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How Academic Engagement Through Graduate Students Can Affect Firms' Search Capabilities for Innovation

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Abstract

This paper contributes to the recent stream of literature developing the concept of ?academic engagement with industry?, which focuses not on commercialization but on the knowledge networks between university and industry. We do so by exploring the firm side of such interactions, and empirically conduct a study of how firm employed PhD students do micro-level activities, which in turn help develop knowledge networks. A firm employed PhD student is a person who is enrolled at the university as a PhD student while at the same time being employed at the firm. We extend an existing conceptual framework, which suggests that there are two pathways whereby collaborative research between university and industry may impact innovation outcomes within firms. We find that microlevel activities develop and support the indirect pathways of academic engagement, and propose this may be conceptualized as organizational routines underlying search capabilities

How Academic Engagement Through Graduate Students Can Affect Firms' Search Capabilities for Innovation: A Micro-level Analysis of Firm Employed PhD Students in Engineering

Abstract

This paper contributes to the recent stream of literature developing the concept of "academic engagement with industry", which focuses not on commercialization but on the knowledge networks between university and industry. We do so by exploring the firm side of such interactions, and empirically conduct a study of how firm employed PhD students do micro-level activities, which in turn help develop knowledge networks. A firm employed PhD student is a person who is enrolled at the university as a PhD student while at the same time being employed at the firm. We extend an existing conceptual framework, which suggests that there are two pathways whereby collaborative research between university and industry may impact innovation outcomes within firms. We find that microlevel activities develop and support the indirect pathways of academic engagement, and propose this may be conceptualized as organizational routines underlying search capabilities.

Keywords: Academic engagement with industry, university-industry interactions, collaborative research, capabilities, and engineering.

1 Introduction

There is an extensive literature on university-industry interactions. Historically, universities and colleges have played a variety of roles, which impact the economy, and much existing literature focuses upon the university per se. During the expansion of universities and colleges (hereafter universities) during the 20th century, the two main roles of universities have been to develop new knowledge through research and diffusing it through teaching students. More recently, the changing production of knowledge in society to Mode 2 is argued to involve a wider range of stakeholders (Gibbons et al 1994). This debate moved to a focus upon the changing nature of the university, with more emphasis upon societal impact, with corresponding changes within universities to become more entrepreneurial, act more like strategic actors, and compete for resources (Etzkowitz 2004; McKelvey & Holmén 2009; Genua 2001). As a consequence of universities taking on these new activities, the attributes of being entrepreneurial and interacting more with the external stakeholders becomes more important (Etzkowitz 2013). Much emphasis is put on specifying how new knowledge developed by universities can be spread and shared with the society and industry, to increase societal benefits and economic development (Salter & Martin 2001; Bozeman et al. 2015). Thus, literature has explored a variety of mechanisms for technology transfer and for conceptualizing these new roles and responsibility of universities, especially through commercialization through patents and university spin-off companies (Ambos et al. 2008; Laredo 2007; Rosli & Rossi 2016). The recent stream of literature developing the concept of "academic engagement with industry" focuses not on commercialization per se but on the knowledge networks between university and industry (Perkmann et al 2013). Much of the university-industry interaction literature focuses upon the university per se (Ankrah & AL-Tabbaa 2015). This paper addresses the other side of

the interaction – e.g. what happens within firms, during activities for academic engagement, when they interact with universities?

There is a reasonably large literature on why firms interact with universities, especially in science-based industries like pharmaceuticals and biotechnology. Existing literature suggests that firms interact with universities for a number of reasons, such as signaling to attract skilled labor, promoting product approval, gain access to networks, and accessing scientific knowledge for radical innovations (Hicks 1995; Powell et al 1996; McKelvey 1996). A consistent result is that larger firms are more likely to interact with universities (Mansfield 1995), and recently, that corporate science may lead to publications and innovations for different reasons (Simeth and Cincera 2016; Simeth and Raffo 2013; Stern 2004). Much of this literature considers the longer-term impacts of interacting with universities upon the firms. As compared to this stream of literature, our focus is less upon the motivations and direct impact upon firms, and instead more upon the university-firm interaction per se. We do not consider alternative theoretical concepts, such as hybrid organizations, academic and commercial logics or entrepreneurial universities.

The purpose of this paper is to explore how firm employed PhD students engage in micro-level activities to develop knowledge networks, in order to link this phenomenon to organizational routines and capabilities for academic engagement. Our definition of a firm employee PhD student is a person who is enrolled at the university as a PhD student while at the same time being employed at the firm (also called industrial PhD student). This configuration may be specific to the national institutional context, but may lead to findings relevant to understand similar configurations, such as firm sponsored PhD students, and PhD students collaborating with industry. During their studies, these PhD students are supposed to develop, share and diffuse new knowledge, which is relevant to both the academia and the corporate world. There is relatively little literature that examines

graduate students as a form of university-industry interactions during their studies, as we do. Previous studies about this phenomenon analyze broader issues related to the students' educational experience and learning outcomes (Thune 2009; Borrell-Damian et al. 2010; Gustavsson et al. 2016). The majority of existing literature related to graduate students examines what happens after graduation, including topics such as career paths, impact on wages, as well as whether and why they can continue to publish after being employed at a firm (Cruz-Castro & Sanz-Menéndez 2005; Garcia-Quevedo et al. 2011; Roach & Sauermann 2010). To be specific, we study activities carried out by PhD students during their studies, and when they are both employed at a firm and simultaneously working on their PhD degree.

We interpret that firm employed PhD students represent one form of collaboration between university and industry, and as such may be conceptualized as an organizational routine (McKelvey & Seamundsson, 2019). We therefore study the microlevel activities which these students engage in. As compared to the academic engagement literature, however, we are more interested here in the impacts upon firms, and especially exploring how these activities may impact the firm's search for innovation. Specifically, we set out to further develop the conceptual framework proposed in (McKelvey & Ljungberg 2016). Based upon a longitudinal study of university-industry collaboration within a traditional center, McKelvey & Ljungberg (2016) propose that there are two pathways whereby collaborative research between university and industry may impact innovation outcomes within firms. One direct pathway is that the research conducted will fairly immediately and directly lead to product and process innovations. An indirect pathway from the research is to develop knowledge, which serves a variety of purposes to the firm, and later has a positive impact upon the firm's capabilities to innovate. Their purpose was to suggest that public policy for science and technology could be re-conceptualized as promoting the

firm's capabilities to innovate. In contrast, we start with their conceptual model and further develop it through relevant concepts from innovation management about capabilities in relation to innovate. Thereafter, we use a qualitative study of micro-level activities, in order to validate whether, and in which dimensions, the conceptual model proposed here is a useful analytical tool. Specifically, we use it in order to analyze firm employed PhD students as one particular form of collaboration between university and industry.

Section 2 develops our conceptual framework, based upon combining two streams of literature. One stream of literature is that on academic engagement and a second from innovation management related to organizational routines and capabilities to innovate. Section 3 presents the research design underlying our qualitative study, including details of data collection and analysis. Section 4 provides a detailed qualitative study of one field in engineering at one Swedish university, in order to explore the micro-level activities and the perceived impacts on the firms. Section 5 presents the discussion in terms of using the empirical data to validate and modify the conceptual model, and Section 6 presents conclusions, future research and limitations.

2 Theoretical background leading to initial conceptual model

2.1 Academic engagement with industry

Academic engagement literature focuses upon knowledge networks and relationships as underlying university-industry interactions. Based on a thorough review of the extensive literature on university-industry interactions leading to their conceptualization, Perkmann et al (2013) propose that universities can either interact through commercialization activities or through academic engagement with industry. On the one hand, commercialization refers to a series of activities that academics do which are designed to commercialize academic knowledge in the marketplace and retain monetary rewards. The

most typical outcomes are patents and start-up firms, and the scientists, technology transfer offices and similar units may engage in activities like licensing of academic patents, providing advice, and creating academic start-up firms. These activities are of entrepreneurial character, sometimes referred to as academic entrepreneurship (Wright et al. 2004; Siegel et al. 2007; Siegel & Wright 2015). On the other hand, academic engagement with industry refers to knowledge networks and relationships (Perkmann et al. 2013). Academic engagement entails a wide range of activities that are both formal and informally defined, such as collaborative research, contract research, consulting, ad hoc advice and networking with practitioners and other forms of knowledge exchange.

Moreover, Perkmann et al. 2013 use the literature review to propose factors that influence the likelihood of academics participating in academic engagement: individual characteristics, organizational context and institutional context, In terms of individual characteristics, certain demographic attributes of researchers' seniority and success rate with grants and publications also are positively related to the level of interaction (Perkmann et al. 2013). Individual researchers are motivated to participate in external collaborations for different reasons, which also reflect on what kind of collaboration they intend pursuing (Perkmann & Walsh 2008; Ankrah & AL-Tabbaa 2015). Organizational context refers to attributes of academics' university or department. Previous research indicates a negative effect on interaction for the higher quality of publications the university or department holds (D'Este & Patel 2007; Ponomariov 2007; Ponomariov & Craig Boardman 2007). Institutional context refers to differences in the scientific disciplines, national regulation and public policy. In applied fields like engineering, collaboration is more likely and various knowledge transfer channels are possible. Still the reasons why firms interact with academia can vary, resulting in multiple types of outcomes and benefits for firms (Bishop et al. 2011; Broström 2010; Perkmann & Walsh 2008; McKelvey & Ljungberg 2016). Because our study is within one field (engineering) and at

one university, we are interested in the links between individuals and organizations. However, in this paper, we are not addressing academics as professors primarily, but instead examining these graduate students.

Specifically in this paper, we study academic engagement with industry, when the decision to collaborate has already been made, and the firms and universities have both agreed to have firm employed PhD students. According to Thune (2009), doctoral students can take on three different roles in university-industry relations: producers of knowledge; channels for knowledge transfer from universities to firms; creating and maintaining network links. The limited existing research finds that firm employed PhD students are heterogeneous phenomena (Thune 2009; Borrell-Damian et al. 2010).

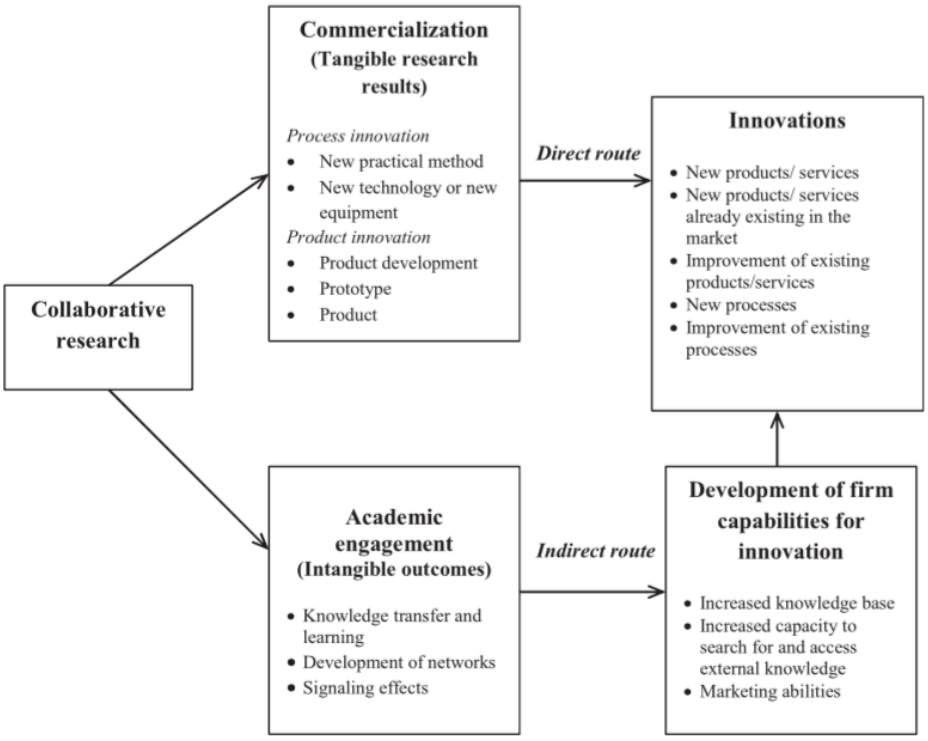
Our first research question is: Along what dimensions are firm employed PhD students a heterogeneous phenomenon?

2.2 When firms engage in collaborative research with universities

Our second starting point is to examine in what ways that firm employed PhD students can impact innovation within firms, either through the direct pathway to innovation or through the indirect pathways of influencing the firm's capabilities to innovate.

We take our departure for this discussion, from an existing conceptual framework, developed in McKelvey & Ljungberg (2016) and further develop it for our purposes.

Figure 1: Conceptual framework of how collaborative research can impact firm innovation



Source: McKelvey & Ljungberg, 2016 p. 541

The direct pathway, found at the top of Figure 1, is related to direct activities that enable commercialization. In this way, collaborative research can lead the firms to outcomes that can be directly transferred to the firm and commercialized in the market. The second pathway, found at the bottom of Figure 1, relates to more indirect impact, conceptualized as academic engagement. These more indirect pathways may still still important in the long run for the development of new products, processes and services in firms, but do not do so directly.

2.2.1 **The direct pathway from commercialization to innovation**

Certain outcomes from university-industry interactions can be linked to direct innovation outcomes. We have categorized these: assisting in problem solving (Bishop et al. 2011), engaging in product and process development (Broström 2010; Gustavsson et al. 2016) and identifying direct business opportunities (Broström 2010). We thereby enrich the

initial conceptual framework with these three activities, and will explore them in the qualitative research.

2.2.2 The indirect pathway from academic engagement through firm capabilities to innovation

The academic engagement literature stresses more intangible and indirect impacts such as knowledge networks and relationships, and McKelvey & Ljungberg (2016) specified these categories: 1) Knowledge transfer and learning, 2) network development and 3) signaling effects.

In terms of the first category, the literature suggests a broader understanding of what this may entail, including human capital management such as recruitment of young researchers, influencing undergraduate education and securing research partners for the firm (Broström 2010) Bishop et al. (2011) Academics can serve as "windows" on new technology (Perkmann & Walsh 2008) and generate patents (Bishop et al. 2011). For firm employed PhD students, they may specifically influence: Access to scientific knowledge (Thune 2009), developing technological competences (Thune & Børing 2014; Gustavsson et al. 2016) and developing internal R&D activities (Gustavsson et al. 2016). For networks, the key idea is that the firm gets value in gaining access to networks. There is a broad literature showing that knowledge networks in general is important for innovation (Ahuja 2000a; Ahuja 2000b; Lam 2007; Wang et al. 2014; Nerkar & Paruchuri 2005; Broekel & Boschma 2012). Finally, signaling effects may be similar to legitimacy. Gustavsson et al. (2016) find that increased legitimacy for a product or process (through for example scientific articles or dissertation) enabled firms to strengthen their ties to clients and business partners (see also Hicks 1995) Signalling firm quality, through financial intermediaries is also important when information asymmetries exist (Leland & Pyle 1977; Campbel & Kracaw 2012; Chemmanur & Fulghieri 2012; Chemmanur 2012; Nicholson

et al. 2005). Star scientist are important signals for securing funding in emerging industries (Higgins et al. 2011).

McKelvey & Ljungberg (2016) proposed, but did not confirm, the following:: "Conceptually, these three categories are intangible outcomes through which research collaboration can stimulate firms' capabilities for innovation", p. 541. Hence, firms obtain 1) an increased knowledge base through the indirect outcomes of knowledge transfer and learning, 2) an increased capacity to search for and access external knowledge through network effects and finally 3) marketing abilities by experiencing signaling effects (McKelvey & Ljungberg 2016).

To further develop the understanding of how collaborative research may impact firm capabilities for innovation, we turn briefly to that literature. There is an extensive literature on firm capabilities for technology and innovation, which we will not review here due to space limitations. The concepts of 'absorptive capacity' and 'technology-based firm' focus attention on the notion that the ability to create, develop and absorb new technology is crucial for firms to survive and remain competitive (Granstrand 1998; Cohen & Levinthal 1990) Zahra & George 2002). Due to the vital role of technological development, firms interact with universities (and other organizations) to develop new knowledge and technology (Mansfield 1995), more recently called open innovation (Chesbrough 2003). Firms have different ways of stimulating their absorptive capacity, such as by involving employees in advanced technical training, and by conducting R&D (Cohen & Levinthal 1990). Cohen & Levinthal (1990:132) argue that "the firms' absorptive capacity depends on the individuals who stand at the interface of either the firm and the external environment or at the interface between subunits within the firm". Thus, individuals operating in overlapping environments, either within the firm or towards external environments, are important for developing firms' absorptive capacity. In this early literature, such individuals were called boundary spanners (Allen 1977; Tushman

1977), and identified as playing an important role in assuring sufficient creation and assimilation of new knowledge within the firm (Cohen & Levinthal 1990). In more recent literature, a boundary spanner takes a structural space in a network (Phelps et al. 2012; Tortoriello 2015). Hence, even though many different conceptualizations of boundary spanners (and others) exist in the literature, here, we study individuals, specifically firm employed PhD students, who we perceive as being at the interface between the university and the firm and therefore act as boundary spanners.

There is also a long debate about how activities impact these capabilities. Pavitt (2009) identifies three broad and overlapping sub-processes of innovation within a firm: the production of knowledge, the transformation of knowledge in to artifacts (products, processes, services, systems) and the continuous matching of artifacts to market need and demand. The sub-processes are overlapping each other (Pavitt, 2009). Similarly the absorptive capacity literature express the importance for innovative firms to be able to 1) recognize the value of new, external knowledge, 2) assimilate it and 3) apply it to commercial ends (Cohen & Levinthal 1990; Cohen & Levinthal 1989). Teece et al. (1997) introduced dynamic capabilities as important for innovation and highlights three critical capabilities that the management team need to posses (Teece, 2007): 1) Sensing opportunities and threats, 2) Seizing opportunities and 3) Managing threats and reconfiguration. There are various ways to approach firm capabilities to search for, select and implement innovations (Tidd & Bessant, 2009). Thus, our interpretation from this literature is that firms aiming to be innovative have different phases (to some extent overlapping each other) of innovation processes as well as they need capabilities to manage these phases.

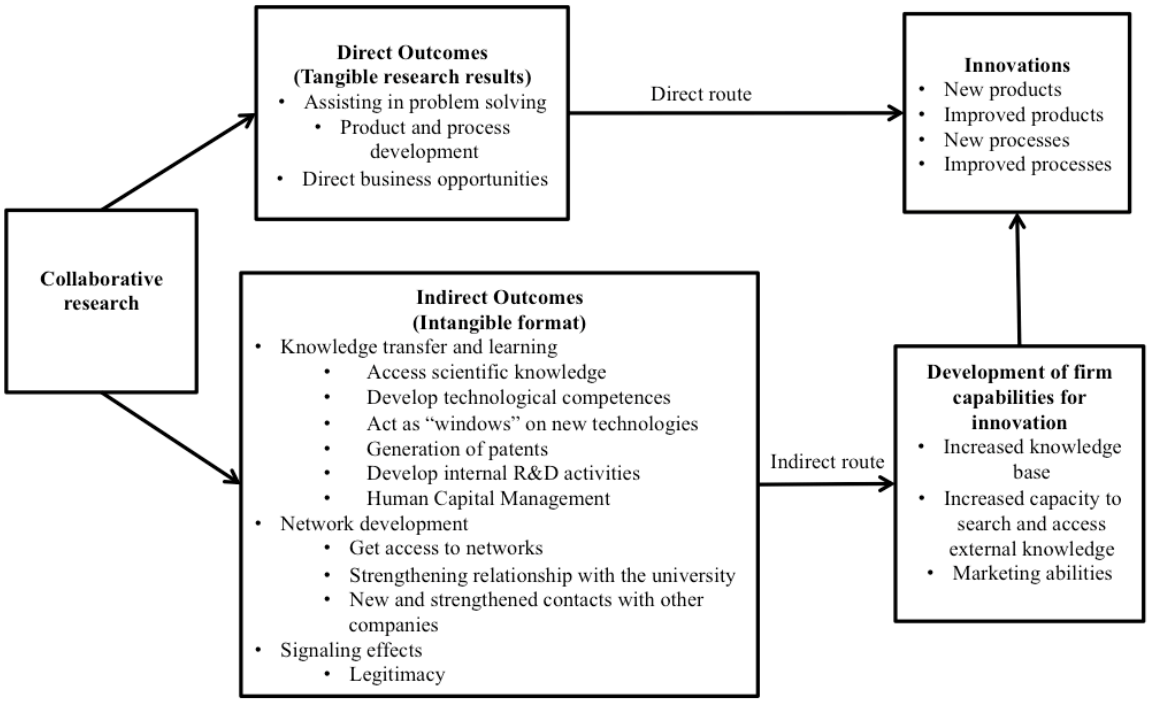
We draw upon one stream in this vast literature. Winter's (2000) definition of organizational capability: "An organizational capability is a high-level routine (or collection of routines) that, together with its implementing input flows, confers upon an

organization's management a set of decision options for producing significant outputs of a particular type*"*(Winter 2000), p.983. This definition indicates that capabilities 1) build upon routines and 2) is reflected in many different firm activities that enables output that impacts the organizations survival and prosperity (Winter 2000). Thus, a routine and a capability are not the same thing.

In this paper we use the absorptive capacity terminology, and specifically, we differentiate between the capability to identify, assimilate and exploit knowledge as separate sets of innovation capabilities. We perceive that for firms to sustain their competitive advantage, they build new and develop existing organizational capabilities. This is achieved by utilizing tangible and intangible assets in a routinized way.

Our enrichment of the theoretical framework is represented in Figure 2 below

Figure 2: Enriched theoretical framework



Therefore, our second research question is: How do firm employed PhD students contribute to firm innovation through 1) direct pathways and 2) indirect pathways?

3 Research design and methods

When investigating how academic engagement can influence innovation in firms, certain empirical environments will be more suitable to study then others, because a huge variety of forms of university-industry collaboration exist (Ankrah & AL-Tabbaa 2015). We have chosen to study firm employed PhD students and their interactions with connected parties. In addition, previous literature reveals little about the phenomenon of firm employed PhD students. Therefore, the research project is a qualitative single case study (Yin, 2014) and the aim is to get an in-depth understanding of firm employed PhD students' experiences in regards to contributing to firm innovation during their education. Note that the focus here is on the graduate students' microlevel activities, which we analyze in relation to the different phases of absorptive capacities. We do not examine direct impacts.

The case includes the firm employed PhD students within engineering at one of Sweden's technological universities (hereafter, The University). The engineering field is chosen due to its long tradition of collaborating with industry and hosting of firm employed PhD students. This research is part of a larger research programme, that focuses on the engineering discipline with the aim of investigating academic engagement in relation to innovation.

3.1 Data collection

The primary data source is gathered through interviews. The total numbers of doctoral students within engineering at The University is 91 of which 17 are firm employed PhD students. Interviews with ten firm employed PhD students have been conducted, of which seven have been interviewed twice. The primary data was gathered through a two-step process, where a first interview aimed at giving broader perspective on what being a firm employed PhD student entails as well as what firm activities they engage in, while the second interview focused more specifically on their contribution in connection to firm innovation. The first interview was organized in a semi-structured way and the interview

guideline was initially developed through a literature review concerning university-industry interaction. For the construction of the interview guide, a pilot interview with a firm employed PhD student was conducted in June 2017. The first round of 1st interviews was conducted in September 2017 and based on the output from the interviews; the interview guide was adopted and further developed. Also, in addition to the interview guide a check-box slip was developed with different activities that firm employed PhD students potentially participated in, which the informants filled in during the interview. This check-box slip helped guide the interview based on the specific situation of the informant as well as introduced a systematic way of approaching this part of the interview. The interview guide was distributed to the informants on beforehand by e-mail, along with two other points of information: 1) the interview was to be recorded and 2) the informant's name, firm and university affiliation would be anonymized. Seven of the interviews were fully transcribed, the remaining three was partly transcribed and for each interview a summary of the interview was sent to the informant in order to assure respondent validation.

The second round of data collection also constituted of semi-structured interviews, but based on the findings from the first interviews, the interview was more focused around how firm employed PhD students experience their contribution to firm innovation during their studies. Thus, the interview guide for the second interview was semi-structured, with open questions, and also had a clear focus on specific examples of how they contributed within the direct/indirect innovation outcomes as discussed by McKelvey & Ljungberg (2016). The interview started out with very open ended questions regarding innovation outcomes and towards the end the informants was shown the extended theoretical framework by McKelvey & Ljungberg (2016). In this way the informant could give their view on the framework and how it relates to their work, as well as it was a helping them to remember even more examples of contributions they made. All information regarding recording and anonymity was communicated at the time of the interview. All interviews

was partly transcribed and used for extended analysis in connection to data gathered from the first round of interviews.

An overview of the collection of primary data is presented in Table 1.

Table 1: Overview of collection of primary data

ID Number	1st interview			2nd interview		
	Date	Interview style	Length of interview (recording)	Date	Interview style	Length of interview (recording)
S.1.CH	September 2017	Face-to-face	01:02:02	November 2018	Face-to-face	01:11:10
S.3. CH	September 2017	Face-to-face	00:39:55	October 2018	Face-to-face	00:58:32
L.4.CH	October 2017	Skype	01:01:29	November 2018	Face-to-face	00:53:11
S.5.CH	October 2017	Face-to face	01:05:43	-	-	-
S.6.CH	October 2017	Face-to-face	01:02:14	June 2018	Face-to-face	00:54:46
S.7.CH	October 2017	Face-to-face	01:21:47	June 2018	Face-to-face	01:16:53
S.8.CH	November 2017	Face-to-face	00:46:59	June 2018	Face-to-face	00:46:53
S.11.CH	June 2018	Face-to-face	00.49.59	November 2018	Face-to-face	01:33:15
L.15.CH	October 2018	Face-to-face	1:02:42	-	-	-
D.16.CH	November 2018	Face-to-face	2:14:04	-	-	-

3.2 Data analysis

The data analysis has followed a two-step procedure. The first interviews were analyzed to create the basis for conducting the second interviews with the informants. In order to analyze the gathered data from the 1st interviews, the interview transcripts (seven fully transcribed and three partly transcribed) was imported into the software tool Nvivo. First, the individual interviews were analyzed separately. Each interview is coded with firs-order codes (for example ‘presentations at firm’, ’firm expectations on patents’, ‘matching own knowledge with firm challenges’ etc.), which later on are grouped into second-order codes. The first-order codes are of more detailed nature, specifying a specific experience of the firm employed PhD student, while the second-order code is on a more aggregated level.

For example, the first-order codes ‘firm expectations on patents’, ‘university expectations on patents’ and ‘filing for patents’ all describe different perspectives and activities connected to the second-ordered code ‘patents’. After coding the individual interviews with first and second-ordered codes, the analysis of the data proceeds by combining all the information in all interviews (Eisenhardt 1989). In doing this, second-order codes can be grouped into third-order codes, or themes, lifting the analysis to an ever more aggregated level. The third-order codes are inspired by both theory and empirical findings.

The analysis of the 2nd interviews was guided both by the empirical findings based on the 1st interview as well as theoretical constructs, in order to give a more detailed picture of how the firm employed PhD students contribute to the firm during their education. As the data collection had a clearer focus, the analysis took on a less explorative approach considering coding. To start with, the individual recordings were partly transcribed based upon two categories of contributions in relation to innovation: general contributions and specific contributions. Thus, the recording was simultaneously analyzed and transcribed focusing on these two categories, leaving certain parts of the recordings un-transcribed. The general contributions capture contributions of more broad and overarching kind, while specific contributions give explicit examples of how firm employed PhD students have contribute to firm innovation during their studies. For instance, while general contributions is exemplified by how the firm employed PhD students think their skills, contacts and intuition can matter for the firms capabilities for innovation, the specific contributions shows explicit examples such a ‘clarifying how to interpret results and concepts in statistics’ or ‘pitching research to top management’. In a second stage, the contributions from all the interviews were analyzed and sub-categories were created within the general and specific outcomes. To give an example, the specific contributions ‘Master thesis supervision and the illustration of application of research’, ‘Supervising master thesis projects on request of a colleague at the firm’ and ‘Close connections to development

teams through supervising master thesis students' was arranged into the sub-category 'Supervising and utilizing master thesis projects'. Hence, the coding has been used in this way to examine the concepts of theoretical interest.

4 Along what dimensions are firm employed PhD students a heterogeneous phenomenon in this empirical context?

This section addresses the first research question. We address this question, by specifying this type of PhD student by first differentiating them from academic PhD students and then by specifying the criteria and characteristics.

In the Swedish context, a majority of PhD students (in general) and especially in engineering are employees, of either the university or the firm. They are then additional enrolled into an education program as a PhD student, with requirements to take course credits and write an independent thesis. In Sweden in 2016, there was 21000 PhD student enrolled across all universities (Statistics Sweden 2017). On average the distribution of male and female students are similar, while with in the specific disciplines this balance might be skewed. The university employs 71% of all doctoral students in Sweden (Statistics Sweden 2017). In this paper, these students are denoted as academic PhD students. Another 23% have various employment arrangements such as stipends, medical doctors or employment in organizations others than universities and firms. The remaining 6% of the doctoral students in Sweden are employed and financed by a firm (Statistics Sweden).

The firm employed PhD students (also called industrial PhD student) must fulfill the following criteria. They are: 1) employed at a firm and 2) financed more than 50% of their salary with financing from non-academic organizations. In the Swedish context, they are most common in engineering disciplines, where 14% of all new PhD students in 2016

where tied to industry in this way (Statistics Sweden 2017). We would also like to point out that writing these contracts and agreements to partake in joint PhD education is a commitment from both parties, the university and the firm. The involved parties must agree to interact and collaborate during a longer period of time, usually between 4-5 years of the PhD education.

The University studied here is one of Sweden's largest technological universities and in 2016, The University hosted close to 1200 PhD students of which 177 where firm employed PhD students (15%). For engineering, the numbers correspond to 17 firm employed PhD students (19%) and 74 academic PhD students (81%).

Table 2 specifies the critieria for The University's enrolment requirements. They differentiate two different types. We study the type 1 in Table 2.

Table 2: The enrolment requirements of a firm employed PhD position at The University.

Definition	Employment and financing	Study pace	Supervision	Teaching	Degree
1) A doctoral student who is employed by a firm (or corresponding organization) and pursuing graduate study at The University. OR 2)A doctoral student that is included in a formalized co-operation agreement.	1) Normally receives the whole salary from the firm as well as part of cost for materials, instruments, supervision and so on by agreement between the firm and The University. OR 2) Doctoral student is entirely or partly on leave from his/her employment at the firm. The Firm entirely or partly finances the salary.	>50%	A supervisor group (two or more researchers) is responsible for the supervision. The main supervisor should be at The University while assistant supervisor often is appointed at the firm.	Teaching time (20%) can be replaced by work at the firm and teaching qualifications of a different kind.	Lic. or doc.

Source: Authors compilation

Of all these firm employed PhD students, this study is limited to a subset of type 1 and in the engineering discipline. The details of the empirical study are as follows:

Six of the informants are collaborating with Firm A, which is a joint spin-of within the field of machine learning. Except for S.8.CH and S.11.CH, these informants have started their firm employed PhD studies within other firms and then been transferred to Firm A in the recent years. The remaining informants, each represents collaborations with other firms. Firm C, Firm D and Firm G are all large and global firms, the first within telecommunications, the second within the transportation and construction equipment industry while the latter is in the automotive industry.

In terms of funding, all ten of the PhD students (the informants) are employed at a firm, but their wages and doctoral education are financed both internally from the firm and from external organizations that co-finance this position. A co-financing organization supports the firms with grants to partly cover the costs of the firm employed PhD student. Co-financing organizations can dispense funds from either the government or foundations and the firm (often with support from the university) applies for grants for each of the individual PhD students. The co-financing grants can be of different lengths (usually 3-4 years in this specific case) and amounts, but they are specifically designated to support the employment and education of firm employed PhD students. In this study, there are three public initiatives (Cofinans Public A, B and C) and one foundation initiative (Cofinans Foundation A) that supports the firm employed PhD students' education. Thus, all informants are employed at a firm with individual employment contracts, which mean that all issues related to HR, such as salary, welfare benefits etc. is handled by the firm.

For the firm employed PhD student, they need to do different tasks, and the division of labor constitutes of two categories. We use these for the analysis of microlevel activities in the next section.

What we call "Academic work" relates to both PhD education and thesis, specifically the amount of time that the informants should spend on their education and research project, and teaching, which is the amount of time that the informant should spend

on teaching activities at the university. Six out of ten informants spend 100% of their time on academic work, for example 90% PhD education and 10% teaching. The remaining four informants dedicate 80-90% of their time on academic work.

What we call "Firm work" refers to the amount of time that the informants are expected (by contract) to participate in firm-specific work. Thus, the tasks that are to be performed are firm specific and can theoretically be anything the firm needs help with. Practically however, these tasks are usually related to the informants' research project in one way or another. It should also be mentioned that even if the main part of the informants don't have time assigned for firm work in their contracts, they still spend time there and help out in different ways. Table 3 below displays an overview of the findings in terms of financing and labor division of the informants.

Table 3: Overview of financing and division of labor for the informants.

ID no.	Firm	Financing of PhD project			Division of Labor		
					Academic work		*Firm work*
		Co-financing	*Firm*	*The University*	*PhD education*	*Teaching*	
S.1.CH	Firm A	Yes, Cofinans Public A	Yes	0%	90%	10%	0%
S.3.CH	Firm A	50%, Cofinans Public A	50%	0%	90%	10%	0%
L.4.CH	Firm C	50%, Cofinans Public B	50%	0%	90%	10%	0%
S.5.CH	Firm D	50%, Cofinans Public A	50%	0%	90%	10%	0%
S.6.CH	Firm A	50%, Cofinans Public A	50%	0%	95%	5%	0%
S.7.CH	Firm A	50%, Cofinans Foundation A	50%	0%	80%	10%	10%
S.8.CH	Firm A	Yes	Yes	0%	80%	10%	10%
S.11.CH	Firm A	100%, Cofinans Foundation A and Cofinans Public C	0%	0%	90%	10%	0%
L.15.CH	Firm D	30-40%, Cofinans Public A	60-70%	0%	80%	0%	20%
D.16.CH	Firm G	50%, Cofinans Public A	50%	0%	80%	10%	10%

Table 3 indicates that in fact, due to public policy, the firms generally finance about 50% of these students' PhD education, which 50% is co-financed from a public or foundation initiative. They generally spend the majority of time on Academic work, and a limited amount of time on Firm work. However, there are important differences due to the individual and organizational level, which we will return to below, as we explore the micro-level activities in which they engage.

In terms of new research and other developments, the informants share information with firms in many ways through different types of activities. We would like to stress that these individuals do appear to act as boundary spanners, and they usually have office spaces and spend some time both the university and the firms. All informants aim to sit at

the firm office at least once a week, whereas others spend all their time at the firms' office except when they have teaching or other scheduled activities at the university.

Table 4 provides an overview of the microlevel activities that they participate in.

Table 4: Microlevel activities that firm employed PhD students participate in

ID no.	Meetings	Presentations	Conferences and papers	Patents	Exchanges and trips to other offices/firms/universities	Fairs and exhibitions	Firm-level coordination of firm employed PhD students
S.1.CH	Weekly/every second week supervision meetings (both academic and industrial supervisor attend), Group meetings	Yes, presenting his research on group level and managerial level. Also at firm offices abroad. Pitching his research to the top management.	Yes	No, hard to patent.	No	Yes (Industry fair)	Yes
S.3.CH	Weekly group meetings. Supervision meetings.	Yes	Yes	Yes	No	No	Yes
L.4.CH	Supervision meeting, staff meetings, group meetings, project meetings.	Yes, several times per year for different parts of the firm.	Yes	No	Yes (through The University)	No	Yes
S.5.CH	Project meetings, supervision meetings, group technological meetings, section technological meeting.	Yes, yearly presentation to management team on research progress.	Yes	No	No	No	No
S.6.CH	Weekly supervision meetings, scrum meetings, "expert meetings" every second week	Yes	Yes	No	No	No	Yes
S.7.CH	No supervision meetings. Group meetings, IT meetings	Yes	Yes	No	Yes (through Private A)	Yes (Industry fair)	Yes
S.8.CH	Supervision meetings, group meetings, staff meeting	Yes	Yes	No	No	Yes (Career fair at a University)	Yes
S.11.CH	Weekly supervision meetings	Yes	Yes	Yes	Yes (through Private A)	Yes	Yes
L.15.CH	No supervision meetings. Meetings connected to his 20% firm work, ex group meetings.	Yes. Presents his research in group meetings. Presented to other brand in Firm D.	Yes	Discussed patents but has not been relevant yet.	No	No	No
D.16.CH	Supervision meetings, group meetings	Yes	Yes	No	Yes (through Firm G)	No	Yes

A more detailed description of some of these activities can be found in the proceeding working paper by Berg & McKelvey (2019).

To summarize our answer to the first research question, we have found that the collaboration between university and industry that is investigated in this study as firm employed PhD students aer characterized by:

- Firm employed PhD students within the field of engineering at The University, Sweden
- The length of the collaboration is at least four years
- Each firm employed PhD student is employed at a firm and usually co-financed with another external organization (which is not the university)
- The majority of the firm employed PhD students' focus 90-100% on their education. However, in practice they also spend time on firm-related work tasks and issues, which means that the workload can exceed full time employment.
- They engage in different types of microlevel activities, related to knowledge generation and technology, inside the firm. There is a wide diversity in types of activities.

These bullet points represent the main dimensions of similarity and heterogeneity amongst the graduate students studied.

5 How do firm employed PhD students influence firm innovation?

This section addresses our second research question: How do firm employed PhD students contribute to firm innovation through 1) direct pathways and 2) indirect pathways? We do so by examining the micro-level activities they partake, as introduced above, as well as how they perceive their own contribution to firm innovation.

5.1 Direct pathways to impact innovation

Table 5 below includes what we consider to be the lower order coding of direct and indirect pathways to impact innovation in firms, including illustrations of each activity.

Table 5: Contribution, Interpretation and illustrative quote for direct and indirect pathways, as identified in interviews

Contribution to firm	Interpretation of qualitative study, relative to heterogeneity of conditions	Illustrative quotes
Direct pathway		
Product Development		
Patenting	Not common. Expectation depends on contracts and whether possible to patent, or not, in that technology area	"The ones that come from industry are more used to"
Being involved in product development	Not common. A few do use their research to look for alternatives in product development	"It's very well connected to reality and we take academic help to see and explore if there are other possible control (engineering) structures that we can use"
Influencing future products	Long time delay to product, even in engineering	"It's not so far ahead but I don't think the code I write will end up in a product. It is rather code that are based on what I have researched, that might end up in a future product".
Wide diversity of whether, and how, long the individuals previously worked in a firm	Ability to contribute seems to be related to previous work experience	"So we identified this gap and that's why we created this project. I was involved pretty early in the phase, we found this gap to be significant and we realized we could work on this with a research interest as well"
Problem-solving activities		
Learning new tools and methods	May be useful to solve problems	"You can suggest new ways of doing the same thing, that's also, or solving the same problem with new solutions"
Indirect pathway		
Knowledge transfer and learning		
Scientific knowledge Bringing in a wider perspective	Developing methods, algorithms and models	"We can be the first ones to have this kind of solution, and that's a good thing. And as we talked about before, its starting to come up some things that can be developed, based on my models, into like some product or tool that can be used either by the firm or our customers."
Develop a technology base	A. Focus on technology, but might not result in a specific product or process B. Developed technology to level 3-4 on the 'Technology Readiness Level' scale	A. "I will be part of a long-term technology road map" B. "Something that happened quite recently is that the firm suddenly wanted to offer a certain product to our customers, and then they started to search

		for knowledge within the firm and then they found me.
Act as window on technologies	Developing a technical vision for future Fulfil part of company goals	"I see it as there are a vision of doing something, you need to break it down in smaller things and I contribute to one of those things"
Generate academic patents (with university)	Filed several patents of which some has been approved	"The latest news is that a patent we started working on for like 2 or 3 years ago, was accepted this summer."
Develop firm R&D	A. Distributing publications inside own firm lead to new contacts, presentations and introducing new knowledge to the firm B. Valuable to have a more academic and a more global perspective	A. "Or results, if I can give them anything or sometimes like present to them what we have done kind of […] And then, often I direct them to the article. You know, I put a lot of time into writing them so then I think it is quite well described in there, what they want to know. But if its not in the article, of course you can help them" B. "You can have really critical discussion on what's the best way to do and that has given interesting conversations for us (the firm), to just not be defensive but to be open and to accept criticism where its due"
Human capital management	Supervising master thesis projects on request of a colleague at the firm	"It was another team that is located in the other side of the building that said: Hey, we had a thought about using machine learning, can you help us supervise a mater thesis project? So it was another team that has asked me for my expertise and help in supervising a master thesis project together with them, they are the ones getting all output and benefits from the master thesis project but they wanted me involved to push it forward"
Network development		
Getting access to networks	Positioning in network, internally and externally	"So I think a lot of people knew what I was trying to do already many years ago and now, well now people know what I'm doing so if someone wants to know something (in this area), then they direct them to me"
Strengthening relationships with university	Getting insight into external organisations	"[The firm] wants to know what's going on at The University. Who are close to

		graduation and which of them might be good to hire".
Develop contact with other companies	Presentations lead to new contacts and meeting Trips abroad and to companies, with graduate students from multiple firms	"For example, it was a technical expert from another area at a presentation I had that I had had brief contact with before, when we both worked at an other firm, that started to talk with me and asked about details."
Signaling effects		
Legitimacy	Engage in activities which make it visible that the firm is engaged in research. Examples: expert at industry fair and present Expert Quick Pitch to customers and suppliers to show excellence	"The whole idea is that when we have firms visiting or guests and want to present what the firm does here […] we do excellence, we work on things that no one else is working on, or that no one has solved yet, and its challenges that most have and then they see that we are working on those problems to solve them"
Prestige	Publishing papers for both individual and corporate prestige	"I think they look at it as a prestige thing, if something is publishable by the section because it brings more valuable to the company as well as the research area so that is them being positive towards publication".

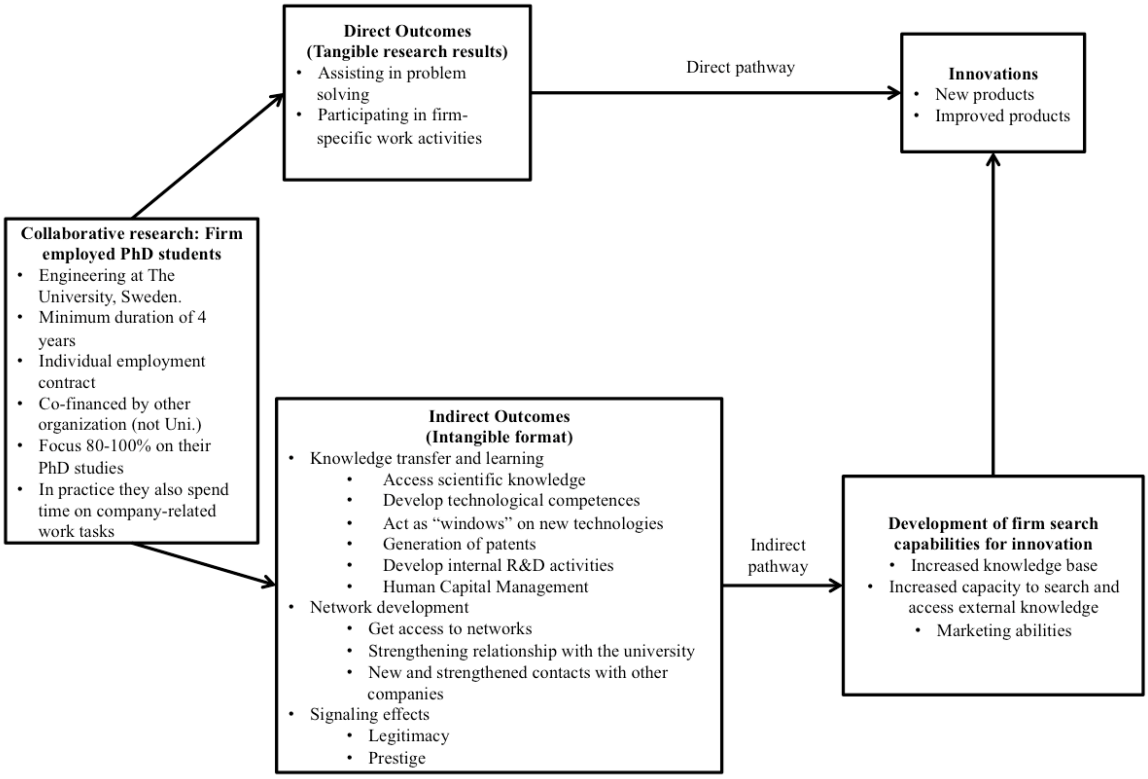
For direct pathways, our qualitative study indicates that from the perspective of the graduate students, there are few instances where their activities will lead directly and immediately to the market as product or process innovations (McKelvey & Ljungberg 2016). (Broström 2010; Gustavsson et al. 2016). If the graduate students are involved, then usually they have previously worked at the firm, and have individual contacts within the firm. We have identified some situations when they do step in and help firm employees with a specific problem they are dealing with or problem-solving more generally, which we consider to present assisting in problem solving, similar to (Bishop et al. 2011). Regarding direct business opportunities (Broström 2010), we do not find this. The closest we find is that they express that their contributions may lead to new product in the future, by for example developing a vision or a technology base. Additionally from our qualitative

research, we have identified the link to work activities. Four of the informants have been assigned firm work (10-20%) in their contracts, and others also participate in firm-specific activities as well, usually through different types of technical and group meetings, or individual contacts in the company. Hence, our interpretation is that direct involvement in normal product development is not the main purpose of having such graduate students. When they do impact the firm more directly, then it is through problem-solving activities, usually related to technology, or to the firm's need to move into new technologies, tools, and methods, which are close to their on-going research projects.

In terms of the indirect pathways, our qualitative study reveals a number of ways in which these graduate students can act as boundary spanners between the two organizations. For knowledge transfer and learning, there are both formal and informal microlevel activities in which they bring knowledge from one to the other, for problem solving. Formal activities include industrial supervision at the firm, meetings, presentations, academic papers and conferences, and activities representing more informal interaction include conversations and discussions with firm employees which may lead to assisting in problem solving or scoping new technological areas. We thereby also confirm existing research about this being one way for firms to access scientific knowledge (Thune 2009; Gustavsson et al. 2016), develop technological competencies (Thune & Børing 2014; Gustavsson et al. 2016) and can act as "windows" on new technologies (Perkmann & Walsh 2008). We interpret that the firms experience human capital management benefits when collaborating with universities (Broström 2010), which we interpret as impacting both in terms of recruitment and training of firm employees (Bishop et al. 2011). We also find that firm employed PhD students can signal research excellence and create a notion of prestige within the firm. Therefore, signaling effects in the theoretical framework will include legitimacy as well as prestige, where the latter is an addition to the framework based on our empirical findings.

Based on the above discussions which analyzes our qualitative research, we propose a revised theoretical framework as displayed in Figure 3 below.

Figure 3: Refined conceptual model of how collaborative research through firm employed PhD students can influence innovation.



We validate the model, and also make a revision, which is primarily in the specification of the indirect outcomes, as well as in what is included in the box of development of firm search capabilities for innovation. We also stress that our main results indicate the importance – to the firm – of having indirect pathway to influencing innovations.

By further opening up the black box of firm capabilities to innovate – in this specific empirical context – then we propose that the following relationship between the three main dimensions of absorptive capacity, seen in Table 6.

Table 6: Linking capabilities, indirect pathway, and microlevel activities

Developing this type of firm capability for innovation	**Indirect pathway**	**Microlevel activities by these graduate students**
Increased knowledge base	Access scientific knowledge	Getting insights in external organizations such as The University, other universities and firms
	Develop technological competencies	Develop technological roadmaps as well as new tools and methods
	Act as 'windows' on new technologies	Developing a vision
	Generate patents	Two of the firm employed PhD students have filed for patents
	Develop internal R&D activities	Bringing an academic perspective as well as a global perspective to the firm
	Human capital management	Becoming future research leader, future employees as well as having insight in potential candidates for employment
Increased capacity to search for and access external knowledge	Get access to networks	Talks and discussions with colleagues at the firm and The University (including getting questions about contact details to both organizations)
	Strengthening relationships with the university	The University organize courses for industry personnel, which the firm employees can attend
	New and strengthened contacts with other firms	Through trips organized by co-financing organizations
Marketing abilities	Legitimacy	Performing presentations internally and externally (such as 'Expert Quick Pitch' or attending industry or career fairs)
	Prestige	Publishing papers

Specifically, we interpret our results to link microlevel activities in these three ways: 1) an increased knowledge base, 2) an increased capacity to search for and access external knowledge and finally 3) marketing abilities.

6. Conclusion, future research and limitations

Based on previous sections, our interpretation is that these graduate students can be interpreted as direct investments in the firm's absorptive capacity (Cohen & Levinthal 1990). By this, we mean that as they are both firm employees and PhD students simultaneously, who are undergo advanced engineering education at the university. The firms tend not to use them as direct pathways to innovation – largely because the firm already have many in technical and product development. Even from the perspective of the firm involved in academic engagement activities (Perkmann et al. 2013), these individuals primarily act as boundary spanners by creating, developing and absorbing new engineering knowledge. In doing so, they contribute to developing firm capabilities through indirect pathways. In this concluding section, we make two points, which are propositions about how to further interpret our results so far, and which define interesting areas for future research.

We propose that our qualitative results above, may be further explored in terms of the 1) Variation in firm routines to deal with these graduate students and 2) Specific set of capabilities needed for each of the different phases of firm innovation, as linked to other employees in the firm. We propose that one way to interpret the heterogeneity of these graduate students – in relation to the development of firm capabilities to innovate – would be through further exploring variations in routines. This notion rests upon the theoretical insights that a) differential capabilities underlie the heterogeneity of firms and 2) the firm's capability to innovate relies, in turn, upon routines (Cohen & Levinthal 1990; Winter 2000).

Hence, our first proposition is that while all firms have some type of organizational routines to handle these graduate students, there is variation. Note that we here consider the firm's organizational routines for collaboration, and not the university's routines for collaboration (as studied in McKelvey and Saemundsson 2019). Diversity in these organizational routines may help explain different ways in which Mode 2 science is enacted within engineering (Gibbons et al 1994).

As identified in answer to our first research question, we confirm that firm employed PhD students can a heterogonous phenomenon (Thune 2009; Borrell-Damian et al. 2010), and we have identified differences in key criteria, characteristics, and microlevel activities. In future analysis, the definitions of organizational capability and routines should be further developed in this context, e.g. that "an organizational capability is a high-level routine (or collection of routines) that, together with its implementing input flows, confers upon an organization's management a set of decision options for producing significant outputs of a particular type*"*(Winter 2000), p.983.

When we went further to answer the second research question of how these graduate students impact innovation in their firms, we have found more types of variety. An important dimension of variety – related to routines – relates to how the firms and firm employed PhD students interact. All these graduate students do some of the same microlevel activities – including attend meetings, perform presentations and visit conferences to present papers. Instead, the variation lies within the intensity of the above, as well as in activities of patents, exchanges and trips to other offices/firms/ universities, fairs and exhibitions and if their affiliated firm has any firm level coordination. The variation in routines is evident in different ways. For example, there are two firm employed PhD students that do not have an industrial supervisor, and our interpretation is that this may hamper the boundary spanning activities and their ability to utilize the benefits from the collaboration due to the most basic connection to the firm is missing. Another example

is the degree of formalization of routines. In Firm A, Firm C and Firm G, there is a high level firm coordination through an annual meeting, conference with presentations, evaluation, venues for discussion and a designated responsible person, whereas Firm D does not have this structure. Additionally, Firm A also has more elements such as the 'Expert Quick Pitch'. Hence, a fruitful avenue for future research is to further conceptualize and analyze these as heterogeneous firm routines. These should likely be interpreted – but from the firm perspective – as collaboration primarily for technical knowledge not for immediate market-based returns. (Salter & Martin 2001; Bozeman et al. 2015). The dimensions of variety appear to be within the actual micro-level activities, as well as how they address problem-solving issues within these firms.

An interesting topic for future research as to do with the impact of such differences. We suggest that the firm routines also depend upon collaboration, such as the universities and the public financers – who cover some percentage of wages. Our empirical findings show, for example, that the activity 'Exchanges and trips' is made possible by Cofinans Foundation A, but not by any other of the co-finance organizations.. The fact that these graduate students employed in Firm A and supported by Cofinans Foundation A will have a higher density and wider range of interaction possibilities than for instance firm employed PhD students at Firm D with financing from Cofinans Public B or C should in turn affect firm routines and innovation. Thus, the first proposition can be developed in later research, in different ways, by interpreting the heterogeneity in the organizational routines that the firms use to interact and utilize innovation outputs from these graduate students.

Our second proposition is that these graduate students need to be understood within the wider set of firm organizational routines and capacities. More specifically for absorptive capacity, there are different phases of a firms' innovation process that requires a specific set of firm capabilities (Cohen & Levinthal 1990; Pavitt 2009; Teece et al. 1997;

Teece 2007; Tidd & Bessant 2009; Zahra & George 2002). These graduate students mainly contribute to the firm's search capabilities, specifically related to capacity to search and access external technical and engineering knowledge. A corollary is that these graduate students are likely only able to develop certain types of firm capabilities for innovation. As explained in the previous section, we find they add benefits to the firms in three ways: 1) an increased knowledge base, 2) an increased capacity to search for and access external knowledge and finally 3) marketing abilities.

Search is closely related to problem-solving by others. As a perhaps natural result that their research projects are closer to tools, methods, and academic knowledge, these graduate students offer opportunities to solve problems for others. The most direct benefit to the fimr appears to be when they provide guidance to search for new technology and problem-solving, and then other employees take over when selecting and implementing the technology. This requires further consideration in relation to the first proposition about organizational routines, because the heterogeneity of the individuals involved seems to impact the likelihood of further impact within the firm.

Hence, future research should examine in detail interactions between different elements of absorptive capacity – inside the firm. In other words, these firm employed PhD students need to be matched with organizational routines and other firm employees who do possess the ability to act upon the technological opportunity presented to them and thereby execute the firm's selection capability (and later on the capabilities connected to implementation). Similarly, as their impact on the firm's marketing abilities first and fore depends upon research and potential future solutions (and not a particular product), our interpretation is that the strengthened marketing abilities rather relates to showcasing that the firm can perform search activities in a sufficient and academic way, rather than help to commercialize new products. The extent to which these graduate students are linked into the firm may also help explain some variation in studies of outcomes after graduation,

including topics such as career paths, impact on wages, as well as whether and why they can continue to publish after being employed at a firm (Cruz-Castro & Sanz-Menéndez 2005; Garcia-Quevedo et al. 2011; Roach & Sauermann 2010). These also represent interesting ideas for future reseach.

6.2 Limitations

We recognize the limitations of our qualitative research, based on indepth case study within engineering at one university. First, it is difficult to produce generalizable results due to the narrow case selection and limited number of interviews. Second, we are primarily focused upon the perceptions and microlevel activities of the graduate students in this study. Third, we are limited to engineering research.

Conflict of interest

The authors declare no conflicts of interest.

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