value as the product of role-specific rehearsed problems is an outcome of two levels of analysis, firm and individual, that can be quantified and measured by future research. Research may quantitatively measure the individual's recognition of value by means of text analysis, conceptualizing a problem as combinations of word classes. Such combinations can address larger quantities of text and distill the named entity and the associated problem. One potential source of data for this could be patent data.

Future research may also address and elaborate on the identified roles. Distinguishing between traits that uniquely can be allocated to each role might be a specifically fruitful avenue. This is specifically needed for the identified translator role. Research that includes the AC exploitation component and aim to identify influential firm roles would complement this research.

Future research could explore how the identified regulations, customer value, and costs as sources of problems as factors influence problem identification in different industries or geographical locations. This research also underlines the importance of the problem definition in the solution discovery phase. Therefore, suggesting that future research could explore methods and strategies for effective problem definition, and how this impacts the quality of solutions discovered.

6.4 Final conclusions

The first conclusion concerns the influential firm roles. The identification and differentiation of the three firm roles—translator, interpreter, and assimilator—contribute to existing theory by incorporating the last two roles. In the context of UIC and the firm's AC, these three roles impact the firm's absorptive capacity and utilization of external knowledge. These three roles and their characteristics conceptually explicate how individual agents affect the firm's AC.

The second conclusion concerns the university–industry collaboration as a source of innovation. Collaboratively developed knowledge can be a source of firm innovations by means of adding knowledge to the firm's knowledge base through the three implementation paths and expressed as solutions to identified problems. Chapters 4 and 5 identified and connected firm innovations that employ collaboration knowledge to some extent. Seldom, however (perhaps on only one occasion in the studied case), is the connection between the identified innovations and the collaboration knowledge linear as cause and effect. Rather the opposite is the case: the collaboration knowledge is an embedded knowledge source often aiding an inventor's solution search by guiding the inventor through a complex mesh of theoretical principles and boundary conditions. The UIC knowledge incrementally adds layers of knowledge to the collaborating firm and its future innovations through the formal meetings and the interpreters. Knowledge connected to a firm's problem can be used directly to make a decision or act, negatively not to take action, or indirectly for decisions and actions at a later time.

The third conclusion concerns the connection between the firm's problem and innovations from university–industry collaboration knowledge. To comprehend how UIC can facilitate innovation in participating firms, a thorough understanding of the problems these collaborating firms face is vital. The firms' problems exert an important influence on the utilization of the collaboration knowledge, because this knowledge is used as a solution to these problems. This concluding finding might be the most important in this dissertation due to its theoretical contribution to absorptive capacity theory, its recognition of value assimilation or transformation, and the possibilities is has identified as connecting collaboration knowledge to firm innovations. The recognition of collaboration knowledge as valuable is, first, connected to its usefulness and thereby the firm's problems; second, recognizing is the act of an individual who has a subjective effect on the identification of valuable knowledge.

Finally, the absorptive capacity component assimilation of collaboration knowledge is effectively employed by the three implementation paths. Because these paths account for the use of collaboration knowledge, this knowledge is incorporated into the existing knowledge structure and thereby assimilated.

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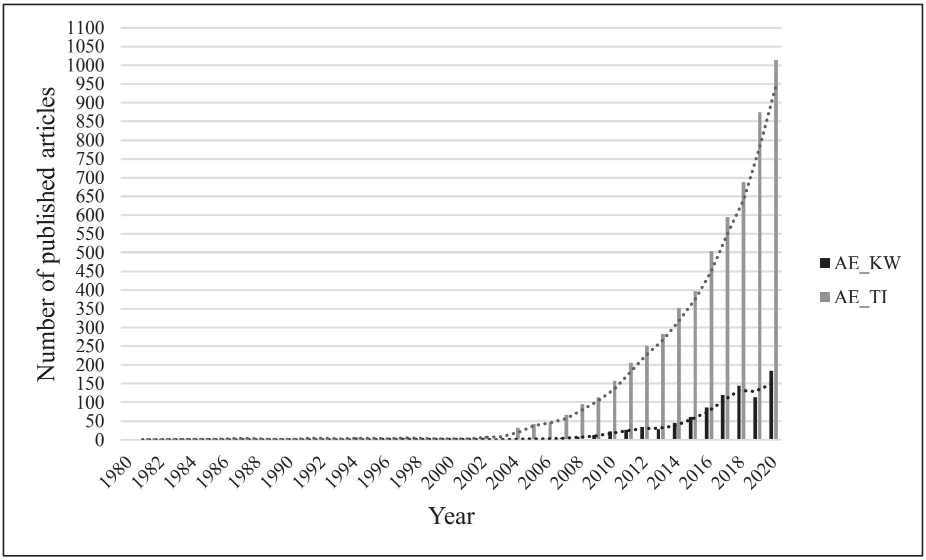
Appendix A – Published articles on academic engagement



Number of articles per year with academic engagement as a keyword (AE_KW) or academic engagement in the title (AE_TI) from Web of Science.

Appendix B – Interview guide, first round

Institutet för Innovation och Entreprenörskap

Hej,

Tack för din medverkan i kommande intervju!

Forskningsprojektet
Det övergripande syftet med studien är att få större förståelse för hur samarbete mellan industri och universitet kan stärka kunskapsutveckling och innovationsförmåga. Tidigare forskning visar att samarbetet mellan de båda parterna utgör en viktig del i detta samspel men på vilket sätt och i hur stor utsträckning är fortfarande oklart. Avsikten med mitt arbete är att få en djup förståelse kring interaktionen mellan parterna och hur detta leder till kunskapsutveckling och innovation. Detta genom att studera CERC samarbetet som ert företag har med i, och hur innovationer har kommit ur detta.

Har du övriga frågor eller funderingar så får du gärna höra av dig.

Jag ser fram emot vår intervju!

Med Vänliga Hälsningar,

Daniel Hemberg
Doktorand

Institutet för Innovation och Entreprenörskap
Institutionen för ekonomi och samhälle
Handelshögskolan vid Göteborgs Universitet
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GÖTEBORGS UNIVERSITET

Institutet för Innovation och Entreprenörskap

INTERVJUDEL

Information

Några praktiska detaljer:

- Intervjun kommer att spelas in och inspelningen kan avbrytas om du önskar.
- Dina personuppgifter kommer att anonymiseras.

Intervjufrågor

Nedan följer ett antal frågor och påståenden som du gärna får fundera på inför vår intervju.

DEL 1: Bakgrundsfrågor

- Berätta om din bakgrund
- Berätta om vad du gör på företaget?
- Beskrivning av CERC
    - Vill du beskriva din relation till CERC?
    - Kan du berätta är dina erfarenheter av att CERC samarbetet?
    - Hur skulle du beskriva CERCs uppgift/arbete?

DEL 2

Beskrivande text innan del två:

Mitt övergripande intresse är att få fördjupad kunskap om hur en idé uppstår och blir en produkt. Därför vill jag idag fokusera kring att prata om din uppfinning/patent. [kan här nämna uppfinningen]

Från starten

Om vi tar det från början:

- **Hur började det? Vad hände först?**
    - Vem/vilka?
    - Vad gjorde de?
    - Roller?
    - När och vad sa han/hon?
    - Vem styrde/bestämde?
    - Vad gjorde du då?
    - Vad ledde det fram till?
- **Vad hände sen?**

Från idén och bakåt

Om vi tittar bakåt:

- Kan du berätta mer om tiden innan idén kom till?
    - Vad behövdes för att skapa idén?
    - Hur/när kom du/ni på idén.
    - Vilka var med?
    - Vad gjorde de?
    - Hur gjorde ni?
    - Kan du berätta mer om det?
- **Vart kom det ifrån? Hur/vad gjorde ni innan?**
- **Om jag förstår det rätt så är det så här.**
    - Vad hände innan?

GÖTEBORGS UNIVERSITET

Institutet för Innovation och Entreprenörskap

Sammanfattnings frågor
(eventuellt ok med problemfråga – problemet uppfinningen)

Stödfrågor:

Beskrivande aktiviteter:
Vem/vilka?
Vad gjorde de?
Roller?
När och vad sa han/hon?
Vem styrde/bestämde?
Vad gjorde du då?
Vad ledde det fram till?
Beskriv så mycket som möjligt!

Följdfrågor
Vilka var med?
Vad gjorde ni?
Har jag förstått det rätt frågor

Frågor för att återkoppla i tiden
Vad hände innan uppfinningen
Vad hände när du/ni kom på idén
Vad hände när det gick från uppfinning till produkt

UPPFÖLJNING EFTER INTERVJU

	Uppfinningen framåt			Uppfinningen bakåt			Cerc-kunskap		
Frågor	External_know	Aquire & Assimilate	Exploit	External knowledge	Aquire & Assimilate	Exploit	External knowledge	Aquire & Assimilate	Exploit
Vem	Vem var med och kom på iden till patentet? Varför dessa individer?								
Vad	Kan du berätta om aktiviteter, möten, eller uppgifter som varit viktiga för patentet? Vad ledde det till								
Vart	Kan du berätta om vart du/ni var när ni fick idén till patentet?								
När	När kom du/ni på idén till patentet?								

Sammanfattning

Hur började samarbetet?

Varför började de samarbeta?

Hur har kunskap applicerats / vart kan den finnas i produkter idag?

Hur identifierades viktig kunskap?

Hur assimilerades viktig kunskap?

Appendix C – Interview guide, second round

Institutet för Innovation och Entreprenörskap

Hej,

Tack för din medverkan i kommande intervju!

Forskningsprojektet
Det övergripande syftet med studien är att få större förståelse för hur samarbete mellan industri och universitet kan stärka kunskapsutveckling och innovationsförmåga. Tidigare forskning visar att samarbetet mellan de båda parterna utgör en viktig del i detta samspel men på vilket sätt och i hur stor utsträckning är fortfarande oklart. Avsikten med mitt arbete är att få en djup förståelse kring interaktionen mellan parterna och hur detta leder till kunskapsutveckling och innovation.

Några praktiska detaljer:

- Intervjun kommer att spelas in och inspelningen kan avbrytas närhelst ni önskar.
- Dina personuppgifter, universitet- och företagsnamn kommer att anonymiseras.

Intervjufrågor
Nedan följer ett antal frågor och påståenden som du gärna får fundera på inför vår intervju.

Bakgrundsfrågor

- Berätta om din bakgrund och vad dina arbetsuppgifter är i samarbetet med universitetet.
- Hur länge och till vilken grad har du samarbetat med eller arbetat nära Universitet?
- När i din karriär började du interagera med universitetet?
- Vad är dina erfarenheter av att samarbeta med universitetet?
- Varför valde företaget att börja samarbeta med universitetet?
- Vilka personer har varit delaktiga i samarbetet?
    - Vilken bakgrund har varit viktig att ha med sig som deltagare från företaget?

Teman
Applicera

- På vilket sätt har samarbetet varit till nytta för företaget?
- Hur har samarbetet på något sätt bidragit till företaget?
    - Om så på vilket sätt har det varit värdefullt för företaget?
    - Vart på företaget kan vi idag se resultatet från samarbetet?
        - Process-, produktion, organisation, produkt, medarbetare.

Identifiera

- Hur visste ni att dessa bidrag var värdefulla för företaget?
    - När blev det tydligt att de var värdefulla?
    - Hur identifierade ni viktiga resultat från samarbetet?
- Har vissa aktiviteter varit mer värdefulla än andra för att identifiera viktiga resultat?
- Har det funnits avgörande aktörer?
    - Om så, ge exempel på aktörer och varför de är viktiga.
    - Beskriv gärna när dessa aktörer blev viktiga

- Har det funnits oväntad kunskap som varit viktig?

Assimilera

- Hur har företaget arbetat för att dela viktiga bidragen/resultat från samarbetet uti företaget?
- Har detta skett på samma sätt?
    - Om inte, hur har detta ändrats under din tid i samarbetet?
- Beskriv gärna om det funnits svårigheter att sprida kunskap från samarbetet.
    - Har det funnit specifika saker som vart svåra att sprida?

- Har det funnits avgörande aktiviteter/processer?
    - Om så, ge exempel på aktiviteter/processer och varför de är viktiga.
    - Beskriv gärna när dessa aktiviteter/processer blev viktiga

Har du övriga frågor eller funderingar så får du gärna höra av dig.

Jag ser fram emot vår intervju!

Med Vänliga Hälsningar,

Daniel Hemberg
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Appendix D – Coding table

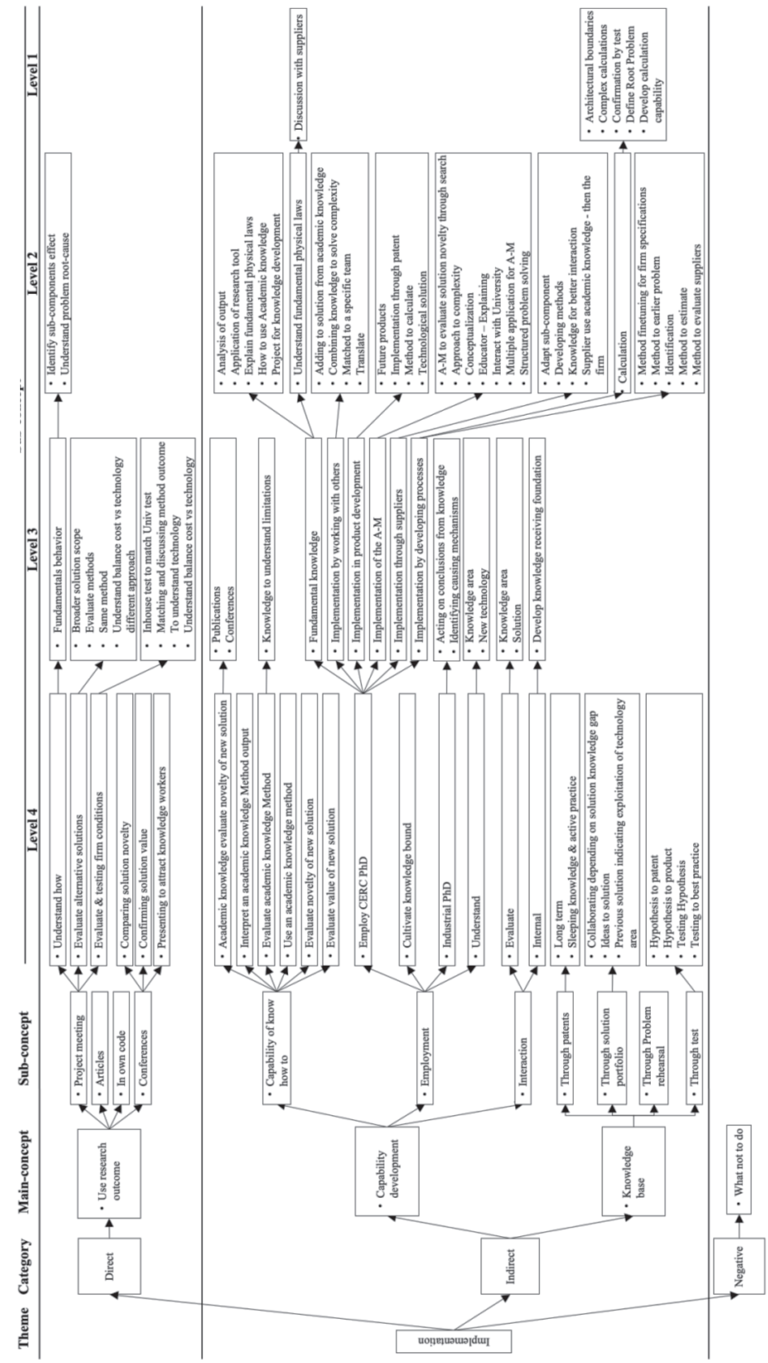
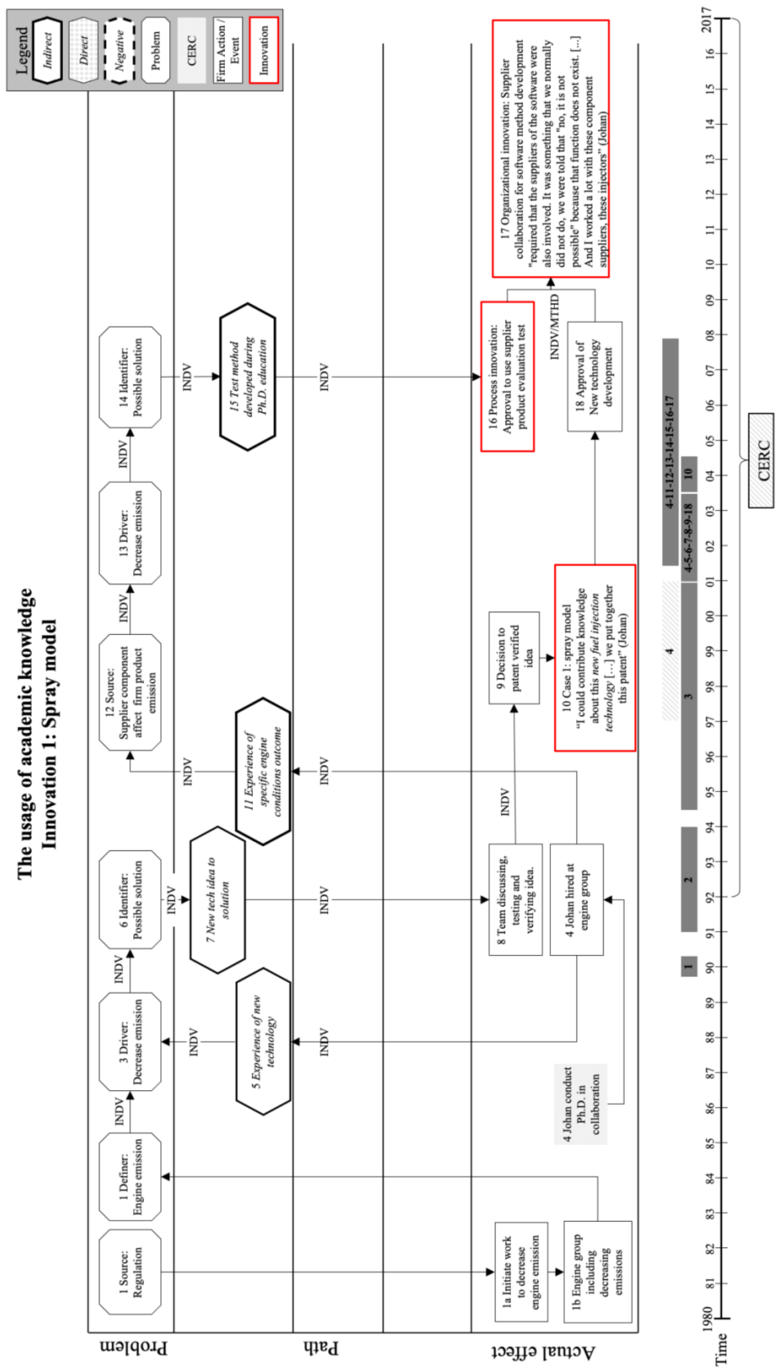
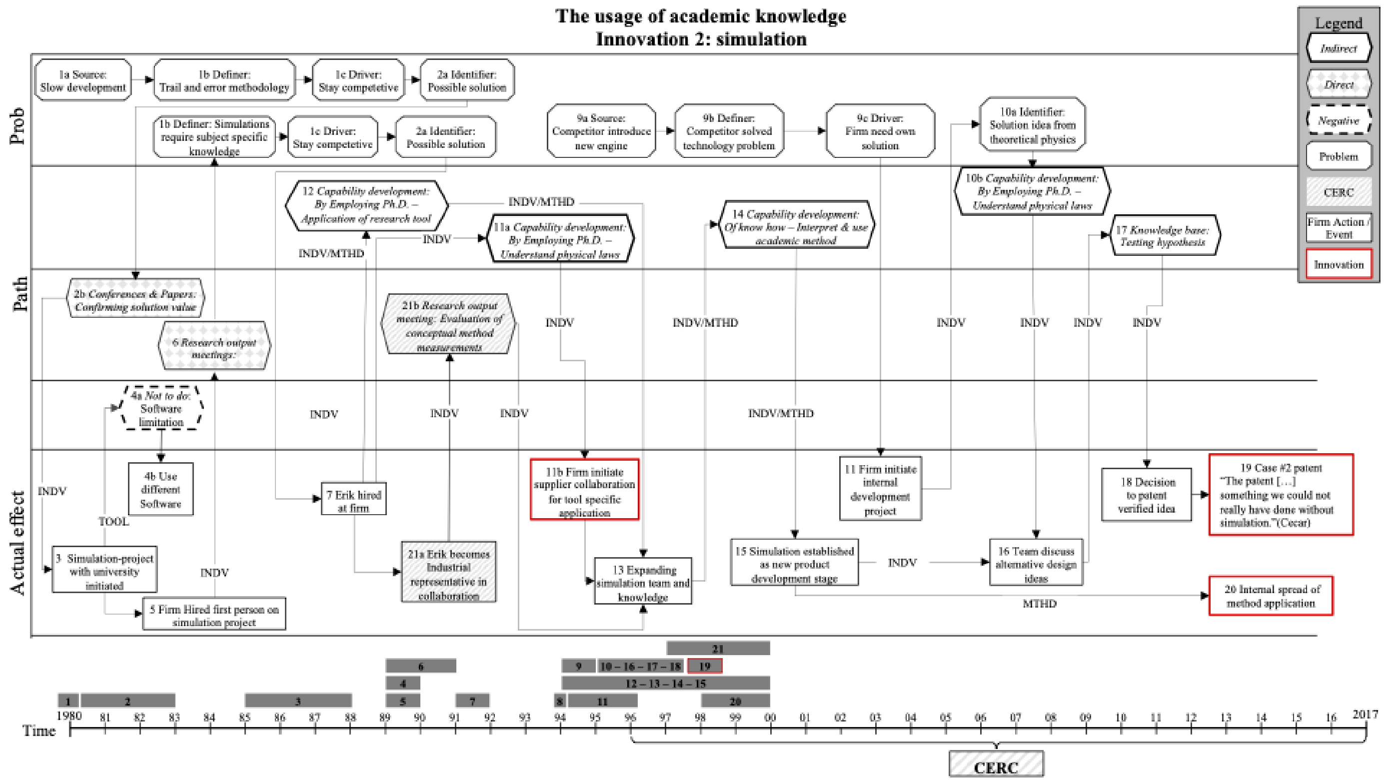


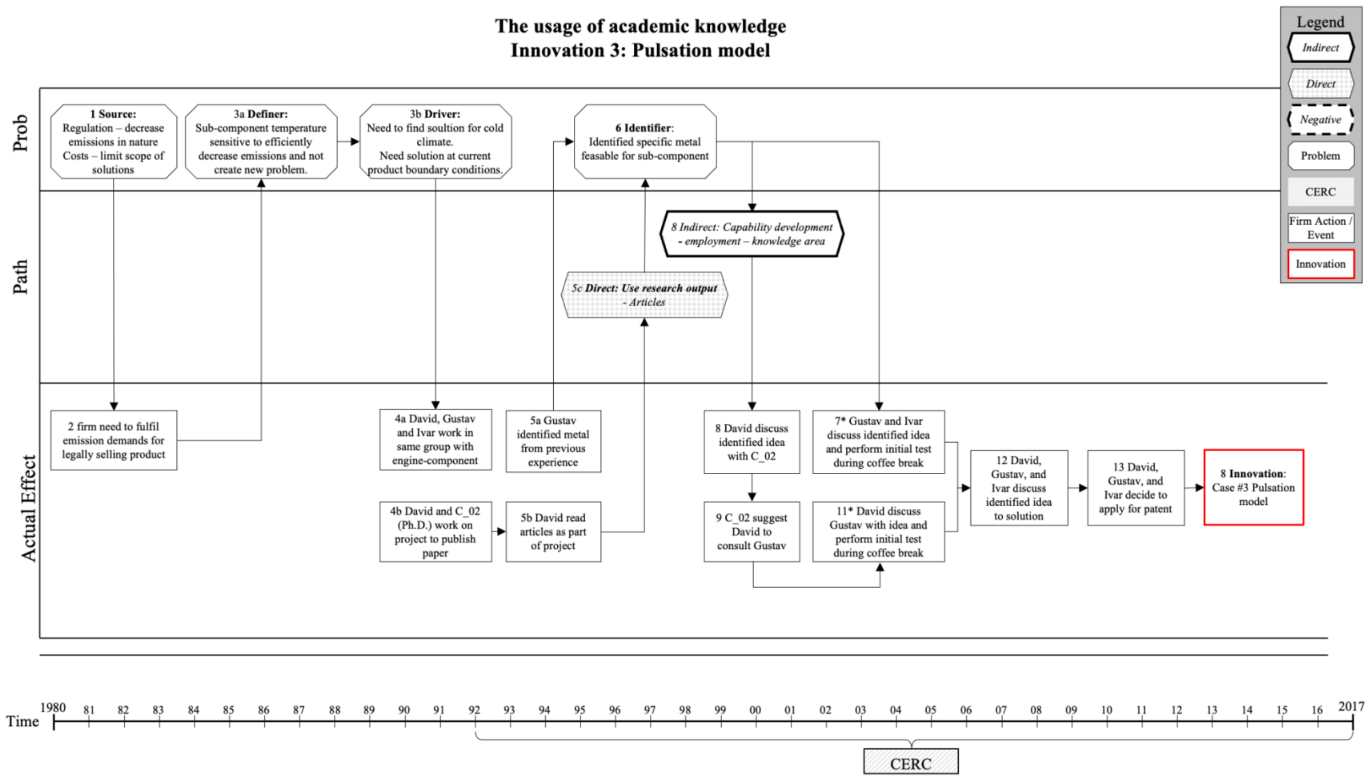
Figure 18: Hierarchical coding table for implementation

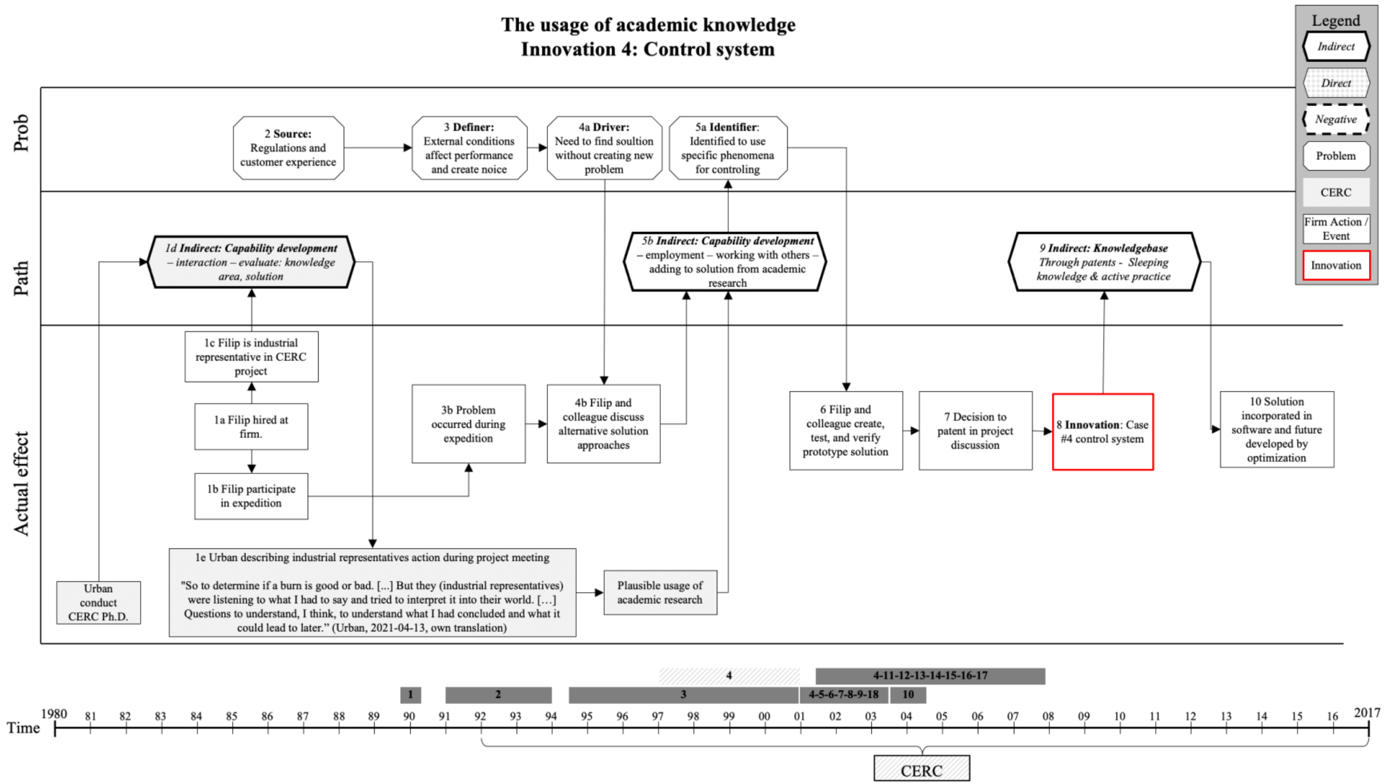
Appendix E – Individual case visualization




The usage of academic knowledge
Innovation 2: simulation
Legend
Indirect
Direct
Negative
Problem
CERC
Firm Action / Event
Innovation
Prob
Path
Actual effect
1a Source: Slow development
1b Definer: Trail and error methodology
1c Driver: Stay competetive
2a Identifier: Possible solution
1b Definer: Simulations require subject specific knowledge
1c Driver: Stay competetive
2a Identifier: Possible solution
9a Source: Competitor introduce new engine
9b Definer: Competitor solved technology problem
9c Driver: Firm need own solution
10a Identifier: Solution idea from theoretical physics
10b Capability development: By Employing Ph.D. – Understand physical laws
12 Capability development: By Employing Ph.D. – Application of research tool
11a Capability development: By Employing Ph.D. – Understand physical laws
14 Capability development: Of know how – Interpret & use academic method
17 Knowledge base: Testing hypothesis
2b Conferences & Papers: Confirming solution value
6 Research output meetings:
21b Research output meeting: Evaluation of conceptual method measurements
4a Not to do: Software limitation
4b Use different Software
3 Simulation-project with university initiated
5 Firm Hired first person on simulation project
7 Erik hired at firm
21a Erik becomes Industrial representative in collaboration
11b Firm initiate supplier collaboration for tool specific application
13 Expanding simulation team and knowledge
15 Simulation established as new product development stage
11 Firm initiate internal development project
16 Team discuss alternative design ideas
18 Decision to patent verified idea
19 Case #2 patent "The patent […] something we could not really have done without simulation."(Cecar)
20 Internal spread of method application
INDV
TOOL
INDV/MTHD
MTHD
Time
1980 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 2017
1 2 3 4 5 6 7 8 9 11 10 – 16 – 17 – 18 19 12 – 13 – 14 – 15 20 21
CERC

The usage of academic knowledge
Innovation 3: Pulsation model





The usage of academic knowledge
Innovation 4: Control system
Legend
Indirect
Direct
Negative
Problem
CERC
Firm Action / Event
Innovation
Prob
Path
Actual effect
2 Source: Regulations and customer experience
3 Definer: External conditions affect performance and create noice
4a Driver: Need to find soultion without creating new problem
5a Identifier: Identified to use specific phenomena for controling
1d Indirect: Capability development – interaction – evaluate: knowledge area, solution
5b Indirect: Capability development – employment – working with others – adding to solution from academic research
9 Indirect: Knowledgebase Through patents - Sleeping knowledge & active practice
1c Filip is industrial representative in CERC project
1a Filip hired at firm.
1b Filip participate in expedition
3b Problem occurred during expedition
4b Filip and colleague discuss alternative solution approaches
6 Filip and colleague create, test, and verify prototype solution
7 Decision to patent in project discussion
8 Innovation: Case #4 control system
10 Solution incorporated in software and future developed by optimization
Urban conduct CERC Ph.D.
1e Urban describing industrial representatives action during project meeting
"So to determine if a burn is good or bad. [...] But they (industrial representatives) were listening to what I had to say and tried to interpret it into their world. [...] Questions to understand, I think, to understand what I had concluded and what it could lead to later." (Urban, 2021-04-13, own translation)
Plausible usage of academic research
4
4-11-12-13-14-15-16-17
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4-5-6-7-8-9-18
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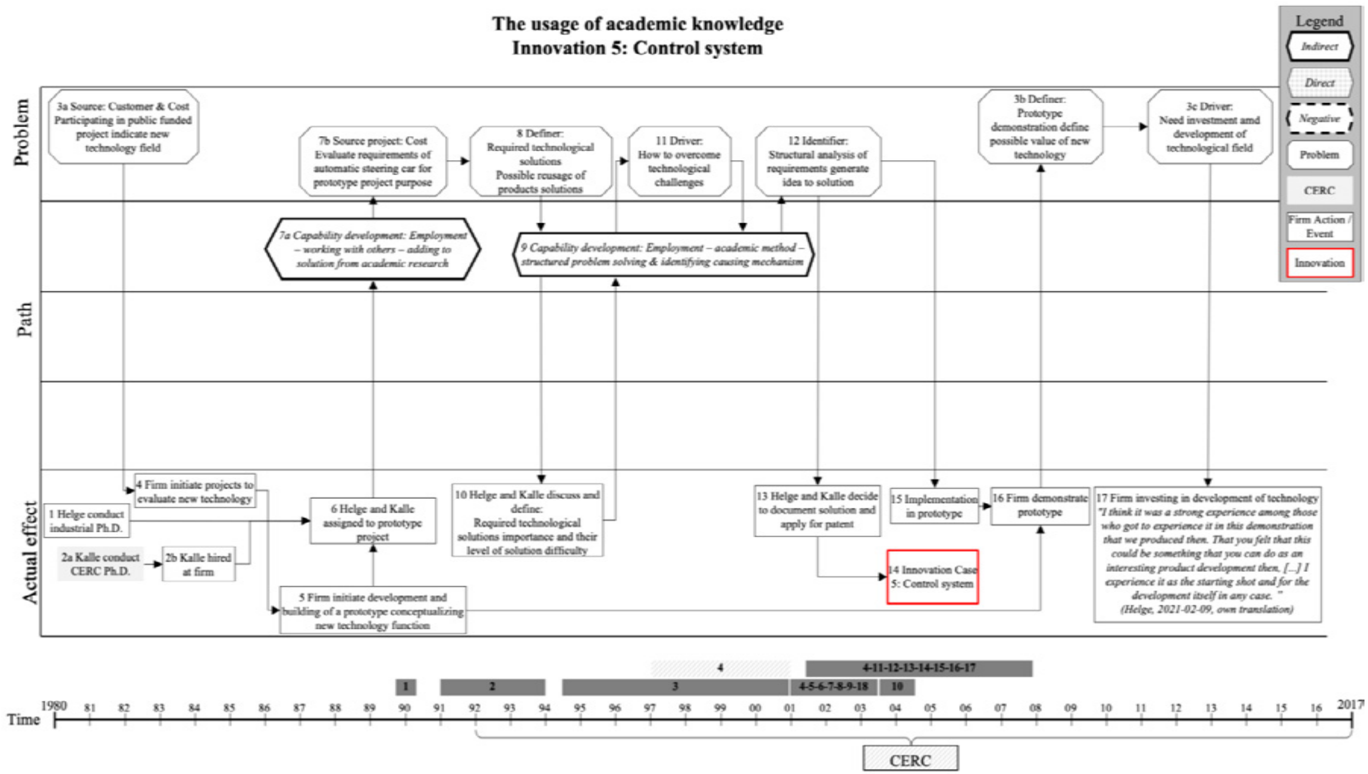
2017
CERC


The usage of academic knowledge
Innovation 5: Control system
Legend
Indirect
Direct
Negative
Problem
CERC
Firm Action / Event
Innovation
Problem
Path
Actual effect
3a Source: Customer & Cost Participating in public funded project indicate new technology field
7b Source project: Cost Evaluate requirements of automatic steering car for prototype project purpose
8 Definer: Required technological solutions Possible reusage of products solutions
11 Driver: How to overcome technological challenges
12 Identifier: Structural analysis of requirements generate idea to solution
3b Definer: Prototype demonstration define possible value of new technology
3c Driver: Need investment and development of technological field
7a Capability development: Employment – working with others – adding to solution from academic research
9 Capability development: Employment – academic method – structured problem solving & identifying causing mechanism
1 Helge conduct industrial Ph.D.
2a Kalle conduct CERC Ph.D.
2b Kalle hired at firm
4 Firm initiate projects to evaluate new technology
6 Helge and Kalle assigned to prototype project
5 Firm initiate development and building of a prototype conceptualizing new technology function
10 Helge and Kalle discuss and define: Required technological solutions importance and their level of solution difficulty
13 Helge and Kalle decide to document solution and apply for patent
14 Innovation Case 5: Control system
15 Implementation in prototype
16 Firm demonstrate prototype
17 Firm investing in development of technology "I think it was a strong experience among those who got to experience it in this demonstration that we produced then. That you felt that this could be something that you can do as an interesting product development then. [...] I experience it as the starting shot and for the development itself in any case." (Helge, 2021-02-09, own translation)
4
4-11-12-13-14-15-16-17
1
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4-5-6-7-8-9-18
10
Time
1980
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2017
CERC

Appendix F – List of abbrevations and definitions

Table 19: List of abbreviations and definitions

Term	Abbreviation	Definition	Source
Absorptive capacity	AC	"the firm's ability to identify, assimilate, and exploit knowledge from the environment"	Cohen and Levinthal, 1989, p. 569
Academic engagement	AE	"knowledge-related interactions of academic scientists with external organizations, set apart from research, teaching and commercialization."	Perkmann et al., 2019, p. 2
Business process innovation		"a new or improved business process for one or more business functions that differs significantly from the firm's previous business processes and that has been brought into use by the firm."	OECD/Eurostat, 2018, p. 21
Center of excellence	COE	"Broadly speaking, there are two types of such centers: "excellence" centers that strive for and to some extent reflect scientific excellence … Centers of excellence tend to be organized around one or more internationally renowned scientist and aim to improve collaboration among university researchers and achieve critical mass."	OECD, 2012, p. 254
Innovation		"An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)."	OECD/Eurostat, 2018, p. 20
Knowledge[17]		"a meaning structure, inherent in the mind of the individual, that combines framed experience, values, contextual information, and insights from experts' which establish a framework for evaluating new information." "Knowledge is information combined with experience, context, interpretation, and reflection"	Davenport et al., 1998, p. 43
Problem		"a question raised for inquiry, consideration, or solution"	Arthur, 2007, p. 274
Product innovation		"a new or improved good or service that differs significantly from the firm's previous goods or services and that has been introduced on the market."	OECD/Eurostat, 2018, p. 21
University–industry collaboration	UIC	The partnership and institutionalization of interactions between any parts of the higher educational system and industry aiming mainly to encourage activities of knowledge and technology exchange, leading to new scientific knowledge and innovations.	

[17] Knowledge and technology are here used interchangeably, as done in other studies (Agrawal, 2001; Bekkers and Bodas Freitas, 2008)

Appendix G – California example: the influence of external factors

This section demonstrates how external forces, such as legislation, influence the empirical context and motivate firm collaboration with a partner from the higher education system. The example here used is from the state of California in the United States.

Following World War II, both the economy and the population of the United States grew. The population became more reliant on personal transportation as a result of increased suburbanization and the closure of some public transportation systems. As a result, the number of cars, trucks, and highways increased. In the early 1950s, a California researcher linked air pollution to cars, claiming that traffic was to blame for the smog over Los Angeles. In 1963, the US Congress passed the Clean Air Act which established emission standards for stationary sources, and in 1970 the US Congress passed an amendment of the act that included emission standards for both industrial and mobile sources (US EPA, 2015). In practice, the 1970 Clean Air Act instructed the automobile industry to develop engines with a 90 % reduced amount of emissions of nitrous oxide, hydrocarbons, and carbon monoxide until 1975 (Elkins, 2013). At the time, California and the city of Los Angeles experienced major issues with pollution and smog. Because the pollution was carried by the downwind to Riverside, the city urged the newly formed Environmental Protection Agency (EPA) to sue the state of California, which resulted in a federal state implementation plan. The plan, and EPA, came to the conclusion that to reduce the amount of pollution the only effective federal enforceable action was a restriction that prevented gasoline to be sold in California(Wise and Calkins, 1970). The width of the consequences for the automotive industry are expressed by the words of William

Ruckelshaus "We held a press conference announcing that 80 percent of the cars were going to have to get off the road." (ibid., p. 9).