Abstract

Industrial PhD students – a means for developing capabilities for innovation?

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Industrial PhD students contribute to firms in these innovation specific matters.

Research gap and research questions: Previous research regarding PhD student-industry collaboration mainly focus on the students’ educational experience and learning outcomes (Thune 2009). In addition, few studies has explicitly targeted industrial PhDs as such, also they do not focus on the actual education but rather address what happens after graduation. This paper aims at clarifying in what way industrial PhD students (during their education and from the students point of view) contribute to firms’ innovativeness. This leads us to the research question:
How do industrial PhD students experience their influence on firms’ capabilities for innovation?

In order to answer the main research question, three sub-questions have been developed to guide the research: 1) How do industrial PhD students contribute to firms new products, processes and services? 2) How do industrial PhD students diffuse their skills and knowledge to universities and firms? 3) What does the dual role between industry and academia entail for industrial PhD students?
Main theoretical arguments: In line with previous research on university-industry interaction, industrial PhD students are considered to have positive influence on firms’ innovativeness (L?f & Brostr?m 2006). The ambition of this study is however to be more specific on what direct and indirect outcomes can be associated with engaging with industrial PhD students. Direct outcomes are considered to be new products and methods while the indirect efforts focus on strengthening capabilities for innovation through knowledge transfer and learning, network development and signalling effects (McKelvey & Ljungberg 2016).

Method and data: The research project is a qualitative case study and the aim is to get a deeper understanding of the dynamics between the industrial PhD students and the other parties, namely firms and universities. The case includes departments of automatic control at three Swedish technological universities in Link?ping, Lund and Gothenburg. The automatic control departments are chosen due to their long tradition of collaborating with industry and hosting of industrial PhD students. So far, 8 semi-structured interviews with industrial PhD students from Chalmers University of Technology in Gothenburg have been conducted. Interviews with the remaining industrial PhD students will be performed during spring 2018. In addition to the interviews, a bibliometric pre-study including all 18 industrial PhD students at automatic control at Chalmers University of Technology will be conducted in autumn 2017. The aim of the pre-study is to map publications and co-authors from both the university and the firms.

Results: The analysis of the 8 interviews is being processed at the moment. Preliminary results indicate that industrial PhD students take part in both direct and indirect efforts. For example, industrial PhD students develop patents together with the firms, participate in problem solving in in-house R&D and share their developments with the firm through supervision, monthly reports and meetings. They act as network brokers and provide the other parties, especially universities, with contact information. Publications are considered, to some extent, to have signalling effects and are connected to prestige for firms.

Reference list:
Industrial PhD students – a means for developing capabilities for innovation?
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Abstract
This paper investigates the collaboration between firms and industrial PhD students, and how this collaboration influences the development of capabilities for innovation at firms. The research is conducted as a case study, focusing on collaborations within the area of automatic control at Chalmers University of Technology in Gothenburg, Sweden. The results of the study show that firms benefit in terms of innovation, both directly and indirectly, when collaborating with industrial PhD students. Direct innovation outcomes are for example patents and problem solving activities, while the indirect innovation outcomes are of more intangible character and contribute to the development of firm capabilities for innovation. Thus, industrial PhD students are utilized as strategic resources by firms and influence the firms’ capabilities for innovation.

Introduction
The rapid change of today’s business environment poses new settings and challenges to be explained, conceptualised and managed. It is through resource allocation and building dynamic capabilities that a firm can prosper under a longer period of time (Tecece et al. 1997; Pitelis & Teece 2009). In this regard, the ability to innovate becomes very fundamental and important to a firm. Innovation is defined as “the successful commercial exploitation of new ideas” (Dodgson et al., 2008, p. 2). According to Pavitt (2006) firms engage in innovation through three broad and overlapping sub-processes. These are the production of knowledge, the transformation of knowledge in to artefacts (products, processes, services, systems) and the continuous matching of artefacts to market need and demand. Mangematin & Nesta (1999) acknowledges that a firm’s knowledgebase determines its ability to recognize, absorb and exploit externalities. In addition, Nieves & Haller (2014) point out that firm’s knowledge-based resources can influence the achievement of dynamic capabilities (Tecce et al. 1997). Thus, knowledge is vital for developing capabilities for innovation and can be seen as a strategic resource to the firm. Knowledge is created on an individual level (Grant 1996; Simon 1991) while firms’ ability to utilize and absorb knowledge is a determinant for the capabilities for innovation (Cohen & Levinthal 1990).

A way for firms to enrich their knowledgebase is to engage with the external environment (Chesbrough, 2003), for example universities and academics. University-industry interactions has a positive impact on firms’ innovative and commercial performance (Lööf & Broström 2006). From the firm perspective, university partnerships can lead to both improved and more novel products and processes (Bierly et al. 2009). In addition to these direct innovation outcomes, firms also gain innovation output of a more indirect and intangible nature, which influences firms capabilities (McKelvey & Ljungberg 2016). University-industry collaboration can take many forms and appears at all levels of seniority, from graduate students to experienced professors. PhD students, which are in the intermediate of being a student and becoming a researcher, take part in university-industry collaborations as well. Collaborations between firms and PhD students is not a standardized relationship and should be considered a heterogeneous phenomena (Thune 2009; Borrell-Damian et al. 2010). According to Thune (2009), doctoral students take on three different roles in university-industry relations. First they are significant producers of knowledge in collaborative research and second, they act as channels for knowledge transfer between universities and firms. Lastly, they are important in creating and maintaining network links between universities and firms. Thus, collaborating with PhD students can be very important for firms in terms of developing innovations.

In Sweden, the majority of all PhD students are employed at universities. However, there are also a group of PhD students that are employed at firms. In this paper, these doctoral students are referred to as industrial PhD students and are defined as PhD students whose salaries is financed 50% or more by funding from non-academic organizations. Both academic (PhD students employed at
The article proceeds as following: First, an overview of the theoretical literature is presented. In the end of this section a conceptual framework is outlined in order to visualize the expected results from the empirical investigation. Second, the research design and methods used for data collection and analysis in this study is presented. After that, the empirical setting of the study is explained and the findings of the empirical investigation are displayed. Next follows a discussion that contrasts the empirical findings with the theoretical framework outlined in the theoretical background. Finally, the conclusion of this study is presented along with future research suggestions.

Theoretical background

In order for a firm to be successful with their innovation processes and sustain their competitive advantage, they need to develop both new and existing capabilities (Teece et al. (1997), Winter (2000)). This paper takes on an evolutionary economics perspective that proposes that capabilities are built on resources that are exercised in a routinized way (Nelson & Winter, 1982).

Resources and capabilities

Several frameworks and concepts have been developed to explain why some firms in an industry or sector are more prosperous than others and what creates this competitive advantage (Teece et al. 1997). For example, the Resource Based View (RBV) (Barney 1991) focus on strategies for exploiting existing firm-specific resources and implies that managerial strategies can be used to develop new capabilities (Teece et al. 1997). Hence, if firm-specific resources are key to firm performance and economic returns, the ability to build and develop these resources is very important. For example skill acquisition, learning and management of knowledge are thereby a strategic issue. According to Teece et al (1997), the resource-based view does not explicitly explain how firms create these specific resources but suggests a concept of dynamic capabilities that aims at explaining firms “ability to achieve new forms of competitive advantage” – Teece et al. (1997), p.515. In line with Barney (1991) and Teece at al. (1997), this paper embrace the idea that it is possible to create and develop firm-specific resources and capabilities to facilitate firm performance and economic returns.

This paper apply Winter’s (2000) definition of organizational capability: “An organisational capability is a high-level routine (or collection of routines) that, together with its implementing input flows, confers upon an organisation’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 is not the same thing. In this setting, organizational routines are defined as “Behaviour that is learned, highly patterned, repetitious, or quasi-repetitious, founded in part in tacit
knowledge” (Winter, 2003, p.991). In terms of resources, they are considered to be the tangible and intangible assets a firm uses to choose and implement strategies (Barney 2001). In sum, 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.

**Collaborative research with universities**

A way for firms to enrich their knowledgebase is to engage with universities and academics. The reason why firms engage with academia can vary but it is clear that collaborations with universities can result in multiple types of outcomes and benefits for firms (Bishop et al. 2011; Broström 2010; Perkmann & Walsh 2008; McKelvey & Ljungberg 2016).

In order to contextualize and consolidate the literature in this subject into a conceptual framework, inspiration is drawn from McKelvey & Ljungberg (2016). In their effort in describing policy implications in the Swedish food industry, they outline a fairly straightforward model that indicates that firms gain innovation output in different ways when conducting collaborative research with universities. In some situations, firms experience outcomes that can be directly transferred to the company and commercialized in the market. In other situations, the output is of more intangible character and does not result in a direct innovation. However, these intangible outputs are still important for the development of new products, processes and services in firms, but in terms of developing firms’ capabilities for innovation. The main take away is that collaborative research impact firm innovation, either direct through commercialization of innovations or indirect through academic engagement that develops firm capabilities for innovation (McKelvey & Ljungberg 2016). Academic engagement have a wider objective than commercialization and entails activities that are both formal and informal, such as collaborative research, contract research, consulting, ad hoc advice and networking with practitioners and other forms of knowledge exchange (Perkmann et al. 2013).

**Direct innovative outcomes**

In the literature addressing university-industry interaction, there are certain outcomes that can be linked to direct innovation outcomes. For instance, assisting in problem solving (Bishop et al. 2011), product and process development (Broström 2010), direct business opportunities (Broström 2010) and generation of patents (Bishop et al. 2011) qualify as direct innovation outcomes due to their direct and/or tangible nature. In the literature specifically addressing firm collaboration with industrial PhD students, I also find product and process development (Gustavsson et al. 2016) as a potential outcome. For this study, four potential direct innovation outcomes have been identified in the literature, which is expected to be applicable when firms collaborate with industrial PhD students.

**Indirect innovation outcomes**

To start with, McKelvey & Ljungberg (2016) distinguish between tree different categories within the indirect innovation outcomes: Knowledge transfer and learning, network development and signalling effects. In terms of knowledge transfer and learning, the university-industry literature presents us with outcomes such as human capital management (Broström 2010) and that academics can serve as “windows” on new technology (Perkmann & Walsh 2008). Bishop et al. (2011) also discuss recruitment and training of company employees as potential outcomes. When looking at the literature addressing firm-industrial PhD student collaboration, other outcomes are presented: Access to scientific knowledge (Thune 2009; Gustavsson et al. 2016), developing technological competences (Thune & Børing 2014; Gustavsson et al. 2016) and developing internal R&D activities (Gustavsson et al. 2016). In addition, Gustavsson et.al (2016) also find recruitment to be a potential outcome for firms that engage with industrial PhD students. Moving on to network development, getting access to networks is an outcome considered by both university-industry literature as well as firm-industrial PhD collaboration references. However, the latter stream of literature also recognize outcomes in terms of strengthening the relationship with the university and new/strengthened contacts with other companies (Gustavsson et al. 2016). Finally, signalling effects are recognised by McKelvey & Ljungberg (2016), it is referred to as legitimacy by
Gustavsson et al. (2016). In sum, five outcomes are identified and related to knowledge transfer and learning, three address network development and one outcome is assigned to signalling effects.

Along with the above reasoning, there are other aspects of McKelvey & Ljungbergs (2016) article that will constitute the base for the theoretical framework used in this paper. First, there are different types of innovation outcome. The Organisation for Economic Co-operation and Development (OECD) identifies four types: Product, process, market and organizational innovation. Just as the originators of the conceptual model, the main focus for this study will be on product and process innovation. Second, the degree of novelty of innovation can span on a continuum of incremental to radical (Freeman, 1974). Incremental innovation involves minor changes to existing processes or products while radical innovation deal with ground-breaking changes that are new to the firm or world. Incremental innovation is about improving existing processes or products while radical innovation could result in an entirely new process or product. Based on McKelvey & Ljungbergs (2016) work and the previous theoretical constructs described in this chapter, I arrive at the following conceptual framework:

![Figure 1: Conceptual framework for collaborative research and innovation outcomes.](image)

The above model outlines the baseline for the empirical analysis. Thus, the expectations are that industrial PhD students influence firms’ capabilities for innovation and that they do so by both direct and indirect innovation output. In order to examine these matters, three research questions will guide the empirical investigation: 1) How do industrial PhD students diffuse their skills and knowledge to firms, 2) how do industrial PhD students contribute to firms’ new products and processes and 3) what role do industrial PhD students play in network development?

**Research design and method**

The research project is a qualitative single case study (Yin, 2014) and the aim is to get an in-depth understanding of the phenomenon of collaborations between firms and industrial PhD students. The case includes the area of automatic control at Chalmers University of Technology in Gothenburg.
The automatic control area is chosen due to its long tradition of collaborating with industry and hosting of industrial PhD students.

**Data collection**

The primary data source is gathered through semi-structured interviews. The total numbers of doctoral students within automatic control at Chalmers University of Technology is 91 of which 18 are industrial PhD students. Eight semi-structured interviews with industrial PhD students have been conducted.

The interview guideline used during the interviews was initially developed through a literature review concerning university-industry interaction. In addition, a pilot interview with an industrial PhD student was conducted in June 2017, which also contributed to the construction of the interview guide. The first round of interviews was conducted in September 2017 and based on the output from the interviews; the interview guide was adopted and further developed.

With exception of the two first and the last interviews, all interviews were transcribed and a summary of the interview was sent to the informant in order to assure respondent validation. An overview of the collection of primary data is presented in Table 1.

### Table 1: Overview of collection of primary data

<table>
<thead>
<tr>
<th>ID</th>
<th>Interview date</th>
<th>Interview style (semi-structured)</th>
<th>Length of interview (recording)</th>
<th>Transcribed</th>
<th>Summary of interview reviewed by Informant</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.1.CH</td>
<td>05-Sep</td>
<td>Face-to-face</td>
<td>01:02:02</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>S.2.CH</td>
<td>07-Sep</td>
<td>Face-to-face</td>
<td>00:53:41</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>S.3.CH</td>
<td>18-Sep</td>
<td>Face-to-face</td>
<td>00:39:55</td>
<td>26/9 2017</td>
<td>Approved</td>
</tr>
<tr>
<td>L.4.CH</td>
<td>05-Oct</td>
<td>Skype</td>
<td>01:01:29</td>
<td>16/10 2017</td>
<td>Approved</td>
</tr>
<tr>
<td>S.5.CH</td>
<td>17-Oct</td>
<td>Face-to-face</td>
<td>01:05:43</td>
<td>20/10 2017</td>
<td>Corrected and approved</td>
</tr>
<tr>
<td>S.7.CH</td>
<td>31-Oct</td>
<td>Face-to-face</td>
<td>01:21:47</td>
<td>5/11 2017</td>
<td>No</td>
</tr>
<tr>
<td>S.8.CH</td>
<td>09-Nov</td>
<td>Face-to-face</td>
<td>00:46:59</td>
<td>No</td>
<td>Corrected and approved</td>
</tr>
</tbody>
</table>

**Data analysis**

In order to analyse the gathered data, each interview (except three) has been transcribed and imported into the software tool NVivo. First, the individual interviews are analysed 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 industrial 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.
Findings
The empirical findings are presented in this section. First, the empirical setting in which the study is taking place will be presented. Second, descriptive empirical data based on the semi-structured interviews will be outlined. Third, the empirical evidence answering the three research questions will be presented in order to facilitate a discussion related to the theoretical framework in the next chapter.

Empirical setting: Industrial PhD students in Sweden
In 2016, the universities in Sweden train close to 21,000 doctorates (Statistics Sweden 2017). On average the distribution of male and females are similar, it is in the specific disciplines this balance might be skewed (Statistics Sweden 2017). The technical fields had 4330 PhD students and 590 registered PhD degrees in 2016, which is similar to the natural sciences. The field of medicine and health is larger with 6830 PhD students and 980 registered PhD degrees for the same year, while social sciences count for 3540 PhD students and 430 PhD degrees.

The PhD education in Sweden is a four-year program, which result in a PhD degree if the student meets all requirements. As much as 20% institutional duties can be added on top the PhD education, resulting in that it takes five years until the student get their PhD degree. However, there is also a possibility to take a licentiate degree, which basically is half as much as a PhD degree (approximately 2 years). In Sweden, 2/3 of all doctoral students are employed at the university (Statistics Sweden 2017). In this paper, these students are referred to as academic PhD students. In other cases, the doctoral student is employed and financed by a company. The PhD students that finance more than 50% of their salary with funding from non-academic organizations are referred to as industrial PhD students by Statistics Sweden. However, in this paper a slightly modified version of Statistics Sweden definition will apply, namely that PhD students that finance at least 50% of their salary with funding from non-academic organizations are referred to as industrial PhD students. Industrial PhD students are most common in technical disciplines, where 14% of all new PhD students in 2016 where tied to industry in this way (Statistics Sweden 2017).

Chalmers University of Technology
In 2016, Chalmers hosted in total 1137 doctoral students of which 177 where industrial PhD students (Chalmers Annual Report 2017). As much as 154 industrial PhD students are within the technical fields and for automatic control, the numbers correspond to 18 industrial PhD students and 73 academic PhD students. Table 2 below visualizes Chalmers enrolment requirements for industrial PhD students.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Employment and financing</th>
<th>Study pace</th>
<th>Supervision</th>
<th>Teaching</th>
<th>Degree</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) A doctoral student who is employed by a company (or corresponding organization) and pursuing graduate study at Chalmers</td>
<td>1) Normally receives the whole salary from company as well as part of cost for materials, instruments, supervision and so on by agreement between the company and Chalmers. 2) Doctoral student is entirely or partly on leave from his/her employment at the company. Chalmers entirely or partly finance the salary.</td>
<td>&gt;50%</td>
<td>A supervisor group (two or more researchers) is responsible for the supervision. The main supervisor should be at Chalmers while an assistant supervisor often is appointed at the company.</td>
<td>Teaching time (20%) can be replaced by work at the company and teaching qualifications of a different kind.</td>
<td>Licentiate or doctorate</td>
<td>Chalmers homepage 31 May 2017</td>
</tr>
</tbody>
</table>
Descriptive empirical data
All of the eight informants are males and have been PhD students between 2.5 months and 4.5 years. All informants have the intent of both taking both a licentiate and PhD degree but so far, none of the informants has taken the PhD degree and only one has taken the licentiate degree. However, three of the informants will soon defend their licentiate (approximately within 6 months). Five out of eight informants are not adhering to their time plan and are lagging behind with their studies. Some informants experience lagging behind with the studies as problematic, while others don’t.

Five of the informants are collaborating with Company A, which is a joint spin-off company within the field of machine learning. Except for S.8.CH, these informants have started their industrial PhD studies within other companies and then been transferred to Company A in the recent year. The remaining informants, each represents collaborations with other firms. Company B is a research center at Chalmers that focus on industrial mathematics. Company C and Company D is both large and global companies, the first within telecommunications and the latter within the transportation and construction equipment industry. An overview of the findings is displayed in Table 3 below.

Table 3: Overview of informants in terms of gender, company, duration of studies, academic degree and adherence to time plan.

<table>
<thead>
<tr>
<th>ID no.</th>
<th>Gender</th>
<th>University</th>
<th>Company</th>
<th>Duration</th>
<th>Licentiate Degree</th>
<th>PhD Degree</th>
<th>On time with studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.1.CH</td>
<td>Male</td>
<td>Chalmers</td>
<td>Company A</td>
<td>3 years</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>S.2.CH</td>
<td>Male</td>
<td>Chalmers</td>
<td>Company B</td>
<td>4 years</td>
<td>No (Soon)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>S.3.CH</td>
<td>Male</td>
<td>Chalmers</td>
<td>Company A</td>
<td>4.5 years</td>
<td>No (Soon)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>L.4.CH</td>
<td>Male</td>
<td>Chalmers</td>
<td>Company C</td>
<td>2.5 years</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>S.5.CH</td>
<td>Male</td>
<td>Chalmers</td>
<td>Company D</td>
<td>2 years</td>
<td>No (soon)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>S.6.CH</td>
<td>Male</td>
<td>Chalmers</td>
<td>Company A</td>
<td>8 months</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>S.7.CH</td>
<td>Male</td>
<td>Chalmers</td>
<td>Company A</td>
<td>2 years</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>S.8.CH</td>
<td>Male</td>
<td>Chalmers</td>
<td>Company A</td>
<td>2.5 months</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

In terms of funding, the main part of the informants has funding from both the companies and a co-funding body. However, S.2.CH is employed 50% at Company B and 50% at Chalmers. In S.8.CHs case, it is not yet decide exactly how the funding will be divided. All informants are employed at the companies (S.2.CH only 50%), each with individual employment contracts. All issues related to HR, such as salary, welfare benefits etc. is handled by the company. In terms of co-funding bodies, Vinnova, Swedish Foundation for Strategic Research (SSF) and Wallenberg Autonomous Systems and Software Program (WASP) supports the informants. Vinnova and SSF are public research agencies while WASP is a private research program.

The division of labor constitutes of two categories. Academic work relates to both PhD education, 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. Five out of eight informants spend 100% of their time on academic work, for example 90% PhD education and 10% teaching. The remaining three informants dedicates between 50-90% of their time on academic work.

Company work refers to the amount of time that the informants are expected (by contract) to participate in company-specific work. Thus, the tasks that are to be performed are company specific and can theoretically be anything the company 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 company work
in their contracts, they still spend time there and help out in different ways. Table 4 below displays an overview of the findings in terms of funding and labor division of the informants.

Table 4: Overview of funding and division of labor for the informants.

<table>
<thead>
<tr>
<th>ID no.</th>
<th>Company</th>
<th>Financing of PhD project</th>
<th>Division of Labor</th>
<th>Academic work</th>
<th>Teaching</th>
<th>Company work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Co-funding</td>
<td>Company</td>
<td>Chalmers</td>
<td>PhD education</td>
<td>Teaching</td>
</tr>
<tr>
<td>5.1.CH</td>
<td>Company A</td>
<td>Yes, Vinnova</td>
<td>Yes</td>
<td>0%</td>
<td>50%-100%</td>
<td>Yes</td>
</tr>
<tr>
<td>5.2.CH</td>
<td>Company B</td>
<td>0%</td>
<td>50%</td>
<td>50%</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td>5.3.CH</td>
<td>Company A</td>
<td>50%, Vinnova</td>
<td>50%</td>
<td>0%</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td>5.4.CH</td>
<td>Company C</td>
<td>50%, SSF</td>
<td>50%</td>
<td>0%</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td>5.5.CH</td>
<td>Company D</td>
<td>50%, Vinnova</td>
<td>50%</td>
<td>0%</td>
<td>90%</td>
<td>10%</td>
</tr>
<tr>
<td>5.6.CH</td>
<td>Company A</td>
<td>50%, Vinnova</td>
<td>50%</td>
<td>0%</td>
<td>95%</td>
<td>5%</td>
</tr>
<tr>
<td>5.7.CH</td>
<td>Company A</td>
<td>50%, WASP</td>
<td>50%</td>
<td>0%</td>
<td>80%</td>
<td>10%</td>
</tr>
<tr>
<td>5.8.CH</td>
<td>Company A</td>
<td>Not yet decided</td>
<td></td>
<td></td>
<td>80%</td>
<td>10%</td>
</tr>
</tbody>
</table>

In the next sections, the empirical evidence connected to the three research questions is presented.

How do industrial PhD students diffuse their skills and knowledge to firms?

In terms of new research and other developments, the informants share information with firms in many ways. In this section, an account is given of the different ways which the industrial PhD students diffuse their skills and knowledge. It should be made clear that the informants have office spaces at both the university and the firms. These can be more or less organized such as separate offices or open space working environments. All informants attempt to visit the firm office at least once a week. Some of the informants’ spend all their time at the company office except when they have teaching or other scheduled activities at the university. Thus, the informants are physically moving between the two organizations during their PhD education.

Meetings at the firm

All except one informant (S.7.CH) has a clearly defined industrial supervisor at the company. In addition there are usually other people supporting the industrial PhD students as well, such as control groups, technical group managers or other people from the particular work group that the informant belongs to at the company. The informants have regular meetings with their supervisor, accordingly one a week. In S.7.CH, the initial supervisor changed position and now there is no other person that takes on the supervisor role to 100%. However, the informant say that he get help from other persons in the company to get help and guidance, for example the technical manager.

Except for the supervision meetings, there are a number of other meetings taking place at the firm where the industrial PhD student can participate. The meetings brought up by the informants are different kinds of group meetings and project meetings. Group meetings seem to be occurring on regular basis according to the informants “Yes so there are like routine meetings, like weekly meetings from the groups”. Group technical meetings are described by S.5.CH as “we also have this group technical meetings at The Company, [...] where you present all technical advancements, within the local group. Its not even the full department or section, its still this small group and still you get to present your results and take a discussion on what you are working on, even informally because this is more deeply and directly connected to the actual application”. These technological meetings also take place one layer up, at the section level at the firm. Project meetings are another forum for the industrial PhD students to attend, which aims at presenting the new developments in a particular research area at the company.

Presentations at firms

All informants share their experiences regarding holding presentations at the firm. For example, L.4.CH state that he presents several times a year at the company and S.5.CH explains “I also present to the management team once a year on the research”. In addition, S.5.CH also presents at
the annual conference organized by the company: “And of course the [...] annual conference that we do every year and that’s at The Company, open to all employees”.

Reports to share the progress with the firm
In L.4.CH case, he provides the company with a written report every month to inform them about the progress of the research project.

Coordination of industrial PhD students at the firm
At Company C and Company D there are structures in place to organize industrial PhD students and their research on a company wide level. Gatherings are organized on a yearly basis for all doctoral students at the company; they meet up and share research developments and other experiences.

Papers and publications
None of the companies has any specific requirements on publishing papers. However, the firms see publications as something positive. Informant S.5.CH explains that prestige can be connected to publishing papers in academic journals: “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”. In addition, S.6.CH talk about that employees at the company publish as well: “I mean those people are also having a lot of potential publications, at least they visit this academic conference every year”.

Seminars and conferences
In terms of participating in seminars and conferences, companies have a positive attitude towards this. For example, it’s a good opportunity to make the research visible.

Talks and discussions with colleagues at the firm
The informants also indicate that they also spend some time on informal talks and discussions with their colleagues at the firm. In terms of asking or getting questions, it seems to be mainly the informants who ask questions to the company employees. For instance, S.6.CH states “normally my working content is so to say, isolated from normal developers so not much related unless I have questions regarding tools or features and how to use their result. I mean normally I will ask them”. However, the opposite occurs and the informants can get questions from company employees as well.

Matching own knowledge with firm challenges
At times, opportunities to contribute to ongoing activities at the company present itself. Usually this happens due to that the industrial PhD students see that they poses knowledge that can be helpful in the firm activities, just as S.3.CH describes: “I saw that they used methods I didn’t think would work and they had problems to get it to work. I realized we could do it in another way and talked to them about it. So we tried my suggestion and I wrote the code and ran a small test and saw that it worked”. Another example is described by S.6.CH “the supervisors at the company is trying to enhance the performance and I was taking a course and I directly saw that maybe some knowledge that I have could be applied, so that’s happening right now”.

How do industrial PhD students contribute to firms’ new products and processes?
This section accounts for how the informants contribute to the development of firms’ new products and processes.

Developing a vision
Industrial PhD students can be part of developing a particular vision that the firm set out to achieve. The informants express that they constitute a way to fulfil a piece or a part of that particular vision. For example, informant S.3.CH states “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. You know what need to be
done but not how it should be done, I see I contribute in solving that”.

Developing a technology base
The research made by industrial PhD students might not result in a particular product or process. However, the informants express it more in terms of that they develop a technology base that can serve as foundation for many different products in the future. Informant S.6.CH express it in terms of being part of a long-term technological roadmap “I will be part of the long-term technology road map so what I’ve been working on is a block within the future map. So basically the experts has been discussing how they can found their architecture and then these are blocks and each block has to be filled in and think I can contribute to one of the blocks or multiple blocks”. The informants also point out the uncertainty inherent in research and stress that their research potentially can end up in new products or processes: “I cant promise anything, it’s a bit unclear […] its research and that’s a bit like gambling, you never know what works on beforehand. You just got to have hope”.

Involvement in product development
On the one hand, industrial PhD students are not involved in the actual product development process. For example, L.4.CH says “I must admit, I’m not involved in product development at all”. On the other hand, it depends on what type of research project the industrial PhD students have. Even though they might not be directly connected to product development at the company, some projects are more closely integrated with already existing products in the market. As S.5.CH notice: “it’s very well connected to reality and we take academic help to see and explore if there is other possible control structures that we can use. But still, it’s going to be practical because that’s our objective, to provide an industrial solution but with the research based solution […] its easier for me to go from research to action, practical implementation”.

New tools and methods
One outcome from the research projects is that the industrial PhD students learn new tools and methods that potentially can be used within the firm for the development of new products and processes. As one of the informants point out “most likely I’ll be learning new tools, methods in the university this half of year and potentially I can see there are applications that can be used”.

Patents
From a firm perspective, the demands on patents differ between the informants. It seems as only Company C has stipulated in their contract with the informant that the goal is to file for a certain amount of patents during the students education. The research area can influence the need for patents in different ways. For example, in areas characterised by software developments it can be hard to file for patents due to open source code etc., while the telecommunications area seem to have more incentives to patent. Also, the companies’ preferences for patents weigh in. So far, one of the informants, S.3.CH, has filed for patents during his education. The informant had five years of previous industry experience and a patent before he began his PhD studies and expresses that his previous experiences have made it easier for him to file new patents during his PhD education.

The industrial PhD students’ competence
This contribution can be divided into two parts: the previous competences and experiences of the industrial PhD students before starting the education and the competences acquired during their education. Previous competencies relates to for example to the informants experience from the industry, two have worked in the same industry before, one has switched industry and five has less than six months work experience since they signed up for the position shortly after graduation. For instance, informant S.3.CH, S.5.CH and S.6.CH all have 5-6 years of previous industry and work experience. S.3.CH is the only one that has a patent of the informants and as can be seen in above quote in the patent section, he acknowledges that it was favourable to have filed for patents before the PhD position. Based on S.5.CH previous experience, he was very much involved in identifying the knowledge gap in the firm that now have become his industrial PhD project: “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 realised we could work on this with a research interest as well”. Both S.3.CH and S.5.CH had previous experience from the same industry that their research projects are within. However, S.6.CH switched industry when he began his industrial PhD studies. He thinks his previous industry experiences were partly the reason he was hired as an industrial PhD at Company A. First, the technological knowledge from the previous industry is now also important in the industry that Company A operates and second, the informant had also experience from a specific work process (scrum), which Company A was aiming at implementing: “these people are shifting from a manufacturer that’s basically dealing with hardware and then the want to build up a new company with software releases [...] I can surely help the, at least in the method I can help the company shifting into that direction. That’s partly why they hired me”. In terms of the acquired competences during the industrial PhD education, L.4.CH states “I think that, above all, it may be about training staff and that it can lead to something in the future, that I will be a good employee in the future”. L.4.CH also point out that he learn things that might impact long term strategic planning and that the technological knowledge he learns over time is important for the company in order to make strategic choices.

Time aspects related to new product
The informants explain that their contributions mainly can lead to new products in the future, rather than straight away: “Right now I’m working with problems that are not connected to any products in the near future [...] but maybe in the long term, within 5-10 years”. Another informant express it in terms that he took on the PhD position to move further away from the testing and robustness checks that need to be done when getting a product ready for commercialisation. Yet another informant states “its not so far ahead but I don’t think the code I write will end up in a product, its rather code that are based on what I have researched that might end up in a future product”. However, there are also examples of contributions that can be applied more directly. Patents for instance are one example that has already been discussed.

Bringing a wider perspective to the firm
A number of informants states that one of the most important contributions they bring to the firm is a wider perspective, both in terms of a more academic perspective but also a global perspective: “bringing the academic perspective and the global perspective into the industry are two main contributions I see for the research at The Company. Because otherwise we do our research in a closed circle, we don’t engage with external parties”. Thus, “you can have really critical discussion on what’s the best way to do and that has given interesting conversations for us, to just not be defensive but to be open and to accept criticism where its due. So I think that’s a positive thing [...] using the academy as a medium to enable this kind of discussion”.

Company work
Not all informants have assigned company work (see Table 4) but for the ones that do, the work tasks are usually related to the informants’ research projects in some way or another. S.7.CH gives an example “I became very involved in building servers for our group during the summer”. He also mention that he usually spend more time on company work than what is stipulated in his contract.

To be a future research leader
Informant S.5.CH had a clear expectation from the company, namely that “they expect you to be a PhD student because they want future research leaders in the fields that they identified”.

Getting insights in external organisations
By engaging with industrial PhD students, companies get insights from external players. Based on the informants’ experiences, three such external organizations can be identified: the academic world, other industries and competitors. In terms of the academic world, it is easier to know what is going on at the universities if you can get insider information. The companies monitor this and as L.4.CH express it “[the company] wants to know what’s going on at Chalmers. Who are close to graduation and which of them might be good to hire”. It is extra important to be up to date with the
universities in some cases: “the real pioneering is happening in some labs, for instant in Berkeley [...], they have been working on that topic like 20 years and then off course it will help to divide those experiences”. Getting insights into other industries and how they solve similar problems can also be very helpful. In S.5.CH’s case, this kind of input comes through Chalmers, which have a long tradition of collaborating with many different industries. As an industrial PhD student it is also possible to get access to competitors in the market as well. This was the situation of S.7.CH: “[The co-funding body] organize trips, I went to USA on one of those two weeks ago and had the possibility to visit competitors to the company”.

What role do industrial PhD students play in network development?
Both universities and companies want the industrial PhD students to engage in network activities. The extended network can be useful in development of technology and future recruitments as S.7.S states “you find valuable contacts, both for yourself and the company. You might find someone working on a problem we need to solve at the company, the you can start to think about whether you should hire that person, read their research or see if you can develop it on your own”. In terms of establishing contact amongst the collaborating university and company, the informants indicate different scenarios. In some cases, it is more common that company employees ask for contact details to people within Chalmers compared to the other way around. However, when people at the university ask for contact details it is usually to someone in a parallel group or other instances at Chalmers. In other cases, it seems that even university employees reach out to the company. Another form of networking activities is that Chalmers organize courses for company employees, as S.5.Ch gives an example of “I would say [Chalmers] is well industrially integrated as well because they hold these courses for the industry people as well so that also brings another channel for networking”. In some cases the co-funding body also enables networking possibilities, as the case with WASP and S.7.CH explained previous in this chapter. It was through WASP the informant got the possibility to travel to USA and meet competitors to Company A.

Discussion
In this section the empirical findings will be discussed and contrasted to the literature presented in the theoretical section.

From resources to capabilities
As stated in the theory section, to utilize firm-specific resources in a routinized way are key to develop capabilities (Winter 2000; Winter 2003; Barney 2001). In this paper, the focus is on firm capabilities for innovation. Thus, knowledge is vital for innovation and can thereby be seen as a strategic resource for the firm. In this particular case, I am investigating the collaboration between firms and industrial PhD students. A few things that aligns with the theoretical argumentation above, becomes visible in the empirical findings. To start with, industrial PhD students incorporate pre-existing knowledge in firms as well as they develop new competencies and skills during their education. Second, the firms have somewhat routinized ways of incorporating the competencies, skills and knowledge the industrial PhD student possess. Examples of this are technical group meetings at different company levels, monthly reports and weekly supervision meetings. A few companies even have specialized functions that aim at organizing all PhD students on a company wide level, through for example yearly meet-ups. Thus, some of these activities are applicable for both students and employees, while some are specifically targeting the industrial PhD students. Third, this specific collaboration takes place during several years and it is not something that happens randomly. The duration is four to five years if the students manage to stick to their time plan, but as the empirical investigation reveals it is not uncommon with delays. To sum up, industrial PhD students can be seen as a strategic resource to the firm and due to the structure of collaboration and integration with the firm, they also contribute to the development of firm capabilities.
The industrial PhD students contribution to firm innovation

It is through collaborative research that firms and universities interact and co-develop innovative outcomes (McKelvey & Ljungberg 2016). Theory has presented us with a number of different types of innovative outcomes such collaboration could lead to. These will now be contrasted to the empirical findings from firm collaboration with industrial PhD students.

Collaboration characteristics

To be more precise, firm collaboration with industrial PhD students that are investigated in this study is characterised by:

- Industrial PhD students within the field of automatic control at Chalmers, Sweden
- The length of the collaboration is at least four years
- Each industrial PhD student is employed at the firm and usually co-financed with another external organisation (which is not the university)
- In most cases, the industrial PhD students focus 100% on their education (stated in the contract). However, in practice they also spend time on company-related work tasks and issues, which means that the workload can exceed full time employment

Commercialization and tangible research results

In some situations, companies experience outcomes that can be directly transferred to the company and commercialized in the market (McKelvey & Ljungberg 2016). In terms of product and processes development (Broström 2010; Gustavsson et al. 2016), the empirical evidence is somewhat contradictory. Even though it is clearly expressed by some of the informants that they do not take part in product development within the firm, others state that it will be fairly easy to go from research to practical implementation. In addition, informants reveal that they sometimes can identify situations where their own knowledge can be matched with firm challenges. So, there are situations when the industrial PhD student can step in and help firm employees with a specific problem they are dealing with. Thus, even though industrial PhD students don’t work directly with product development as such, they occasionally identify opportunities to assist in problem solving (Bishop et al. 2011). Hence, industrial PhD students engage in problem solving rather than in product development activities. In addition, there is no evidence in the empirical data that industrial PhD students participate in process development.

Patents are visible both in the theoretical literature and the empirical data as a tangible research result. Even though a patent might not lead to a commercial offer, it still constitutes a very tangible research outcome and is therefore assigned within this category of innovation output.

Regarding direct business opportunities (Broström 2010), there is no clear empirical evidence supporting this theoretical output. Thus, industrial PhD students’ contributions mainly lead to new product in the future, by for example developing a vision or a technology base.

Three of the informants have been assigned company work (10-50%) in their contracts. It is also clear that some of the other informants participate in company-specific activities as well. Usually this kind of work is somewhat related to the industrial PhD students research projects. Thus, the company collaborating with industrial PhD students also experience participation in company-specific work activities to some extent. This will be included in the direct innovation outcomes due to its tangible character, especially since its stipulated in some of the informants contracts.

Summarizing the above discussion, it clear that the empirical data support some, but not all, direct innovation outcomes found in theory. Thus, industrial PhD students create direct innovation outcomes in three ways during their education; namely through assisting in problem solving, patents and company-specific work activities. Industrial PhD students in this study do not contribute to product and process development or the generation of direct business opportunities.
Academic engagement and intangible outcomes

Except for the direct innovation outcomes discussed above, firms also experience indirect innovative outcomes when collaborating with industrial PhD students. These outcomes are of more intangible character and contribute to the firms capabilities to innovate (McKelvey & Ljungberg 2016). Three categories of intangible innovation outcomes are identified in the literature and they will be contrasted to the empirical findings one by one.

Knowledge transfer and learning

The empirical data reveals that the industrial PhD students interact with the companies in several ways. For instance, activities such as supervision at the firm, meetings, presentations, reports, academic papers, seminars and conferences all represent examples of formal ways of interaction. However, it is not only through formal interaction that industrial PhD students contribute to knowledge transfer and learning, it also happens through informal interaction. Examples of this are conversations and discussions with company employees as well as occasionally assisting in problem solving.

Due to the industrial PhD students’ natural connection to the university, it simplifies access to scientific knowledge (Thune 2009; Gustavsson et al. 2016) for firms. This is confirmed in the empirical evidence of this study, visualising that firms want to learn what’s going on in the academic world. It is also clear in the empirical findings that industrial PhD students develop technological competencies (Thune & Børing 2014; Gustavsson et al. 2016) and can act as “windows” on new technologies (Perkmann & Walsh 2008). For instance, the informants describe that they help firms develop visions and technological roadmaps as well as learn new tools and methods that can be applied in the firm. In some cases, the latest development within a specific field happens at universities. Firms access this pioneering knowledge by having close connections with the academic sector, as is the case when engaging with industrial PhD students.

In terms of developing internal R&D activities (Gustavsson et al. 2016), the empirical findings indicate two main contributions: bringing an academic perspective and also a global perspective to the company. These perspectives enable the firm to open up their internal research instead of staying in a closed circle. For instance, the academic perspective enables critical discussions on what’s the best forward is, without putting too much emphasis on commercial aspects. By bringing in the global perspective, there is a possibility to learn how companies in other industries and sectors tackle similar problems.

In theory, companies experience human capital management benefits when collaborating with universities (Broström 2010), both in terms of recruitment (Gustavsson et al. 2016; Bishop et al. 2011) and in terms of training of company employees (Bishop et al. 2011). These two outcomes are also identified within the empirical data. For instance, it is a clear expectation from Company D that informant S.5.CH will be a future research leader in the company. In terms of recruitment, several informants agree on that it is an important outcome from the collaboration.

Network Development

Companies collaborating with industrial PhD students can benefit in terms of network development. For instance, the companies can access people within the university by asking the industrial PhD student for contact details or directions on to whom to turn to at Chalmers. Another way of strengthening the connection to the university is to attend courses that Chalmers organize for the industry. Finally, the co-financing organizations can pose opportunities for network development. Even though the empirical material doesn’t give concrete examples of new or strengthened contacts with other companies, there are some indications of that this is happening. For example, S.7.CHs trip to USA enabled visits at competitors to Company A, which can be categorised as new company contact even though it might not be in a very collaborative sense. Also, the courses arranged by Chalmers for industry entail network opportunities with other companies. So even if there are no explicit examples of new and strengthened contacts with other
companies, above explained indications still make it possible to say that the empirical findings
seem aligned with theory regarding network development.

**Signalling affects**
In terms of signalling effects, the only evidence found in the empirical investigation is connected to
papers and publication. S.5.Ch express it in terms of 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”. Thus, the only
signaling effect found is the matter of prestige. Whether or not prestige entail the same thing as
legitimacy (Gustavsson et al. 2016) is hard to tell since it is not clear in what way the matter of
prestige can benefit the company. Therefore, prestige will replace legitimacy in the conceptual
model.

**Conclusions**
This paper has shown how industrial PhD students are utilized as strategic resources by firms and
how they can influence the firms’ capabilities for innovation. The paper contributes to the literature
addressing firm capabilities for innovation as well as literature concerning university-industry
interaction. Important insights have been provided regarding how collaborations with industrial
PhD students work, as well as what outcomes firms can expect by engaging in this particular type
of university-industry collaboration.

Firms collaborating with industrial PhD students experience both direct and indirect innovative
outcomes. However, the empirical investigation has proven some differences with existing theory
and a revised conceptual model is presented below (Figure 2).

**Collaborative research: firms and industrial PhD students**
The research collaboration between firms and industrial PhD students in this paper has been studied
within the field of automatic control at Chalmers University of Technology, Sweden. The firms
employ the industrial PhD students and the duration of the collaboration is at least four years. The
industrial PhD students normally focus 100% on their education (stated in their contracts).
However, in practice they also spend time on company-related work tasks and issues, which means
that the workload can exceed full time employment.

**Commercialization - Direct innovative outcomes**
Industrial PhD students contribute in three ways to tangible and direct innovation outcomes: 1) they
assist in problem solving at the firms when they identify opportunities to do so, 2) they take part in
company-specific work activities and 3) they file for patents. This contradicts existing literature to
some extent. First, there is no empirical evidence that industrial PhD students contribute to product
/process development or generate direct business opportunities, as is expected in theory. Second,
outcomes concerning company-specific work activities have been identified in the empirical
analysis and are added to the theoretical framework.

**Academic engagement – Indirect innovation outcomes**
Industrial PhD students mainly contribute to firms’ knowledge transfer and learning through
creating access to scientific knowledge, development of technical competencies and internal R&D
activities as well as human capital management. In terms of network development, they contribute
by opening doors to new networks, strengthening the relationship with universities, as well as to
other companies. Lastly, industrial PhD students also impact the firms in terms of signaling effects,
such as prestige. The empirical analysis is very well aligned with theory, except within signaling
effects where legitimacy is replaced by prestige.

**Innovations**
The main outcomes from collaborating with industrial PhD students are related to product
innovations and not process innovations, as was the initial expectation. Based on the empirical
analysis, the theoretical framework is therefore revised and will only include new and improved products.

**Figure 2: Refined conceptual model of Firm-Industrial PhD student Collaboration and innovation outcomes.**

**Future research**

Even though the paper present important insights in what collaboration between firms and industrial PhD students might entail, there are still aspects of this phenomenon that need to be investigated. For example, an interesting study would be to capture the firms’ and universities’ perspectives regarding this matter. Thus, a more holistic picture can be painted and we would gain more insight about the dynamics going on between industry and universities. In terms of innovation outcomes, it would also be interesting to investigate other fields than automatic control, such as medical and health or natural sciences. Finally, longitudinal studies of this phenomenon would help clarify when and how indirect innovation outcomes turn into innovations, which is of interest to firms, public policy and for the society as a whole.
Reference list


McKelvey, M. & Ljungberg, D., 2016. How public policy can stimulate the capabilities of firms to innovate in a traditional industry through academic engagement: the case of the Swedish food


