

Doctoral students on the university–industry interface: a review of the literature

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Abstract Doctoral students are highly important in university–firm relationships, since they are significant producers of knowledge in collaborative research projects, they are an important channel for knowledge transfer between universities and firms, and are vital in network configurations between firms and universities. An increasing number of doctoral students interact with firms, but we know relatively little about the experiences of these students or how collaboration influences their training, research and subsequent careers. With this in mind, this paper presents a literature review of (1) theoretical assumptions concerning the roles doctoral students are expected to fulfill in university–industry relationships, and (2) empirical research of doctoral students’ interaction experience and outcomes of doctoral student–industry interaction. The aim of the paper is to develop hypotheses for further research on doctoral student–industry interaction.

Keywords University–industry collaboration · Doctoral students · Roles · Experiences and outcomes

Introduction

Doctoral students are highly important in university–firm relationships, but doctoral student–firm interaction represent a topic of little systematic research. Doctoral students are important in this context since they are significant producers of knowledge in collaborative research projects, they are a primary vessel of knowledge transfer between universities and firms, and are vital in network configurations between firms and universities. Changes in how knowledge is produced, increasing interaction between universities and industry, and changes in labor markets for doctoral degree holders are forces that has lead to a debate about the future organization of doctoral education and the necessary

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competences doctoral holders need to master to work as scientists and researchers in a distributed landscape of knowledge production.

In several countries, new ways of organizing research and training of doctoral students has become a topic in higher education and research policy, focusing on increasing the quality, efficiency and relevance of doctoral education. Current research, innovation and higher education policies also emphasize strengthening collaboration between firms and universities as a key policy for fostering innovation in the economy and public funding of research is increasingly targeted to collaborative research. Doctoral level education is increasingly seen as part of collaborative arrangements between firms and universities. Different programs provide financial support for doctoral students that work on a firm R&D projects in collaboration with universities, such as the Industrial PhD-programs in Norway and Denmark, the Industrial Research Schools in Sweden, the Co-operative awards in science and engineering in UK and several other national programs. Aims of such programs are to increase research carried out in industry, to educate researchers with insight into industrial perspectives on R&D, and to make research an attractive career for people who are not ‘normally interested’ in a traditional university career. Overall, the aim is to educate a new cadre of researchers that are not only prepared for a career in the academe but who posses competences relevant for other sectors and professions as well (European commission 2003).

A recent Norwegian survey of doctoral degree holders that graduated in 2002 and 2005 found that 7% of doctoral degree holders had been funded by industry, and that 20% had collaborated with industry during their doctoral studies (Kyvik and Olsen 2007). In engineering, the respective figures where 16% of the respondents had industrial funding and 40% had collaborated with industry. Empirical research suggests that it is a link between type of funding received during the PhD and sector of employment after graduation (Mangematin 2000; Martinelli 2001; Cruz-Castro and Sanz-Menedez 2005; Kyvik and Olsen 2007). In several countries, doctoral degree holders increasingly find work outside universities and there has been a growth in private sector employment (Enders 2005; Gulbrandsen and Nerdrum 2007; Metcalfe 2007; Auriol 2007). Thus, recent data indicate that an increasing number of doctoral students interact with firms, receive funding form firms and work in the private sector after graduation, but we know relatively little about the experiences of these students or how collaboration influences their training, research experience and subsequent careers.

Research problem and methodology

Recent literature on university—firm relationships tend to emphasize the importance of graduate students in university—industry collaboration, but there is little empirical research on this topic. Empirical research tends to be either based on a few university cases or based on evaluation of particular programs. Systematic attempts at developing coherent frameworks for exploring and testing preconditions, processes and outcomes of student—industry interaction are rare. With this in mind, this paper emphasizes the two following research questions:

- What theoretical assumptions are made as to the roles doctoral students are expected to fulfill in university—industry relationships?
- What has been found in empirical research with respect to doctoral students’ interaction experience and outcomes of student—industry interaction?

To shed light on these questions review of published research on graduate student—industry relationships is presented. First, literature on university-firm relationships more generally have been reviewed, as a lot of these publications contain assumptions as to the importance of and potential roles doctoral students play in university-firm relationships. In the next section three sets of assumptions are presented, based on this review. Following this, a literature review of empirical research on graduate students—industry relationships is presented.¹ Literature search revealed two areas of empirical research that separately attempt to investigate student—industry interaction, but their focus and units of analysis are different. The first area deals predominately with the experiences of doctoral students who collaborate with firms during the PhD, while the second focuses on the labor market outcomes of collaborating doctoral students. As such, they target different units of analysis: the doctoral students whilst in training and the graduated PhD. The papers on students' experiences are of two types. There are several papers that focus on describing how doctoral students collaborate with firms and how they experience the collaboration process. Other papers focus on the effects of collaborating on student experience, career ambitions, scholarly productivity and other study outcomes. Papers focusing on labor market outcomes compare actual career destinations (employment status, sector of employment and type of job) in relation to individual and PhD experience characteristics, including the extent of collaboration with firms during the PhD.

Based on the two literature reviews, the aim of the paper is to summarize and refine the current conceptual framework of doctoral student—industry interaction by linking pre-conditions, experiences and outcomes. This is presented in the last section of the paper. The paper contributes to the research literature on university–industry relationships by systematically documenting theoretical assumptions and empirical findings from research on doctoral students on the university–industry interface, and by developing a set of hypotheses to guide further research.

Theoretical assumptions related to doctoral students in university–industry relations

The research literature that has focused particularly on doctoral students in university–industry relationships is not large, but studies of university–industry relationships frequently point to the importance of graduate students in university–industry relations (Faulkner and Senker 1995; Rappert et al. 1999; OECD 1999; Gulbrandsen and Larsen 2000; Santoro and Gopalakrishnan 2000; Lam 2001). In the literature, three roles are attributed to graduate students in university–industry relations: graduate students are central for the production of knowledge, for transfer of knowledge, and for the formation and maintenance of network ties between universities and firms.

Doctoral students and knowledge production

Empirical research has repeatedly found that doctoral students are significant producers of knowledge in universities (Enders 2002; Slaughter et al. 2002; Mangematin and Robin 2003; Kyvik and Olsen 2008). Since doctoral students are important as researchers in universities; changes at the level of doctoral student research have consequences for the

¹ ISI Web of science and ERIC were used to search for empirical research on graduate students and university – industry collaboration. 20 empirical studies were found that dealt with this particular topic.

overall production of scientific knowledge in universities. Training of doctoral students is also a process of reproduction of academic environments, and changes in doctoral education are related to changes in modes of academic knowledge production (Enders 2002). Academic research is increasingly carried out in a context of application (Gibbons et al. 1994) and collaboratively by networks consisting of university, firm and government representatives (Etzkowitz and Leydesdorff 2000). Such changes have been accompanied by institutional changes in the universities, and in the policy and funding system of academic research, emphasizing collaboration across disciplines and across sectors. Doing research in such a context requires a range of competences in addition to academic excellence. Thus, a new “mode of knowledge production” has been followed by discussions about new modes of graduate student training that better fits present competence demands (Enders 2005; Gemme and Gringas 2004). “The apprentice-researcher will not only have to master the foundations of his or her discipline and the specialized knowledge of a specific research area, but also to develop sufficient command of the problems related to the context of application (...) and be skilled in the management of non-academic demands of academic peers” (Gemme and Gringas 2004, p. 4).

This also has bearing on the question of what a PhD is a preparation for. Traditionally a PhD was seen as the preparation for an academic career in universities and similar research and teaching institutions. It is the only degree that qualifies for entry into permanent faculty positions in universities, and as such the *raison d'être* of the PhD is preparation for the academic profession. However, data from different countries indicate that this is no longer so. PhD graduates increasingly work outside the academy, since academic jobs have not grown proportionally to the production of PhD graduates (Mangematin 2000; Beltramo et al. 2001; Mangematin and Robin 2003; Cruz-Castro and Sanz-Menedez 2005; Kyvik and Olsen 2007). Overall, institutional changes in universities, changes in how knowledge production is funded and carried out, and changes in scientific labor markets has led to a debate about the relevance of today's research training and demands for “changes in the structures and practices of research training” (Enders 2005, p. 10).

Doctoral students and knowledge transfer

Another role attributed to doctoral students is that they serve as channels of knowledge transfer between universities and firms whilst they are students, and particularly after they graduate. Studies of university—firm relationships emphasize that recruitment of graduate students is an important motivation for firms to interact with universities (Faulkner and Senker 1995; Rappert et al. 1999; OECD 1999; Gulbrandsen and Larsen 2000; Santoro and Gopalakrishnan 2000; Lam 2001). Several studies emphasize that graduate students are a main channel of knowledge transfer between firms and universities (Faulkner and Senker 1995; Lam 2001; Moug  rou 2001; Mangematin 2000; Graversen and Friis-Jensen 2001; Gluck et al. 1987; David and Dasgupta 1994). In the words of Mangematin (2000, p. 674): “...they serve as a channel for the transfer of knowledge from academia to firms when they are hired by companies at the end of their PhD. Thus, for the firm, PhDs and postdoctorates represent a channel to absorb tacit knowledge and to capture know-how developed elsewhere.”

Recruiting university graduates to the industry sector can be regarded as knowledge transfer of a special kind. Vinding (2004) proposes that recruiting university graduates impacts on innovation in firms through three interrelated mechanisms. First, recruitment of graduates increases the firm's stock of scientific knowledge. Secondly, university graduates have similar cognitive resources as researchers at universities as a result of common

education and understanding of basic knowledge, which increases the ability to absorb knowledge developed outside the firm. Also, university graduates are located at the interface between universities and firms, and as ‘gatekeepers’ they are helpful in reducing mismatch in language and cognitive orientation between the two sectors, which is beneficial for collaboration and knowledge transfer (Thune 2009).

Doctoral students and network ties

Doctoral students are also seen as important for formation and maintenance of network ties between firms and universities, whilst they are students and after they graduate (Lam 2001; Slaughter et al. 2002). The role of doctoral students in network formation focus on the social ties that exist between students and their supervisors, and how such established relations are central when forming new links (Liebeskind et al. 1996; Powell et al. 1996). The newly employed university graduates join the firm with their prior social relationship, especially with their former supervisors and colleagues from their university, which naturally extends the network of the firm. In Faulkner and Senker’s (1995) words, existing contacts connect firms to a wider network of people and make new links possible. The role of the graduate student in maintaining ties between universities and industry argues that graduate student is an essential part of the “bartering arrangements” that are used to strengthen social ties (Lam 2001; Slaughter et al. 2002). Industry and university representatives engage in exchange of data, equipment and students to foster these ties (Slaughter et al. 2002). Networking is also regarded by employers as an effective way to gaining future human resources, because they believe that faculties tend to send their students to people who they have contact with (Lam 2001). Recruiting graduate students is not only a channel for networking, but it is also a way for the firm to ensuring trust in collaboration with academia. Granovetter (1985) argues that most behavior is closely embedded in networks of interpersonal relations which generates trust and discourages malfeasance in exchange relationships. Thus when graduate students are employed, their networks with their former supervisors are a vital asset, which facilitate further networking as well as facilitates positive exchange processes by generating trust and familiarity (Thune 2006).

Doctoral students are regarded as significant in university–industry collaboration. Research focus on three perspectives on the role that doctoral students play in such relationships: As producers of knowledge within an altered environment for knowledge production, as part of the wider distribution of knowledge and as nodes in network configurations between universities and firms. Doctoral students play central roles in university–industry relations both whilst they are students and after they graduate. Doctoral level research and training are an intricate part of changes at policy and institutional levels emphasizing stronger interaction between universities, the commercial sector and governments (Etzkowitz and Leydesdorff 2000). This interaction in turn changes the structure and content of graduate education, and influence the experience and outcomes of the doctoral students. Research targeting these changes is reviewed next. In the following, findings from research focusing on student experiences is described, followed by a review of the findings of the research on labor market outcomes and career trajectories of collaborating doctoral students. The focus in this review is to identify the central concepts and variables that have been investigated along with the key findings. By comparing these areas of research, some interesting observations emerge that are relevant for understanding doctoral student–firm collaboration.

Doctoral student—industry interaction: empirical findings

Characteristics of doctoral student—firm interactions

Research indicates that doctoral student—firm collaboration is a heterogeneous phenomenon and that doctoral students' collaboration experiences vary accordingly. Several characteristics of the collaborations (partner traits, type of organization, resource exchange and routines developed during the course of collaboration) have been investigated and found to have an impact on students' interaction experiences. Gemme and Gringas (2004) discern three different organizational arrangements for graduate student—industry collaboration: Scholarships (grant award schemes for applied research partly funded by the firm), contractual (individual contract with firm) and non-contractual arrangements (students involved in collaborations but do not have individual contracts with firms. The supervisor usually has a contract). Their findings indicate that the mode of collaboration—in terms of level of resource exchange and frequency of meetings—vary according to organizational arrangement, where scholarship holders and contractual collaborators experience higher intensity interactions. Wallgren and Dahlgren's (2005) qualitative study of Swedish PhD students in industrial research schools indicate that the type of firm involved in the collaborations (R&D intensive firm, engineering firm and consultancy firm) have an impact on how collaborations are carried out, and how supportive the firms are as research environments for doctoral students. Wallgren and Dahlgren's (2007) paper point to organizational practices and routines in different collaborative arrangements, which influences the learning experience of the students. Butcher and Jeffrey (2007) emphasize that how supervision and communication is handled in collaborative projects, has an impact on how successful the collaboration is perceived by the students. As supervision is vital to any graduate research process, changes in doctoral student—supervisor relationships as a result of collaboration have been investigated. Slaughter et al. (2002) and Salminen-Karlsson and Wallgren (2008) come to different conclusions as to whether the collaborations represent difficult socialization dilemmas for the students. Slaughter et al. (2002) find that PhD students collaborating with industry are being exposed to very different value systems, and that this poses problems for the students. Salminen-Karlsson and Wallgren (2008) recent study on the other hand indicates that academic and industrial supervisors are able to cooperate well and are able to cope with these potential dilemmas in such a way that it does not pose particular problems for the doctoral students.

Study experience and study outcomes of doctoral student—industry collaboration

The papers focusing on outcomes of doctoral student—industry collaboration emphasize the same tendency in respect to impact on doctoral students' satisfaction with their research training experience and study outcomes. Interacting with industry either directly or indirectly does not seem to have a significant effect on students' perception of their research/training experience (Gluck et al. 1987; Behrens and Gray 2001; Harman 2002; Gemme and Gringas 2004). In terms of study outcomes—that is outcomes realized during the PhD period—several outcome variables have been included in empirical research, such as scholarly productivity (number of papers, presentations etc), commercial productivity (number of patents, trade secrets etc) and perceived academic freedom. The results are somewhat mixed. Some studies find a positive impact on scholarly productivity (Behrens and Gray 2001); some find a negative impact (Gluck et al. 1987) or no impact at all (Gemme and Gringas 2004). Several studies find a positive impact on commercial

productivity (Gluck et al. 1987; Gemme and Gringas 2004). Research on faculty publication behavior also find that engaging in UI interactions or commercialization activities does not negatively impact on scholarly productivity. Rather, academics that are productive commercially are also productive academically (Gulbrandsen and Smeby 2005). Doctoral students, who work with faculty that engage in UI interactions or commercialization activities, might be socialized into this dual mode of productivity.

The effect of collaborating on perceived academic freedom, particularly related to the issue of intellectual property rights and freedom to communicate findings, have been a particular focus in several of these studies (Gluck et al. 1987; Behrens and Gray 2001; Powles 1993; Slaughter et al. 2002). Results are mixed here as well. Several studies report negative effects on freedom to communicate findings (Powles 1993; Gluck et al. 1987; Slaughter et al. 2002; Gemme and Gringas 2004) where as others do not find a negative impact on perceived academic freedom (Behrens and Gray 2001). As seen above, prior interaction experience and familiarity by senior faculty and firm representatives is important for finding ways of negotiating differences, including patterns of communication. Partners who have collaborated previously are probably able to devise a publication strategy that caters to both the student's need to openly publish the results of the research with the firms need withhold commercially important information.

Another set of outcome variables that have been included in the analyses are related to doctoral students' perceptions of their future careers, seen in terms of career ambitions (preferred sector of employment) and perceived career prospects (how easy the candidates think it is to get a relevant job). Several of the studies reviewed find no significant effect of collaborative experience on career ambitions. Doctoral students collaborating with industry have similar career ambitions in terms of preferred sector of employment as non-collaborating students (Gluck et al. 1987; Harman 2002; Behrens and Gray 2001). A few studies find that students involved in collaboration with industry are more optimistic about their career prospects. They believe that it will be easier to find relevant work after they graduate than students that do not collaborate (Powles 1993; Harman 2004).

Overall, it seems fair to conclude that collaborating with industry have few negative effects for the students during the course of their studies. Compared to non-collaborating students, the effects of collaborating are modest and positive in terms of experience and outcomes realized during the PhD period. This pattern has been found in different disciplines, countries, time and type of university–industry link. Consequently one can have some confidence in the pattern of modest positive effects on doctoral student experience and study outcomes. However, a weakness in these papers is that they attempt to investigate effects of collaboration by focusing on student perceptions. This is a problematic issue particularly with respect to labor market effects, since research focus on the doctoral students' career ambitions and not on actual careers.

Labor market outcomes of doctoral student—industry collaboration

Research on career trajectories and labor markets for Ph.D. graduates is another area of research that is relevant for understanding the characteristics and impact of graduate student—firm collaboration. There is a substantial research literature on the link between graduate education and PhD labor markets, (Ehrenberg 1992; Nerad and Cerny 1999; Kivinen et al. 1999), but research into career trajectories of collaborative and non-collaborative PhD graduates is of particular importance to this study. In the last years, a few studies on careers of PhD graduates and determinants of career trajectories have been made, that investigates the effect of collaborating with industry for subsequent careers of

PhD graduates (Mangematin 2000; Mangematin et al. 2000; Mangematin and Robin 2003; Enders 2002; Moug  rou 2001; Beltramo et al. 2001; Martinelli 2001; Gaughan and Robin 2004; Cruz-Castro and Sanz-Menedez 2005).

A few studies have investigated career trajectories of PhD graduates in Germany, France and USA, and these studies explore actual career destinations in relation to individual and PhD experience characteristics. The results of these investigations indicate a certain ambiguity with respect to determinants of career destinations. Enders (2002) investigated a number of different disciplines, find that experiences during the PhD does not determine career trajectory. Mangematin (2000), on the other hand, have studied doctoral students in engineering, and his findings indicate that experiences during the PhD—particularly collaborating with industry—determine career trajectories. Mangematin et al. (2000) identify the same pattern in the social sciences. Moug  rou (2001, 2002) discusses different labor market prospects (particularly private and public career trajectories) in terms of competence requirements, and claims that competencies required during the PhD accounts for differences in career trajectories. His findings, based on studies of science and engineering graduates, are similar to Mangematin’s, and indicate that graduates who collaborate with industry during the PhD, have better labor market prospects and are more frequently employed in the private sector than PhD students who do not collaborate with industry. The pattern emphasized by Mangematin and Moug  rou is also found by Martinelli (2001). His study indicates that labor market prospects for PhD graduates in France depend on discipline as well as PhD experience, particularly on links developed with industry during the PhD. Cruz-Castro and Sanz-Menedez (2005), on the other hand, find that trajectories are not inflexible immediately after graduation, but that mobility across sectors after the first post-graduate job is low. According to Moug  rou (2001, 2002) students that collaborate with industry during the PhD acquire broader competencies, and are more attractive as private sector employees. Studies that have investigated firms’ recruitment policies of R&D personnel (Lam 2001; Beltramo et al. 2001) indicate that firms will only recruit PhDs with broader competencies than traditional disciplinary expertise. This indicates that firms prefer to recruit graduates that have industry relevant competencies in addition to academic knowledge, and that such competences are acquired by interacting with firms during the Ph.D.

Doctoral students on the university–industry interface—lessons learnt and issues for further research

The research reviewed in this paper represents a broad range of approaches to the study of doctoral student—industry relations. Some target the roles students play in such relations and address this in light of overall changes in the relationships between industry, higher education and government. The importance of doctoral students is regarded as significant in such relations since doctoral students occupy three roles simultaneously. As “bench scientists” doctoral students are important workers in the academe and central for the whole knowledge production and “reproduction” system in universities. At the same time doctoral students are important as channels of knowledge transfer and are central for network configurations between universities and firms. Since doctoral students are central in the changing relations between universities and their surroundings—as students and after they graduate—we should make efforts to increase our understanding of roles, experience and outcomes of doctoral student—industry interaction.

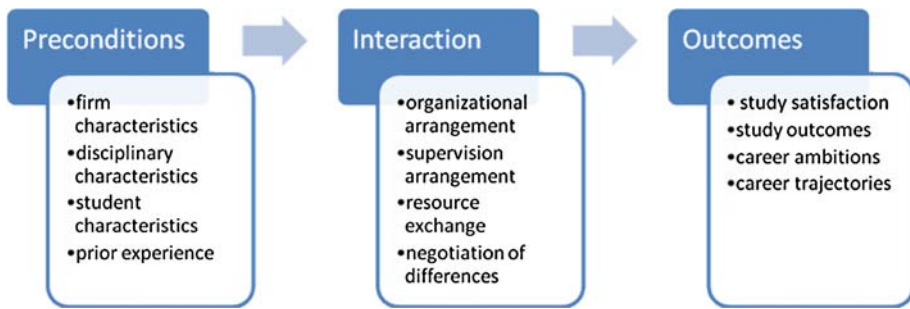


Fig. 1 Main variables investigated in research on doctoral students on the university–industry interface

At the same time, present research is quite fragmented and has included several empirical foci and variables. Figure 1 provides a conceptual map of the most important variables that have been investigated in empirical research on doctoral students on the university–industry interface until now.

The studies reviewed also represent a broad range of methodologies. Research publications focusing on describing the characteristics of collaborations and research targeting interaction experiences use both qualitative and quantitative data, whilst research focusing on study and career outcomes uses quantitative data mainly from surveys of doctoral students. Several studies combine empirical foci and they often target particular student groups that are involved in particular programs set up to stimulate doctoral student–industry interaction (Table 1). Evaluations of such programs have however often included a comparison group of non-collaborating students, as to determine the impact of the programs. This quasi-experimental design increases the confidence in the findings of these studies. As seen in Table 1, research to date has mainly focused on graduates in engineering, science and life science—as these are amongst the fields with the highest degree of interaction with industry (Rappert et al. 1999).

Comparing the main results of empirical research with respect to doctoral students experience and outcomes, there seem to be some common findings that can be used as a baseline for developing a set of hypotheses to guide further research on doctoral student–industry relations. The studies reviewed here emphasize that doctoral students involved in collaborative arrangements with industry have a markedly different researcher training experience than non-collaborative students. The physical surroundings in which they work, the supervision they receive, the research projects they work on and the norms of conduct they are exposed to are much more heterogeneous than what non-collaborating students are exposed to. But at the same time, the students’ assessments of the PhD experience are fairly similar, and the research productivity (number of publications and presentations) of the students is not very different either.

What can explain this relative similarity in outcomes? Most of the studies are carried out in academic fields where university–industry collaboration is common, mainly engineering, life sciences and natural science fields. University–industry collaboration is a ubiquitous phenomenon in such fields and constitutes a “normalized practice” (Behrens and Gray 2001; Slaughter et al. 2002). Due to previous collaboration, the people involved from the universities and firms often have experience in handling collaboration processes; they have knowledge about each others’ differences and the challenges that might occur in collaborative research. The faculty and industry supervisor seem to have developed collaborative ways of working that offers a good learning environment for doctoral students

Table 1 Summary of empirical research on graduate student—industry collaboration

Paper	Research focus	Main findings	U-I link	Population	Approach
Gluck et al. (1987)	Effect of funding on experience outcomes	No effect on experience No effect on career ambitions Effect on productivity	Industry sponsoring of students and faculty	Life sciences USA	Quantitative
Powles (1993)	Costs and benefits experience outcomes	Positive effect on experience Positive effect on career	Joint supervision	APRA (I) recipients Australia	Quantitative
Behrens and Gray (2001)	Effect of funding on experience and student outcomes	No effect on experience Positive effect on productivity No effect on career ambitions No effect on academic freedom	Industry funding	Engineering USA	Quantitative
Harman (2002)	Effect of funding on experience and outcome relations	No large effects on either experience or outcomes Socialization dilemmas Tokens of exchange	Collaborative research centers	PhD students Australia	Quantitative
Slaughter et al. (2002)	Effect of funding—student relations	Higher level of satisfaction More optimistic about career Positive attitudes towards working with industry	Industry sponsoring of faculty	Science, life science and engineering faculty, USA	Qualitative
Harman (2004)	Effect of funding on experience and career attitudes	Different firms represent different research environments that influences the experience of graduate students	Collaborative research centers	Science PhD students, Australia	Quantitative
Gemme and Gringas (2004)	Experience and student outcomes for collaborating and non-collaborating students	Collaborative experiences are highly diverse, but significantly different than for non-collaborative students No significant effect on student productivity or career ambitions	Scholarship, contractual and non-contractual collaborations	Science, mathematics and engineering graduate students in Canada	Quantitative
Wallgren and Dahlgren (2005)	Experience of industry PhDs	Experiences vary a lot due to five factors: entrance conditions, thesis project, the organization of the schools, supervision, and the students aspirations	Industrial research schools	Students in three industrial research schools in Sweden	Qualitative
Wallgren and Dahlgren (2007)	Factors influencing the learning process of industrial PhDs	Three classes of factors that influence perceptions of collaborative success: supervision, communication and project management	Industrial research schools	Students in three industrial research schools in Sweden	Qualitative
Butcher and Jeffrey (2007)	Graduate students' perceptions of collaborative projects		Joint supervision	EngD and CASE participants, UK	Quantitative

Table 1 continued

Paper	Research focus	Main findings	U-I link	Population	Approach
Salminen-Karlsson and Wallgren (2008)	Cooperation between academic and industrial supervisors	Cooperation depends on backgrounds of supervisors, but academic supervisors play a main role. Joint supervising require joint engagement and both focus on the education of the student	Industrial research schools	Supervisors of students in three industrial research schools in Sweden	Qualitative
Mangematin 2000	Career trajectories of PhD students	Career trajectories are not flexible, collaborating during the Ph.D increase likelihood of private sector employment		Engineering science PhDs, France	Quantitative
Mangematin et al 2000	Career trajectories of PhD students	Career trajectories are not flexible		Social science PhDs, France	Quantitative
Moguerou 2001	Labor market prospects of PhDs	PhD linkage experience determine labor market outcomes	Industry funding of PhDs	Engineering graduates, France	Quantitative
Martinelli 2001	Labor market prospects of PhDs	PhD linkage experience determine labor market outcomes	CIFRE industry funding of PhDs	National survey of all PhD graduates in France	Quantitative
Lam 2001	Recruitment of PhDs in the private sector	Firms will only recruit PhDs with industrial experience and broader competences			
Beltramo et al. 2001	Recruitment of PhDs in the private sector	The organization of industrial R&D determine recruitment of PhDs		Firms in UK, Spain & France	Quantitative
Mangematin and Robin 2003	Early careers of PhD students	Diffusion of knowledge depend on mobility Need to train life science PhDs for jobs in the private sector		Life science PhDs, France	Literature review
Gaughan and Robin 2004	National science training policy in France and USA	National policies have an impact on the relationship between mobility and employment Industry funding do not have a negative impact on the ability to get permanent employment in the academe		PhDs students in life science in France Life science scientists in the USA	Quantitative
Cruz-Castro and Sanz-Menedez 2005	Employment of PhDs in firms	Careers are not inflexible after graduation		Spain	Quantitative

and are able to identify suitable research projects for the students (Salminen-Karlsson and Wallgren 2008). Solutions to potential problems, such as intellectual property issues, have been found, and problems are dealt with in such a manner that it does not create problems for the students or unduly delays publication (Slaughter et al. 2002).

In terms of collaborative arrangements, most of this research has focused on highly institutionalized forms of university–industry collaboration such as collaborative research centers and industrial research schools. Research on university–industry relations indicates that there is a high degree of interaction of more informal kinds (Schartinger et al. 2002). University–firm interactions in highly institutionalized collaborative contexts can be described as ‘mature’ and are probably built upon many years of collaboration and networking (Thune 2006). Prior experience may be a very important factor that conditions the experience of doctoral students, and one might expect that collaborations are less problematic than in less institutionalized contexts. The experience and outcomes of doctoral students involved in more informal and project based interactions are not well understood in present research. Gemme and Gringas (2004) and Wallgren and Dahlgren (2005) indicate that different types of collaborative arrangements have an impact on students’ experiences, such as resource involvement, type of firms and/or degree of formalization of relationships. A larger variety of collaborative arrangements should therefore be included in further research on this topic.

Also further research should attempt to gain insight into experiences and outcomes of a broader set of actors. Present research has dominantly focused on students’ experiences and outcomes, and has not focused on experience and outcomes of industry, firms and other stakeholders. Firms’ motivation behind engaging in such collaborations is assumed to be connected to access to scientific knowledge, increased absorptive capacity and access to networks. There seems to be a relationship between the type of innovation a firm or industry centers on, recruitment strategies and the extent of collaboration with universities (Lam 2001). The size of the firm and how R&D activities are organized in firms are also probably relevant. Firms’ innovation strategies are thus likely connected to firms’ expectations and experiences when engaging in collaborations with doctoral students.

Based on these findings three propositions are made as to the relationship between preconditions and interaction experience, to guide further research on doctoral student–industry collaboration:

- Proposition 1: The doctoral students’ experience and study outcomes is conditioned by the involved parties’ (department, faculty supervisor and firm) prior collaborative experience.
- Proposition 2: The doctoral students’ experience is conditioned by the degree of institutionalization of the collaborative arrangement.
- Proposition 3: Firms who carry out R&D experience collaborating with PhD students more positively and report more positive gains than firms who have little experience in R&D activities.

Another pattern found in empirical research on outcomes of doctoral student–firm interaction is that with respect to career ambitions as reported by PhD students during the course of their studies, collaborative and non-collaborative students are not markedly different. However, as noted, how students perceive their future careers is not necessarily a good indication of actual behavior. Studies that have tried to test actual career outcomes with respect to differences in PhD experience reach different conclusions with respect to the link between experience and outcome. These studies indicate that interfacing with industry during the PhD is associated with less unemployment and larger likelihood for

private sector employment. This pattern is also found in investigation of firms' recruitment policies. Comparing the findings of these studies with the ones above, one can see that whilst students during the PhD do not have significantly different career ambitions, research on doctoral holders careers indicates that they have different career trajectories. On the other hand, it is also possible that students who choose to collaborate during the doctoral degree have particular motivations and characteristics that make them both inclined to collaboration and later private sector employment, and that it has relatively little to do with the PhD experience itself (Gemme and Gringas 2004; Wallgren and Dahlgren 2007). Such individual characteristics could be age, gender, family background, prior employment and particularly private sector employment prior to entering the PhD program. These findings can be summarized in terms of two propositions with opposite predictions to guide further research:

- Proposition 4: Collaborating with firms during the doctoral degree influences career trajectories (sector of employment) and increases the likelihood of private sector employment, since the students gain insight in industry relevant problems and competences.
- Proposition 5: Differences in career trajectories (sector of employment) is explainable by individual characteristics (age, gender, family background, prior employment) and not by collaborative experience during the doctoral degree.

Further research should attempt to gain information about different contexts of collaborations that doctoral students are involved in by sampling more varied collaborative arrangements. More longitudinal research is also needed, as present research largely focus on the initial transition from university to work, and not on career trajectories as they develop over time. One approach that will give a broader spectrum of experiences as well as more information of long term effects of doctoral student—industry interaction is research that follows collaborative projects over time. Collecting longitudinal data by following concrete R&D collaboration projects over time will provide further knowledge about initiation of collaborations, and also about coordination of R&D collaboration, and about how knowledge is created and exchanged in UI collaborations, and how doctoral students are involved in these exchanges.

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