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Negin Salimi, Rudi Bekkers and Koen Frenken

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Eindhoven Centre for Innovation Studies (ECIS),
School of Innovation Sciences,
Eindhoven University of Technology, The Netherlands

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Negin Salimi [1], Rudi Bekkers [1,2], Koen Frenken [1]

[1] School of Innovation Sciences

Eindhoven University of Technology

The Netherlands

[2] Dialogic innovatie & interactie

the Netherlands

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Abstract – Faced with ever-increasing pressure to innovate and perform, firms consider universities as a significant, external source of knowledge. There is a variety of ways through which such knowledge flow can take place, including academic publications, contract research, staff mobility and university patents and licenses, but also more collaborative modes such as joint research projects. This paper focuses on a specific – and promising – collaborative model, in which firms and universities are together involved in a Ph.D. project, carried out by a doctoral candidate. We model the relationship on the one hand on various aspects of governance, and the success of the collaboration on the other. Here, success is operationalized in a number of different ways, including the successful transfer, the application and the commercialization of knowledge. Our model was tested using a survey conducted at the Eindhoven University of Technology. We conclude that governance decisions have a significant impact on the ultimate success. Among other things, the choice of university supervisor plays a pivotal role. Moreover, success is more likely if there is joint decision-making by both university and partner on the content of the project, and communication between the Ph.D. candidate and their supervisor in the firm has a high frequency and quality. We believe our findings can help universities and firms to collaborate successfully.

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1. Introduction

In the past decade, there has been increasing interest in inter-organizational relationships, especially as an external source of innovation (Perkmann and Walsh, 2007). Such outsourcing of knowledge creation has both an effect on an organization's financial performance through decreasing costs (Bettis et al., 1992), as well as non-financial effects, such as an increased focus on organizations' core competencies (Dess et al., 1995).

The knowledge of inter-organizational relationships generally stands on the shoulders of two theories: the theory of interdependency and the theory of interaction (Geisler, 1995). The interdependency theory considers the impact of the external environment on inter-organizational relationships, and argues that a firm's survival is a function of its ability to adapt and fit in with the external environment. Accordingly, firms try to get involved in collaboration to manage resource interdependency and environmental uncertainty (Pfeffer and Nowak, 1976). The interaction theory, in contrast, considers the process (internal development) of the relationships, and argues that inter-organizational relationships are based on the prior relationships, mutual trust, commitment, and prior beliefs of partners (Levinthal and Fichman, 1988). For the purpose of this study we endorse both views, and we adopt the definition of inter-organizational relationships as proposed by Oliver and Ebers (1998) and Knoben (2011): the relatively long-term connections between a firm and other actors in order to exchange or acquire knowledge for its own innovative activities.

There are different categories of inter-organizational relationships, such as alliances, joint ventures, outsourcing initiatives (Vlaar et al., 2006), buyer-supplier relationships, franchising and licensing relationships (Dekker, 2004), innovation networks, and R&D consortia (Trott, 2005). While such relationships can involve a wide array of different partners, one particularly interesting type (from the perspective of source of external knowledge) is the relationship between firms and universities. There is a huge body of literature on this type of relationship and its impact on economic growth (e.g. Van Dierdonck et al., 1990; Bonaccorsi and Piccaluga, 1994; Etzkowitz, 1998; Eun et al., 2006; Mueller, 2006; Perkmann and Walsh, 2007; Ahrweiler et al., 2011; Bodas Freitas et al., 2012). Universities are considered one of the most powerful partners for a firm to acquire knowledge in order to be innovative. Industry and policy makers try to promote such ties to make university research more relevant to industry (Cohen, 2001), and allow firms to have better access to ideas, facilities, expertise, and knowledge (Butcher and Jeffrey, 2007). Not only do firms tend to establish relationships with universities, but also universities are enthusiastic to develop closer relationships with firms. The Public Policy Center for Stanford Research International identified that more than 90 percent of all universities in their sample are eager to increase interaction with industry (see Thursby and Kemp, 2002). They want to engage in relationships with firms in order to align their research to industry needs, and contribute to the regional and national economy – sometimes prompted by policy pressure (Perkmann and Walsh, 2007). There is a considerable amount of evidence illustrating increasing interaction between universities and industry, including the growing propensity of universities to patent (Nelson, 2001), the universities' rising licensing revenues (Thursby et al., 2001), the increasing number of university spin-offs (Shane, 2005), and the increasing number of science parks (Siegel et al., 2003). By considering this reciprocal proclivity and motivation for entering into university-industry relationships, different knowledge transfer channels come into the picture including joint research or research and development (R&D) projects, patents and licensing, and published papers (Bekkers and Bodas Freitas, 2008). Research collaboration between universities and firms has been shown to be possibly one of the most successful knowledge transfer channels (Bekkers and Bodas Freitas, 2011).

While joint collaborative research projects can be in various forms, one interesting way to collaborate is via a Ph.D. project, carried out by a doctoral candidate. The importance and value of Ph.D. graduates for industry have been highlighted in several studies (e.g. Stephan et al., 2004; Cruz-Castro and Sanz-Menendez, 2005). Such studies often investigate the trajectories and mobility of Ph.D. graduates to industry and the effect of this mobility on innovation. Furthermore, Thune (2010), by reviewing the literature, has attempted to demonstrate the importance of the Ph.D. candidate's role in university-industry collaboration.

While this mode of collaboration is far from uncommon, we believe it has been unfairly neglected in the literature. Doctoral candidates are not only key producers of new knowledge but potentially also important channels for transferring such knowledge to firms (Thune, 2009). There may be specific reasons (or motivation) for universities as well as industries to choose a Ph.D. project as a means of collaboration. For universities, it offers opportunities to align their research with what is going on in the industry, and thus also absorb industry knowledge. Companies' motivation might be to recruit a very valuable Ph.D. candidate after the project is finished, or they might use the project to increase the knowledge level of an individual already working with the firm before the collaboration began. Indeed, as Thune (2009) pointed out, recruitment can positively influence innovation processes at firms through increasing the firm's stock of scientific knowledge, increasing the absorptive knowledge ability, and increasing cognitive orientation between university and industry, which is beneficial for collaboration and transferring knowledge.

Although it seems obvious that a collaborative Ph.D. project can be an effective knowledge transfer channel, it is not clear how the collaboration between university and industry via the Ph.D. project is best governed in order to achieve successful collaboration. That is, no studies exist that consider the different characteristics of governance and relate those to the success of this type of collaboration. Therefore the aim of our study is to propose a structure which measures the relationship between governance characteristics and successful collaboration.

The remainderof this paper is organized as follows. In Section 2, we review the literature on collaboration governance and its characteristics, as well as the literature on measuring a collaboration's success. In Section 3 we propose a methodology to investigate the relationship between governance characteristics and successful collaboration. Then, in Section 4, we present our empirical analysis and discuss the findings. The paper ends with conclusions, managerial implications and future research directions (Section 5).

2. Literature on research collaboration

If we consider (research) collaboration in a broader sense, and include collaborations outside the field of university-industry relationships, there is already a large body of literature on research. This section reviews that literature, starting with *definitions and features* of research collaborations (Section 2.1), continuing with the *governance* of research collaboration (Section 2.2) and finally the *success* of research collaborations (Section 3.3). Each time we will start with more general works and end with literature that specifically considers university-industry collaboration (or even collaborative Ph.D. projects, if available).

2.1. Definitions and features of (research) collaboration

Collaboration has been addressed in various disciplines of science, including economics, business, sociology, political science, organizational behavior, organization theory, and strategic management (Smith et al., 1995). Himmelman (1995) offers a typology for partnerships consisting of networking, coordinating, cooperating and collaboration.

Different types of partnerships have different levels of interaction, integration, commitment and complexity (Thomson and Perry, 2006), and it is becoming apparent that collaborations have a higher level of collective action than other types of relationships (e.g. networking, coordination, or cooperation). However, Thomson and Perry (2006), as well as Rezaei and Orrt (2012), argue, that despite those differences, most researchers have called all of these relationships 'collaboration' or 'partnering' in general.

In the literature, several authors have offered definitions of the phenomenon collaboration. For example Thomson (2001) and Thomson and Perry (2006) define collaboration as "a process in which autonomous actors interact through formal and informal negotiation, jointly creating rules and structures governing their relationships and ways to act or decide on the issues that brought them together; it is a process involving shared norms and mutually beneficial interactions". For other definitions we refer to (Gray, 1989; Mattessich and Monsey, 1992; Bardach, 1998; Gronski and Pigg, 2000; Thomson, 2001; Thomson and Perry, 2006).

Collaboration is mostly a process of activities that may involve two actors in order to achieve its goals. What is specific about the type of collaborations we are interested in, namely Ph.D. collaborations, is that there are actually three central actors: the firm, the university, and the doctoral candidate (i.e. the individual who is enrolled full or part-time in a program leading to a doctoral degree). This candidate is quite different from 'regular' collaboration partners, yet plays a pivotal role in this process. Thune (2009, 2010) states that a doctoral candidate may have each of the following three roles: creation of knowledge; transfer of knowledge; and formation and maintenance of network ties between university and firms. This latter role relates to the social ties that exist between Ph.D. candidates and their supervisor and can also lead to new links after graduation (Thune, 2009, 2010). In a collaborative Ph.D. project, the research project is a planned and structured activity that is carried out by the Ph.D. candidate. A research project can be defined as *"a systematic study directed toward fuller scientific knowledge or understanding of the subject studied; It also involves the training of individuals in research techniques where such activities utilize the same facilities as other research activities"* (definition adopted from the University of North Texas, 2010).

Considering the above, we here define a collaborative Ph.D. project as *"a project with a typical duration of 3-4 years and which involves a university, a firm, and a Ph.D. candidate, all working together to meet (common or individual) expectations."*

2.2. Governance of collaborative projects

Partners who become involved in collaboration must discover how to manage their relationships in order to make joint decisions, as well as find a way to solve problems and conflicts (Artz and Brush, 2000). Thomson and Perry (2006) believe that governance is at the 'heart of collaboration" and focus on the negotiation between, and commitment of, partners. They emphasize the creation of structure in order to come to an agreement on activities during the collaboration and collaboration goals. Regarding the assessment of the success of university-industry collaboration, governance of collaboration may influence a firm's innovative performance (Jung et al., 2010). This organization structure is also related to the arrangement for achieving a balance between the goals and the benefits to universities and industry, as well as their participation in managing the relationships (Foray and Steinmueller, 2003). Significant governance characteristics of a collaboration are, for instance: who had the initial idea for the collaboration (Bekkers and Bodas Freitas, 2011), who is most prominent in managing the relationship (Butcher and Jeffrey, 2007), and how are risks or rewards shared (Ostrom, 1990; Lambert, 2008).

Although governance is sometimes referred to as joint decision making (McCaffrey et al., 1995), joint-problem solving (Artz and Brush, 2000), reciprocal perception and understanding of drivers, needs and interest (van Gils, 2012), and a shared power arrangement (Crosby and Bryson, 2005), it is at the same time based on negotiation and on respecting the other's opinion (Thomson and Perry, 2006). That is, parties must agree to collaborate under conditions that are not necessarily in their best interest (Thomson and Perry, 2006).

Within governance, trust (Ostrom, 1990; Lambert, 2008) and commitment (Mattessich and Monsey, 1992; Barnes et al., 2002; Lambert, 2008) can be seen as necessary conditions. These are can be built by maintaining close relationships and good communication between partners (Mattessich and Monsey, 1992; Lambert, 2008).

In literature, collaboration is mostly considered as a black box that can have an impact on (or is impacted by) other aspects. There has not been enough focus on the elements of collaboration, or what it actually is (Thomson and Perry, 2006). Rezaei and Ortt (2012) describe collaboration elements as "information sharing, trust, coordinated planning arrangement, shared risks, mutual benefits, recognition of independence, shared goals, integrated process, shared culture, compatibility and understanding and open book accounting". For other collaborative elements we refer to (Roberts and Bradley, 1991; Mattessich and Monsey, 1992; Ring and Ven, 1994; Borden and Perkins, 1999; Thomson and Perry, 2006; Thune, 2009).

In this paper we particularly focus on the elements for managing collaborative Ph.D. projects. More precisely, we would like to open the governance black box, to understand what elements form the core of collaboration governance and how actors make joint decisions to solve problems and govern their relationships. In doing so, we not only adopt findings in the related literature of university-industry collaboration (see previous paragraphs) but also combine these with three main categories to study the effectiveness of collaborative research as proposed by Butcher and Jeffrey (2007). These three categories are: project management, characteristics of supervisors and communication. In Section 3.2 we use these categories as the basis for our analysis. In terms of project management, we mostly focus on the partner managing the relationship and providing the most leadership in the project. The various characteristics of project supervisors such as their level of knowledge and enthusiasm to be involved in the project are considered in the second category. Finally, regarding the characteristics of communication, we consider the quality and frequency of communication between partners of a collaborative Ph.D. project.

2.3. Success of collaborative Ph.D. projects

An important aspect of our model is determining the collaboration's success. It is important to stress that in this study, success refers to the extent to which the goals of the collaboration are met. Here, the view of collaboration is based on civic republicanism so that despite existing differences, actors collaborate to achieve mutual understanding, trust, and implementation of shared preferences (March and Olsen, 1989). We do, however, acknowledge that each partner may have their own interpretation of the collaborative achievement. This interpretation is called satisfaction and can be distinguished from the success seen in Behrens and Gray's (2001) work,[1] in which they state that a collaborative project is successful if all the partners are satisfied with the collaboration. The basis of their perspective is classic liberalism, whereby each actor engages in the collaboration to achieve their own goals and interests without considering other actors' preferences (Thomson and Perry, 2006).

[1] This study considers the success of collaborations involving projects carried out by graduated students including (but not only) Ph.D. candidates.

Given the central role in this study of collaboration's success, we need to find a good way of measuring this success. In the literature, the success of university-industry collaboration is determined by several indicators: technology or knowledge development (Barnes et al., 2002), knowledge transferring ability between partners, development and commercialization of a new product (Bekkers and Bodas Freitas, 2011). Van Gills (2010) categorized such success indicators into two groups:

- Technical criteria, generally relating to the quality of knowledge that has been transferred and the level of satisfaction about meeting the partners' objectives.
- Non-technical criteria concerning the process of collaboration, generally relating to the application of external knowledge and continuation of internal activity.

Determining factors of collaboration success can be measured by collecting data from one of the partners in the collaboration (industry, university, Ph.D. candidate) and in an ideal situation, from all partners. Partners may differ in their evaluation of the success of the collaboration, depending on their perspective (Bekkers and Bodas Freitas, 2011). In this study, although the data has been collected through Ph.D. candidates, we consider all the partners' perspectives. Barnes et al. (2002) show that through a Ph.D. candidate's opinion and experiences as a main actor in the collaborative project, the perspective of both industry and academia is accessible. In addition to the importance of a Ph.D. candidate's role as a main actor in the collaboration, the better accessibility of Ph.D. candidates is also a relevant aspect from a practical perspective. Finding the supervisor(s) at university and the contact person in industry is very difficult compared to tracking a Ph.D. candidate, even if that person graduated as long as 10 years ago. It is clear that in most cases, the Ph.D. project is the only special project such a candidate has been working on during a three to four year period, whereas the same project may be only one of many with which a university or firm supervisor is involved. Finally, because in many cases it is the Ph.D. candidate who actually conducted the research, rather than other partners (Behrens and Gray, 2001), the quality of data that can be gathered from a Ph.D. candidate is likely to be higher than the data gathered from supervisors. Also other studies, like that of Butcher and Jeffrey (2007), evaluated collaborative projects in terms of being successful or unsuccessful from the Ph.D. candidate perspective due to considerations about response rate and quality of responses. Therefore in terms of subjective evaluation for this study, the measurement of collaboration success relies on the perception and experience of the Ph.D. candidate in the collaboration. Wherever possible when evaluating collaboration, we use factual, objective measurements such as academic publication track records, and patents resulting from the project (Barnes et al., 2002). We also measure the level of knowledge transfer, absorbed, applied, or commercialized (Bekkers and Bodas Freitas, 2011), whether the relationship between university and collaborating partner was continued (van Gils, 2012), and whether the university or collaborating partner offered the Ph.D. candidate a job after graduation.

Jeffrey and Butcher (2007) investigated the correlation between collaboration success factors (supervisor, project management and communication) and the perceived collaborative research success (from the Ph.D. candidate's perspective). Unfortunately, however, these researchers did not consider different dimensions when measuring collaboration success, i.e. they used a single measure only. In this paper, we use the same three collaboration dimensions as governance characteristics (somewhat adapted), but applying different measurements of success. Our approach is illustrated in Figure 1.

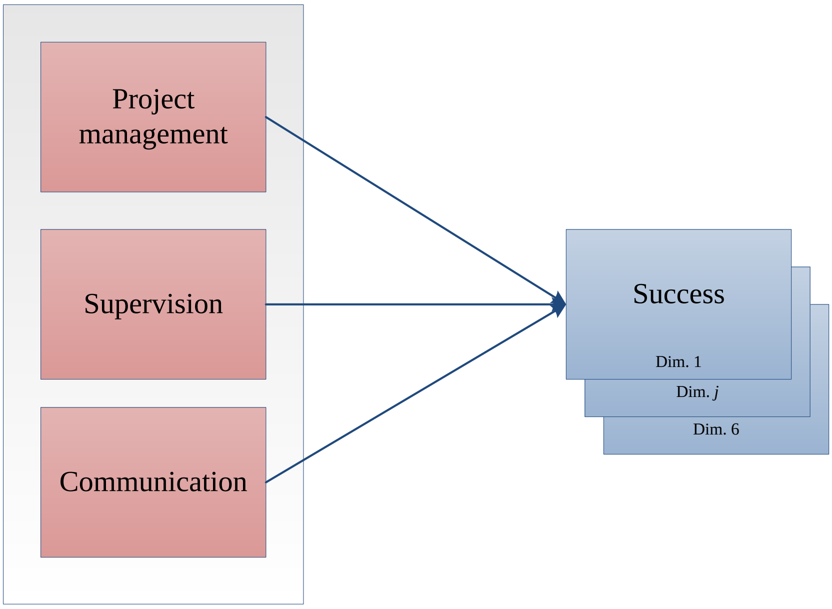

Figure 1 A model of collaborative Ph.D. project governance

3. Data and Methodology

3.1. Data collection

In our study, the collaborative Ph.D. project as such is our main unit of analysis. Our population is defined as those projects between the Eindhoven University of Technology (TU/e) and a firm or a research institute that resulted in a published Ph.D. thesis between the years 2000 and 2011. We include projects from all the different departments at this university: Applied Physics, Chemical Engineering and Chemistry, Electrical Engineering, Mathematics & Computer Science, Mechanical Engineering and four departments involved in management and design.[2] We adopt a broad concept of collaborations, also including those with (public) research institutes, but we do not include collaboration with institutions such as governmental bodies, or other universities. There is a special reason why we decided to collect data for our study at a technical university: as argued by Stephan et al. (2004), doctoral education in science and engineering is critical to the role that universities play in fostering economic development. Therefore we are likely to find this type of collaboration (industry-university) much more in technical rather than other universities.

Taking all 1783 doctoral theses published between 2000 and 2011 by the TU/e as a starting point, we determined that 496 of these were the result of a collaboration with a firm or research institute (in this paper we call these 'collaborating partner' or, simply, 'partner'). For 408 of these, we were able to retrieve up-to-date contact details of the former Ph.D.

[2] These are the departments of Built Environment, Biomedical Engineering, Industrial Design, and Industrial Engineering and Innovation Sciences.

candidate, using a variety of approaches. Instead of taking a sample, we approached the full population. Data acquisition took place between January and April 2012. After sending two reminders, we received a total of 191 complete and valid responses, of which 103 represented collaboration with firms and 88 represented collaboration with research institutes,[3] bringing our overall response rate to 47%.

As explained above, we sent the survey to (former) Ph.D. students, not to the university supervisor or supervisor at the collaboration partner. Measuring from a single source may cause concern in terms of common method variance (Podsakoff et al., 2003). One solution would be to obtain measurements from different sources (Podsakoff et al., 2003). However, if we would require all the partners' opinions on a specific project, although in this case there is no common method bias, the response rate would decrease dramatically, thus hampering the data analysis.[4] As it is not feasible to follow the strategy of different sources, in order to prevent common method bias, we devised other solutions. More specifically, following solutions suggested by Podsakoff et al. (2003), we designed the survey questionnaire with differently formatted responses (e.g. Likert scale, ordinal, categorical, and dichotomous). Having tried out the draft questionnaire in a pilot test, and based on the respondents' feedback, we improved the text. In particular, we addressed any perceived ambiguity, removed some concepts that were found to be vague, defined unfamiliar terms, and added examples. Apart from all these solutions, and to ensure there would be no common method bias, after conducting our survey, we used Harman's one-factor test. This technique involves all the (independent and dependent) variables being entered into an exploratory factor analysis (Podsakoff et al., 2003). Based on the result of the factor analysis, 13 factors were extracted, accounting for 71.8 percent of the total variance (the first factor accounts for 11.5 percent of the total variance). This proved that our study does not suffer from common method bias.

To check for non-response bias, we used the projected respondent method offered by Armstrong and Overton (1977). In this method it is assumed that non-respondents are more similar to late respondents. We compared non-respondents with two waves of respondents and found no non-response bias.

3.2. Variables

Table 1 provides an overview of the dependent variables for this study. We measure success in different ways (see also Section 2-3). The first – and perhaps the most important – measurement is that of the level to which knowledge was actually transferred to and used by the collaborating partner. It uses a progressive, ordinal scale as specified in Table 1. For academic publication(s) and patent(s) scores, we originally had continuous measurements, but

[3] Although research institutes are of course not the same as regular firms, most of these institutes in our sample have only limited public funding and basically fund their activities by offering commercial activities (e.g. studies) to the market. In that sense, their behavior is not so different from firms in the context of our study (Bienkowska et al., 2010). We did use a control variable, though, to see whether our findings for research institutes are different from those for firms (see Section 3.2).

[4] More specifically, if the probability of getting a response from each actor (Ph.D. candidate, university and collaborating partner supervisors) is *Ri*, then the probability of getting a sample of completed questionnaires from all three actors would *be* $R_{Ph.D.} * R_{collaborating\ partner} * R_{university}$. For example, assuming that the probability of getting a response (response rate) from each actor be 40 percent and be fully independent of each other, the probability of having a sample of completed questionnaires from all three actors would be 0.4 * 0.4 * 0.4 = 0.064, which we call the combined response rate.

after investigating their distribution, decided to translate them into dichotomous variables. Our last three success variables are dichotomous variables on whether the university offered the candidate a job after the end of the project, whether the collaborating partner did, and whether the relationship between the university and collaborating partner was continued.

Table 1 Descriptive statistics of dependent variables

Dependent variable	*Values*	*N*
Level of knowledge transfer to collaborating partner	Not transferred at all: n=20 (11%) Transferred[(a)] : n=78 (41%) Absorption[(b)]: n=46 (24%) Application[(c)]: n=25 (13%) Commercialization as a smaller element of product or process: n=12 (6%) Commercialization as the main basis of product or process: n=8 (4%)	189
Resulted in academic publication[(d)]	Yes: n=168 (89%)	189
Knowledge was patented[(e)]	Yes: n=48 (25%)	189
Subsequent job offer from university	Yes: n=41 (22%)	189
Subsequent job offer from collaborating partner	Yes: n=60 (32%)	189
Collaboration was followed up	Yes: n=129 (81%)	160

(a): knowledge is now effectively available to the staff of the collaborating partner working in this field. It is for instance available in the library, or there has been a presentation; (b) the collaborating partner's researchers have studied and now master this knowledge; (c) the knowledge is being used by the collaborating partner in a business context; (d) the Ph.D. project resulted directly in publications in academic journals (either during or after finalization); (e) the Ph.D. project resulted in one or more patents or patent applications, with the Ph.D. student listed as inventor.

Table 2 reports the correlation between dependent variables. For correlation between the first dependent variable (level of knowledge transfer) and other dependent variables, we used the Mann-Whitney test and the Phi coefficient for the remaining variables. As can be seen from the table, almost all the correlations are very low, which in fact suggest a high discriminate validity (Hair et al., 2006).

Table 2 Correlation between dependent variables

Variables	*Level of Knowledge transfer*[1]	*Resulted in academic publication*[2]	*Knowledge was patented*[2]	*Subsequent job offer from university*[2]	*Subsequent job offer from collaborating partner*[2]
Level of knowledge transfer					
Resulted in academic publication	1795.5				
Knowledge was patented	2842*	-.080			
Subsequent job offer from university	2825	.039	-.101		
Subsequent job offer from collaborating partner	2575.5***	.010	.098	-.056	
Collaboration was followed up	1966.500	-.024	-.002	.081	-.018

*p<0.10; **p <0.05; ***p<0.01

1. Mann-Whitney test was used to measure the association between this ordinal variable and other dependent variables.

2. Phi coefficient was used to measure the association between dichotomous variables.

Table 3 provides an overview of the independent variables. As discussed in Section 2.2, we asked respondents to evaluate their Ph.D. projects in terms of "project management", "characteristics of supervisor" and "communication". All continued variables were measured on a five point Likert-type scale.

Table 3 Descriptive statistics of independent variables

Independent variable	*Value / mean*	*S.D*	*Min*	*Max*	*N*
Project management aspects:					
Ph.D. project funder	Collaborating partner: n=109 (57%) Others: n=82 (43%)				191
Prominent partner in managing the coordination	The university: n=88 (46%) The collaborating partner: n=38 (20%) Both partners: n=65 (34.0%)				191
Type of decision making between both partners	By the university: n=93 (49%) By the collaborating partner: n=37 (19%) Both partners: n=61 (32%)				191
Publication was prohibited due to the collaborating partner's restrictions	Yes: n=19 (10%)				191
Characteristics of supervisor:					
Academic position of the university daily supervisor	Assistant professor: n=92 (48%) Associate professor: n= 51 (27%) Full professor: n=48 (25%)				191
Academic degree of the collaborating partner supervisor	Bachelor or Master: n=23 (12%) Ph.D.: n=88 (46%) Assistant, Associate or Full professor: n=80 (42%)				191
Level of university supervisor's knowledge in Ph.D. topic	4.0785	.894	1	5	191
Level of collaborating partner supervisor's knowledge in Ph.D. topic	3.9144	1.156	1	5	187
Level of university supervisor's enthusiasm in Ph.D. topic	4.2094	.869	1	5	191
Level of collaborating partner supervisor's enthusiasm in Ph.D. topic	3.8871	1.130	1	5	186
Similar opinion between university and collaborating partner supervisors on Ph.D. topic	3.5225	1.218	1	5	178
Replacing any of the supervisors during the Ph.D. project	Yes: n=32 (17%)				191
Openness of university supervisor to any idea	4.0160	.904	1	5	188
Openness of collaborating partner supervisor to any idea	3.7104	1.031	1	5	183
Characteristics of communication:					
Meeting frequency of Ph.D. candidate and university supervisor	4.8848	1.475	1	7	191
Meeting frequency of Ph.D. candidate and collaborating partner supervisor	3.8953	1.903	1	7	191
Meeting frequency of both supervisors	3.2670	1.383	1	5	191
Quality of communication between Ph.D. candidate and university supervisor	4.0209	.978	1	7	191
Quality of communication between Ph.D. candidate and collaborating partner supervisor	3.6754	1.218	1	7	191

In this study we further consider the effect of five control variables, which may offer an alternative explanation of the phenomena we measure. These control variables are: (1) whether the collaborating partner's office is in the same city as the university, (2) whether the collaboration is with a research institute (opposed to a firm), (3) whether the Ph.D. candidate is a former employee of the collaborating partner, (4) whether TU/e and the collaborating partner have a prior relationship and, finally, (5) differences between the various disciplinary departments at the university as introduced earlier in this paper. Here, we group the four departments in the area of design and management.

4. Results and discussion

Our results are shown in Tables 4, 5 and 6. In each case we have two columns for every dependent variable, one without the control variables (see previous section), and one with these variables.[5]

4.1. How does project management affect collaboration success?

We will discuss the findings of our analysis, starting with how project management is related to our various measurements of collaborative success (see Table 4). Altogether, our Nagelkerke R^2 values indicate that project management items account for between 2 and 10 percent of the variance within our different dependent variables.

The first dependent variable is the *level of knowledge transfer* (Table 4, columns 1 and 2). As discussed earlier, this is an ordinal variable, for which we use the ordinal logit model. We find that knowledge transfer is: (a) positively related to the partner being the main decision maker – opposed to university; (b) positively related to the situation where both partners (university and collaborating partner) are equally involved in decision making. We think this is because in these situations, the collaborating partner is more dominant regarding decisions or has at least an equal role in decision making. This can therefore facilitate transferring more knowledge, which is one of the main goals of the collaborating partner; and (c) positively related to the situation where the collaboration partner imposes a restriction on publications. Arguably, this is because such cases represent strategic knowledge that the partner is keen to obtain (and keen to patent; see below). In terms of our control variables, we observe that the significant effect of the collaborating partner's role as a decision maker disappears when adding control variables, while the positive effect of joint decision making remains significant. Moreover, a high level of knowledge transfer is more likely at the departments of Applied Physics and Electrical Engineering. It is also more likely if the Ph.D. candidate is a former employee of the partner; perhaps this person is then better embedded in this organization.

Table 4: Regression analysis of how different measurements of collaboration success (dependent variables) are impacted by project management aspects

	Level of knowledge transfer [1,2]		Resulted in academic publication [3,4]		Knowledge was patented [5,6]		Subsequent job offer from university [7,8]		Subsequent job offer from partner [9,10]		Collaboration was followed up [11,12]	
Funding funded by partner	-.160 (.334)	-.418 (1.871)	-.095 (.041)	-.172 (.110)	**.865** (5.188)**	**1.121** (5.962)**	-.241 (.414)	-.295 (.514)	.372 (1.245)	.348 (.876)	**.740* (3.026)**	**.880* (3.018)**
Relationship managed by partner (1)	-.462 (.957)	-.426 (.725)	.499 (.360)	.343 (.136)	-.581 (.819)	-1.212 (2.389)	**-2.372** (7.660)**	**-2.496** (7.729)**	.267 (.233)	.276 (.211)	-.184 (.063)	-.265 (.101)
Relationship managed by both (1)	.253 (.583)	447 (1.540)	.035 (.004)	.396 (.429)	-.144 (.109)	**-.998* (3.576)**	**-.962** (4.143)**	**-1.064** (4.330)**	.578 (2.195)	.414 (.933)	-.028 (.003)	.148 (.056)
Decision making by partner (2)	**.947** (3.998)**	.362 (.484)	-.656 (.686)	-.093 (.010)	.443 (.509)	.873 (1.199)	1.177 (2.611)	.809 (1.042)	.006 (.000)	.291 (.215)	.328 (.202)	-.234 (.072)
Decision making by both (2)	**.998** (8.866)**	**.682* (3.523)**	-.483 (.771)	-.133 (.049)	.062 (.020)	.045 (.007)	.614 (1.934)	.495 (1.075)	.303 (.607)	.253 (.342)	.451 (.715)	.319 (.298)
Publication restriction imposed by partner	.724 (2.609)	**.917* (3.714)**	-.177 (.065)	.493 (.385)	**1.202** (5.347)**	**1.202** (4.179)**	.050 (.007)	-.197 (.091)	-.191 (.124)	-.484 (.686)	-1.016 (2.712)	-.757 (1.254)
Partner's office in same city as university		-.399 (1.631)		-.767 (2.209)		**1.232** (7.571)**		.241 (.330)		.023 (.004)		.796 (2.266)

[5] Please note that in some cases, the significant effect of independent variables on the dependent variables disappears after adding control variables. In a separate analysis (not shown), we observe that each significant individual control variable makes the core variable lose significance.

Collaboration with research institute (opposed to firm)		-.437 (1.931)		.944 (2.657)		**-1.194**** **(6.062)**		-.001 (.000)		-.181 (.225)		-.446 (.720)
Department of Applied Physics (3)		**.941**** **(3.885)**		-.201 (.040)		-.055 (.007)		.623 (.863)		-.807 (1.615)		.731 (.803)
Department of Electrical Engineering (3)		**.839*** **(2.736)**		-.504 (.291)		-.171 (.064)		.857 (1.512)		-.262 (.170)		-.959 (1.680)
Department of Mathematics & Computer sciences (3)		.048 (.007)		**-2.002**** **(5.112)**		-.533 (.470)		**1.464**** **(4.070)**		-.011 (.000)		-.448 (.259)
Department of Mechanical Engineering (3)		.235 (.259)		-1.094 (1.739)		-1.130 (2.699)		.474 (.543)		.785 (2.128)		-1.105 (2.510)
Management or design department (3)		.679 (1.881)		-.819 (.807)		-1.196 (2.232)		**1.305*** **(3.738)**		.219 (.140)		.599 (.423)
Ph.D. candidate is former employee of partner		**1.172**** **(5.902)**		.445 (.266)		.123 (.035)		-.430 (.362)		.859 (2.417)		1.274 (1.300)
Prior relation between TU/e and collaborating partner		.089 (.057)		.834 (1.866)		-.714 (2.002)		-.300 (.342)		**-.719*** **(2.728)**		**1.306**** **(5.372)**
Model fit (Nagelkerke R^2)	R^2=.103	R^2=.195	R^2=.016	R^2=.184	R^2=.103	R^2=.292	R^2=.099	R^2=.160	R^2=.045	R^2=.134	R^2:.058	R^2:.222

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. Columns (1) and (2) are ordinal logit regressions; all others are binary logit regressions. Note: (1) Baseline is relationship managed by university. (2) Baseline is decision making by university. (3) Baseline is the department of Chemical Engineering and Chemistry, the largest department in terms of collaborations.

For our second outcome variable, *academic publications* (Table 4, columns 3 and 4), we find no significant relationships. Apparently, project management aspects do not affect the likelihood of Ph.D. candidates having their results published in academic journals. We observe that collaborative projects in mathematics & computer sciences are less likely to result in publications. This may be a discipline-specific effect. As previously mentioned, we did not check this against overall differences between publication performances at different departments.

Our third outcome variable considers whether the developed *knowledge is patented* (Table 4, columns 5 and 6). We find that the likelihood of patents is (a) positively related to the collaborating partner funding the project. Arguably, this might be because the collaborating partner sees more commercial potential in the project, or has more control of the scientific direction. This finding is in agreement with those of Czarnitzki and Fier (2003), who found that if a project is funded by a firm, the chance of patents increases because in this situation, the focus is on commercialization activities. Moreover, Blumenthal et al. (1997) report that in this situation, industry financially supports the project because of more involvement in commercialization activities, and publications decrease; (b) the likelihood of patents is negatively related to both university and partner managing the relationship. Such a shared management apparently does not go well with patenting objectives. (Note that we do not observe whether the patent is assigned to the university or the collaborating partner, limiting our interpretation of this result.) Furthermore, (c) the likelihood of patents is positively related to a publication restriction imposed by the collaborating partner. This makes sense as such a restriction is usually aimed at ensuring outcomes meet the novelty requirement of the patent office. Interestingly, the restriction does not negatively affect the likelihood of publication. Perhaps patented outcomes do get published, but only after the patent application is completed. In the control variables, we see that patenting likelihood increases if the collaborating partner's office is situated in the same city as the university. When considering this result, however, we should bear in mind that our data was collected at the Eindhoven University of Technology, which is located in a city that is also home to Philips research and many other Philips offices that collaborate with this university. With over 54,000 patents, Philips is a very patent intensive company and this may affect our results. We also observe that the positive effect of funding by a collaborating partner and publication restriction still remain significant after adding control variables that show the robustness effect of these two independent variables. Furthermore, collaboration with a research institute (i.e. a Public Research Organization – PRO) is less likely to result in patents than one with a firm, which is not surprising.

Our fourth and fifth outcome variables are whether the Ph.D. candidate – after successful completion of the project – *is offered a job by the university or the collaboration partner respectively* (Table 4, columns 7 to 10). Remarkably, a job offer by a university is less likely if the collaborating partner was involved in managing the relationship, either alone or together with the university. Although we have no idea why this would be the case, we only know that it is not due to the candidate already having been employed by the partner, because we include that as a control variable and it remains insignificant. A job offer by the collaborating partner is not related to any project management aspects.

Our sixth and final outcome variable is whether *the collaboration was followed up by a new one* (Table 4, columns 11 and 12). Here we observe that such a follow-up is more likely if the collaborating partner funded the project. This result still remains significant after adding control variables that show the robustness effect of this independent variable. We also observe that this is more likely if the project was also preceded by other collaboration. So, in effect, we see the successful occurrence of longer 'chains' of subsequent Ph.D. collaborations.

4.2. How do supervisors affect collaboration success?

Table 5 provides an overview of our regression results of the effect of supervisors' characteristics on the six different measurements of success. According to our Nagelkerke R^2 values, the supervisors' characteristics account for 4 to 20 percent of the variance within our different dependent variables.

Table 5, columns 1 and 2 show that *level of knowledge transfer* is: (a) negatively related to the level of university supervisor knowledge. Perhaps this is because a supervisor with a high knowledge level is more interested in publications than in facilitating knowledge transfer; (b) positively related to the level of enthusiasm of a university supervisor for the specific Ph.D. project topic. University supervisor enthusiasm might indicate how much a university supervisor likes the project topic and tends to be involved in that project. We think such willingness and enthusiasm help the collaborating partner to better achieve its goals, transferring knowledge from a university; (c) positively related to similar opinions between supervisors at both university and collaborating partner. We think such similar opinions facilitate the transfer of knowledge from university to collaborating partner; and (d) negatively related to supervisor replacement during the project. If we focus on transfer of knowledge as a measurement of success, the collaborating partner benefits more from the collaboration. Therefore to achieve successful collaboration in terms of knowledge transfer, especially with cooperation from the university side, crucial factors are supervisor enthusiasm to be involved in the project, and opinion similarity with collaborating partner supervisor. We observe that the significant effect of university supervisor knowledge, opinion similarity between both supervisors, and supervisor replacement at the level of knowledge transfer still remain significant after adding control variables, while the significant effect of university supervisor enthusiasm disappears. Knowledge transfer is also more likely if the Ph.D. candidate is a former employee of a partner; perhaps this person is better embedded in the organization.

Table 5: Regression analysis of how different measurements of collaboration success (dependent variables) are impacted by supervisors' characteristics

	Level of knowledge transfer [1,2]		Resulted in academic publication [3,4]		Knowledge was patented [5,6]		Subsequent job offer from university [7,8]		Subsequent job offer from partner [9,10]		Collaboration was followed up [11,12]	
Level of university supervisor knowledge	-.409** (4.066)	-.377* (2.765)	.558 (2.656)	.220 (.307)	-.585** (4.849)	-.453 (2.159)	-.059 (.049)	.063 (.045)	-.617** (5.918)	-.534* (3.414)	.628** (4.589)	.540 (2.295)
Level of partner supervisor knowledge	.239 (1.890)	.278 (2.207)	-.229 (.517)	-.194 (.293)	-.061 (.079)	-.157 (.419)	-.019 (.007)	-.109 (.199)	.293 (1.876)	.364 (2.416)	-.074 (.085)	.058 (.042)
Level of university supervisor enthusiasm	.443** (4.160)	.380 (2.547)	-.375 (.933)	-.046 (.010)	.556* (3.541)	.651* (3.342)	.241 (.633)	.145 (.196)	.477* (2.997)	.359 (1.376)	-.272 (.756)	-.170 (.195)
Level of partner supervisor enthusiasm	-.032 (.026)	-.071 (.103)	-.322 (.844)	-.554 (1.620)	-.115 (.209)	-.118 (.152)	.202 (.588)	.205 (.489)	.240 (.995)	.222 (.670)	-.036 (.015)	-.318 (.686)
Similar opinions between both supervisors	.388** (5.839)	.323* (3.694)	-.012 (.002)	-.049 (.027)	.250 (1.417)	.254 (1.026)	-.046 (.051)	-.045 (.042)	-.094 (.239)	.005 (.001)	.178 (.485)	.173 (.314)
Supervisor replacement	-1.286** (9.711)	-1.183** (6.989)	-.223 (.107)	-.618 (.661)	.542 (1.293)	.221 (.147)	-.008 (.000)	.075 (.018)	-.525 (1.119)	-.548 (.903)	.205 (.117)	.220 (.090)
Openness of university supervisor	.153 (.673)	.089 (.195)	.045 (.020)	.069 (.028)	.113 (.181)	.022 (.005)	-.166 (.457)	-.179 (.467)	.070 (.095)	.234 (.857)	-.295 (.895)	-.540 (1.767)
Openness of partner supervisor	-.013 (.006)	.098 (.275)	-.174 (.276)	-.081 (.039)	.259 (1.222)	.143 (.279)	.077 (.107)	-.007 (.001)	-.045 (.044)	-.108 (.203)	-.258 (.841)	-.359 (.978)
Academic position of daily university supervisor	.180 (1.053)	.146 (.546)	-.798** (6.363)	-.840** (4.527)	-.151 (.406)	-.240 (.684)	.236 (1.034)	.103 (.159)	-.296 (1.841)	-.305 (1.508)	.408 (1.863)	.371 (1.012)
Academic degree of partner supervisor	.003 (.000)	.112 (.215)	.837** (4.589)	.637 (1.844)	-.544* (3.663)	-.471 (1.970)	-.277 (.900)	-.148 (.223)	-.205 (.581)	-.100 (.111)	.522 (2.227)	.818* (3.639)
Partner's office in same city as university		-.410 (1.528)		-.978* (2.872)		.904** (4.106)		.162 (.148)		.125 (.092)		.616 (1.134)
Collaboration with research institute (opposed to firm)		-.470 (1.901)		.796 (1.384)		-.632 (1.694)		-.109 (.059)		.104 (.060)		-1.000* (2.891)
Department of Applied Physics (1)		1.089** (4.305)		1.158 (.781)		.447 (.410)		.401 (.332)		-.211 (.094)		1.494 (1.544)
Department of Electrical Engineering (1)		.986* (3.501)		.264 (.060)		.372 (.294)		.467 (.438)		.248 (.147)		-1.176 (1.985)
Department of Mathematics & Computer sciences (1)		.269 (.235)		-1.040 (1.287)		.181 (.065)		.926 (1.780)		.430 (.400)		-.375 (.180)
Department of Mechanical Engineering (1)		.448 (.763)		-.765 (.625)		-.912 (1.430)		.196 (.083)		1.330** (4.526)		-.727 (.836)
Management or design department (1)		.568 (1.058)		-.244 (.054)		-.669 (.649)		.104 (.020)		.586 (.754)		.002 (.000)
Ph.D. candidate is former employee of partner		.936* (3.293)		.000 (.000)		.025 (.001)		-.473 (.438)		1.041* (2.835)		19.959 (.000)
Prior relation between TU/e and collaborating partner		-.296 (.519)		1.221* (2.861)		-.562 (1.100)		-.044 (.007)		-.540 (1.168)		.938 (1.938)
Model fit (Nagelkerke R^2)	R^2: .201	R^2: .251	R^2: .149	R^2: .290	R^2: .140	R^2: .248	R^2: .036	R^2: .052	R^2: .122	R^2: .189	R^2: .117	R^2: .332

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. Columns (1) and (2) are ordinal logit regressions. All other columns are binary logit regressions. Note: (1) Baseline is the department of Chemical Engineering and Chemistry, the largest department in terms of collaborations.

Regarding having an *academic publication* as outcome of a collaborative Ph.D. project (Table 5, columns 3 and 4), we find that the likelihood of academic publications is: (a) negatively related to the academic position of the university supervisor, and (b) positively related to the academic degree of the collaborating partner supervisor. It seems that, on the one hand, a collaborating partner's supervisor with a higher academic degree can be a sign of having more knowledge on the topic. On the other hand, a knowledgeable supervisor is not necessarily involved in more managerial tasks in the firm but rather involved more in research work. As a result, publication likelihood might increase. However in the university, supervisors with a higher academic position are likely to have more managerial responsibilities in their university department as well. Consequently, the probability of publication might decrease; (c) positively related to the level of university supervisor knowledge (significant at p=0.103) that shows the publication orientation of such a supervisor. By adding control variables, the positive effect of a collaborating partner supervisor's academic degree disappears, while the negative effect of a university supervisor's academic position still remains significant for academic publications. Furthermore, the probability decreases if the collaborating partner's office is located in the same city as the university. As discussed, our results may be affected by several Philips offices collaborating with TU/e as that increases the probability of knowledge being patented. Moreover, prior relations between university and collaborating partners induce trust between both partners; hence they increase the likelihood of academic publications.

Based on our third outcome variable, whether the *developed knowledge is patented* (Table 5, columns 5 and 6), we find that the likelihood of patent is: (a) negatively related to the level of university supervisor knowledge, while adding control variables causes this result to disappear. As discussed earlier, it is perhaps thanks to the publication orientation of a supervisor with high knowledge; (b) positively related to the level of university supervisor enthusiasm. This result still remains significant after adding control variables; (c) negatively related to the collaborating partner's academic degree. As previously mentioned, the collaborating partner's supervisor having a higher academic degree can mean having more knowledge on the topic, positively and negatively impacting on publication and patent respectively. In terms of control variables, the negative effect of university supervisor knowledge and collaborating partner's academic degree disappear by adding control variables, while the positive effect of university supervisor enthusiasm remains significant. Moreover, if the collaborating partner's office is in Eindhoven, the likelihood of having patents increases.

For our fourth outcome variable, *job offer to Ph.D. from university* (Table 5, columns 7 and 8), we find no significant relationships. None of the supervisor characteristics affects the likelihood of the Ph.D. being offered a job by the university after successful completion of the project.

For the fifth outcome variable (Table 5, columns 9 and 10), we find that *a job offer by collaborating partner* is: (a) negatively related to the level of university supervisor knowledge. This is because the knowledgeable university supervisor is likely to be more publication oriented and the collaborating partner focuses more on the commercialization aspects of knowledge; (b) positively related to the university supervisor enthusiasm to get involved in the project. By adding the control variables, the significant effect of the latter result disappears while the negative effect of university supervisor knowledge on offering a job to the Ph.D. student remains significant. We also observe that it is more likely if the Ph.D. candidate is a former employee of the collaborating partner. This person is perhaps better embedded in the organization. Moreover, job offers to Ph.D. candidates are more likely at the department of Mechanical Engineering.

Finally, for the sixth outcome variable, whether *the collaboration was followed up by a new one* (Table 5, columns 11 and 12), we find that such a follow-up is more likely if the level of university supervisor knowledge and academic degree of collaborating partner supervisor are high. Perhaps because in this situation both supervisors are sufficiently knowledgeable on the project topic, the cognitive proximity between them can facilitate new collaboration. We find that the significant effect of university supervisor knowledge disappears after adding our control variables. Moreover, new follow-up collaboration is less likely if the original collaboration is with a research institute than with a firm. This result makes sense and is not surprising.

4.3. How does communication affect collaboration success

The regression results on how different measurements of collaboration success are influenced by communication are shown in Table 6. Nagelkerke R^2 values show that characteristics of communication account for between 1 and 20 percent of the variance within our different dependent variables.

Regarding *the level of knowledge transfer* (Table 6, columns 1 and 2), we find it is: (a) positively related to the frequency of meetings between the Ph.D. candidate and collaborating partner supervisor. As the Ph.D. candidate has a role of knowledge transfer between university and industry (Thune, 2009), the frequency of meetings between Ph.D. candidates and their supervisor in the collaborating partner provides the conditions to facilitate transfer of knowledge through discussion, brain storming, etc.; (b) the level of knowledge transfer is positively related to the quality of communication between the Ph.D. candidate and collaborating partner. This result remains significant after adding control variables that show the robustness effect of this independent variable while the effect of frequency of meetings between Ph.D. candidate and collaborating partner supervisor disappears. Besides, we observe that a high level of knowledge transfer is less likely if collaboration is with a research institute as opposed to a firm. Moreover, it is more likely at the department of Electrical Engineering and if the Ph.D. candidate is a former employee of the collaborating partner.

Regarding the second outcome, *academic publications* (Table 6, columns 3 and 4), we find are less likely if the frequency of meetings between both supervisors is high. However, this result disappears when control variables are added.

For our third and fourth outcome variables, *patent and offering job to Ph.D. from university* (Table 6, columns 5 to 8), we find no significant relationships. We do observe that if the collaborating partner’s office is in Eindhoven, a patent is more likely. Moreover, collaboration with a research institute compared to a firm reduces the likelihood of patents. Regarding the university offering a job to the Ph.D. candidate, a collaboration project at the department of Mathematics & Computer science increases this likelihood.

Table 6: Regression analysis of how different measurements of collaboration success (dependent variables) are impacted by communication characteristics

	Level of knowledge transfer [1,2]		Resulted in academic publication [3,4]		Knowledge was patented [5,6]		Subsequent job offer from university [7,8]		Subsequent job offer from partner [9,10]		Collaboration was followed up [11,12]	
Meeting frequency of Ph.D. candidate and university supervisor	-.078 (.545)	-.050 (.198)	-.105 (.335)	-.024 (.013)	-.021 (.026)	-.014 (.009)	.151 1.125	.121 (.648)	.073 .325	-.058 (.146)	**-.315** (4.040)**	-.248 (1.813)
Meeting frequency of Ph.D. and partner supervisor	**.184** (4.169)**	.104 (1.002)	-.075 (.217)	.017 (.008)	.066 (.347)	.158 (1.227)	036 .089	-.147 (1.136)	**.306** 7.225**	**.497** (11.570)**	-.142 (1.143)	-.184 (1.253)
Meeting frequency of both supervisors	.093 (.666)	.185 (2.074)	**-.444* (3.855)**	-.362 (2.042)	-.021 (.021)	-.073 (.171)	.078 .250	-.006 (.001)	.157 1.227	.124 (.556)	**.380** (4.760)**	**.488** (4.871)**
Quality of communications between Ph.D. and University supervisor	.107 (.400)	-.064 (.124)	.109 (.120)	.049 (.021)	.199 (.838)	.325 (1.738)	-.132 .330	-.152 (.388)	.249 1.332	**.448* (3.175)**	.074 (.091)	.027 (.008)
Quality of communications between Ph.D. and partner supervisor	**.299** (5.113)**	**.296** (3.999)**	-.098 (.124)	-.055 (.036)	.042 (.065)	-.209 (1.112)	.221 1.515	.320 (2.582)	.018 .011	-.070 (.109)	-.171 (.735)	-.406 (2.368)
Partner's office in same city as university		-.412 (1.758)		-.758 (2.150)		**.876** (4.545)**		.260 (.415)		.046 (.013)		.702 (1.704)
Collaboration with research institute (opposed to firm)		**-.721** (5.523)**		.904 (2.518)		**-1.215** (7.411)**		.007 (.000)		-.189 (.231)		-.652 (1.597)
Department of Applied Physics (1)		.689 (2.024)		-.327 (.099)		-.161 (.060)		.640 (.876)		**-1.396** (3.902)**		1.163 (1.941)
Department of Electrical Engineering (1)		**.844* (2.853)**		-.484 (.268)		-.052 (.007)		.730 (1.156)		-.637 (.948)		-.642 (.737)
Department of Mathematics & Computer sciences (1)		-.182 (.107)		**-1.541* (3.026)**		-.182 (.067)		**1.360* (3.680)**		-.828 (1.396)		-.407 (.200)
Department of Mechanical Engineering (1)		.290 (.390)		-1.084 (1.663)		-.863 (1.754)		.635 (.990)		.614 (1.140)		-.583 (.696)
Management or design department (1)		.209 (.173)		-.793 (.696)		-1.233 (2.449)		1.078 (2.641)		-.431 (.452)		.969 (.969)
Ph.D. candidate is former employee of partner		**1.032** (4.627)**		.266 (.097)		.097 (.021)		-.609 (.768)		**1.056* (3.114)**		**2.138* (2.994)**
Prior relation between TU/e and collaborating partner		-.192 (.264)		.934 (2.284)		-.696 (2.040)		-.196 (.158)		**-.924** (3.864)**		**.972* (3.092)**
Model fit (Nagelkerke R^2)	R^2: .119	R^2: .199	R^2: .088	R^2: .205	R^2: .013	R^2: .202	R^2: .024	R^2: .073	R^2: .130	R^2: .261	R^2: .074	R^2: .260

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. Columns (1) and (2) are ordinal logit regressions; all other columns are binary logit regressions. Note: (1) Baseline is the department of Chemical Engineering and Chemistry, the largest department in terms of collaborations.

For our fifth outcome variable (Table 6, columns 9 and 10) we find that *offering job to Ph.D. from collaborating partner* is: (a) positively related to the high frequency of meetings between Ph.D. and collaborating partner supervisor; (b) positively related to the quality of communication between Ph.D. candidate and university supervisor. After graduation, the Ph.D. candidate is considered the main channel of knowledge transfer to the collaborating partner and tacit knowledge can be absorbed from this channel (Mangematin, 2000). Moreover, close and frequent relationships play an important role in obtaining tacit knowledge (Tamer Cavusgil et al., 2003) and inspire the collaborating partner to hire a Ph.D. candidate after graduation. This motivation can be increased in cases where the Ph.D. candidate has high quality communication with the university side. We find that the effect of frequency of meetings between Ph.D. candidate and partner supervisor remains significant after adding control variables. Moreover the Ph.D. candidate is more likely to receive a job offer from a collaborating partner if the Ph.D. candidate is a former employee of the collaborating partner.

For the last outcome variable, *following-up of collaboration by a new one* (Table 6, columns 11 and 12), we find that this is: (a) negatively related to the frequency of meetings between Ph.D. and university supervisor. However, the result disappears when control variables are added; (b) positively related to the frequency of meetings between both supervisors. This result remains significant after adding control variables, proving the robustness effect of this independent variable. Arguably, this might be because both sides find each other helpful in solving other problems, which could lead to new collaboration. By adding control variables, we observe that such a follow-up is more likely if the Ph.D. candidate is a former employee of the collaborating partner and both partners have a prior mutual relationship. These results show the importance of trust and commitment that can be fostered in previous collaborations between partners and which can inspire them to continue their collaboration.

5. Conclusions, managerial implications and future research

University-industry collaboration via Ph.D. projects is a promising mechanism for knowledge transfer, and this paper aims to contribute to the deeper understanding of this mechanism. More specifically, we investigate how choices related to the governance and the management of such collaborations impact the ultimate success of such projects. Although collaborations certainly can carry benefits for all partners, they inherently carry costs as well in terms of time, energy and money (Thomson and Perry, 2006). This paper provides a specific framework to analyze a project's success. Using this framework as the basis of our empirical study, this study has several implications for both university and industry, enabling partners to manage and govern collaborative Ph.D. projects successfully.

We will briefly highlight some of the most important implications. In order to promote collaboration success, we advise partners to implement joint decision-making on the content of the project. Involving all partners in this decision-making process increases the synergy between them. Regarding the source of project funding, our findings suggest that the collaborating partner funds the project, while the university manages the relationship between the partners. The level of the university supervisor's enthusiasm and motivation to be more involved in the project is one of the more significant determinants of success. Based on our results, a recommendation for partners, especially collaborating partners, would be making it a condition that a university supervisor is sufficiently motivated to cooperate in the project. Moreover, replacing a supervisor is a challenging issue for every partner during a project, and should be avoided whenever possible. Furthermore, we advise the collaborating partner to oversee the frequency and quality of communication with the Ph.D. candidate during the project. Finally, in line with findings in other studies on collaboration in other fields, previous collaboration experience between the two partners helps to achieve a higher level of success (Hahn et al., 2008).

Our study has several limitations that could encourage researchers to work on the governance of collaborative Ph.D. projects. We think more empirical studies are needed to look at the governance effect on the success of collaborations in other technical universities, as well as other types of universities, to better validate the proposed governance model. Finding out how the collaborative Ph.D. projects are managed in other types of universities and conducting a comparative study among different universities, are just two of the interesting avenues for future research. Another limitation of this study is that it only considers Ph.D. projects that have resulted in a published Ph.D. thesis (i.e. a successful defense). While such projects achieve diverse scores with our collaboration success measurements, we have not included projects that, for whatever reason, were aborted during their execution. Although such data is much harder to collect, it might provide new insights into collaborative Ph.D. projects. Moreover, it would be ideal to measure collaboration success from all the partners' perspectives (university, Ph.D. candidate and collaborating partner) in the study, however, gathering enough data for statistical analysis is problematic. As such, we suggest conducting case studies to compare the three perspectives. Finally, studies on the differences between governing non-collaborative and collaborative Ph.D. projects in order to achieve successful collaboration should be considered for future research.

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