Success factors of university-industry PhD projects

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Success factors of university-industry PhD projects

Abstract – Faced with ever-increasing pressure to innovate, firms consider universities as significant sources of knowledge. Such knowledge flow can take place in a variety of ways such as academic publications and contract research, but also more collaborative modes such as joint research projects. This paper focuses on a specific collaborative model, in which firms and universities are involved together in a Ph.D. project. We analyze the effects of project management, communication, and supervision characteristics on the success of such PhD projects using a survey conducted at Eindhoven University of Technology in the Netherlands. We conclude that management decisions, supervision and communication characteristics have a significant impact on the ultimate success of a project. 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. We believe our findings help universities and firms to collaborate successfully.

Keywords – University-industry collaborations; collaborative Ph.D. projects; collaboration success.

1. Introduction

In the past decade, there has been considerable evidence of an increase in linkages between universities and industry, including the growing propensity of universities to patent (Nelson, 2001), universities' growing licensing revenues (Thursby et al., 2001), an increasing number of university spin-offs (Shane, 2005), and an increasing number of science parks (Siegel et al., 2003b). There is already a considerable empirical literature on knowledge transfer from university to industry (e.g. Tijssen, 2012; Ryan et al., 2008; Baldini, 2006; Dutrénit et al., 2010; Fernandes et al., 2010). Most studies focus on formal, non-collaborative forms – such

as patenting and licensing – while some recent studies also highlight the importance of collaborative forms (e.g. Bekkers and Bodas Freitas, 2008; Perkmann et al., 2013). Going beyond mere commercialization of academic knowledge, Perkmann et al. (2013) introduce the concept of academic engagement, defined as "knowledge related collaboration by academic researchers with non-academic organizations". This definition includes differentiated forms of interaction, from formal activities such as collaborative research, contract research and consulting, to informal activities like meetings or attending conferences (D'Este and Patel, 2007; Grimpe and Hussinger, 2013).

A key form of university-industry collaboration, which has nevertheless received relatively little scholarly attention, is joint PhD projects. Here, we 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.*" Doctoral candidates are not only key producers of new knowledge but potentially also important channels for transferring such knowledge to firms (Thune, 2009). In this context, studies hitherto have focused on comparing joint PhD projects with university PhD projects in terms of their outputs. For example, Lin and Bozeman (2006) found the negative impact of industry involvement in the scientific productivity of Ph.D. candidates during their entire career, while Salimi et al. (2015) found that the output and impact of the Ph.D. project itself was higher for collaborative projects compared to in-house university projects. There is further evidence that industry involvement in PhD projects leads to higher patenting rates (Gemme and Gringas, 2004) and job opportunities (Mangematin, 2000; Mouge´rou 2001), though one study did not find such an effect (Enders, 2002).

The question what factors drive the success or failure of collaborative PhD projects, however, has remained largely unanswered (Butcher and Jeffrey, 2007; Thune, 2009). We know that for university-industry collaboration in general, that despite the perceived mutual benefits success is by no means guaranteed. There exist high failure rates in R&D collaboration (Brouthers et al. 1997) and many projects report considerably lower outcomes than expected (Spekman et al., 1998). Various factors can cause collaborations to fail such as choosing an inappropriate partner for collaboration (Beamish and Inkpen, 1995), coping with management issues (Dodgson, 1991; Kelly et al., 2002) and communication problems (Kelly et al., 2002). In addition, supervision characteristics are also expected to affect success of projects (Butcher and Jeffrey, 2007).

Based on extensive survey among past PhD students engaged in university-industry

projects, this study analyses how management, supervision and communication characteristics of projects impact on their success. We contribute to the literature in three ways. Firstly, it fills the existing gap in the area of determinants of success in university-industry collaboration. Secondly, it is one of the very few contributions that focuses on collaborative Ph.D. projects (Butcher and Jeffrey, 2007; Thune, 2009). Such collaborations are quite common, especially at technical universities: as we will show later, in the university where we collected our data, almost one third of all 1783 doctoral theses published between 2000 and 2011 were the result of a collaboration. Thirdly, we measured the success of collaboration as a construct with multiple components whereas previous studies tend to focus on one aspect of success only (Butcher and Jeffrey, 2007). We also believe that this study, in addition to its scientific contributions, has several practical implications, not only for universities, but also for their partners in industry, that could increase the chance of collaboration success. More precisely, an understanding of the success factors underlying joint PhD projects between universities and industries, can increase the benefits and reduce the risk in inherently costly and complex projects.

The remainder of this paper is organized as follows. In Section 2, we review the literature on collaboration dimensions and their characteristics, as well as the literature on measuring collaboration success. In Section 3 we propose a methodology to investigate the relationship between management, supervision and communication characteristics on the one hand and project success on the other. Then, in Section 4, we present our empirical analysis and discuss the findings. The paper ends with conclusions, managerial implications and future research directions.

2. Success factors in collaborative Ph.D. projects

The literature on inter-organizational collaboration highlights several factors that can influence collaboration success. Three main dimensions, identified by Amabile et al. (2001), are collaborative team characteristics, collaboration environment characteristics, and collaboration processes. They found three factors in particular that are important for successful collaborations: (a) skills and knowledge of project leader, (b) mutual trust, and (c) communication with high frequency. Literature on other forms of firm collaboration looked at factors leading to failed collaborations, such as selection of inappropriate partner for collaboration (Beamish and Inkpen, 1995), and communication problems and management

issues (Kelly et al., 2002). How the partners of collaboration manage their activities is another factor that influences the success of collaboration (Starbuck, 2001; Morandi, 2013). In fact, this dimension of collaboration emphasizes the joint action and behavior among collaborative partners. Based on this view, partners who become involved in collaboration must learn 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). Here, the significant management characteristics of a collaboration include: 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 risks or rewards are shared (Ostrom, 1990; Lambert, 2008).

Thomson and Perry (2006) argue that managing the cooperation is at the 'heart of collaboration', focusing on the negotiation between, and commitment of, partners. In order to achieve joint management and decision-making among partners, trust (Ostrom, 1990; Lambert, 2008) and commitment (Mattessich and Monsey, 1992; Barnes et al., 2002; Lambert, 2008) can be seen as necessary conditions. These aspects of collaboration can be created by maintaining close relationships and good communication between partners (Mattessich and Monsey, 1992; Lambert, 2008). Therefore another crucial dimension of collaboration is how partners who are involved in a project communicate to each other (Senker et al., 1998; Rappert et al., 1999; Schartinger et al., 2002).

In the specific case of a collaborative Ph.D. project, supervisors in both university and industry are vital partners that have important role in order to have higher outcome (Thune, 2009). Salminen-Karlsson and Wallgren (2008) focused on the role of university supervisors and firm supervisors of graduate candidates in the specific context of industrial research schools, within the special framework of Swedish higher education. They found that collaboration between university supervisors and industry supervisors requires ongoing cooperation between them even in other areas (i.e. personal relation), as well as frequent meetings. Moreover, mutual understanding, similar motivations and goals of supervisors are other elements of successful collaboration (Butcher and Jeffrey, 2007). Hence, supervision is one another dimension of collaboration between university and industry that can be considered as a success factor.

In sum, there are many factors influencing the research process in a joint PhD project between universities and industries. These factors can be grouped under the headings of management, supervision and communication characteristics. These are also the dimensions

proposed in the framework by Butcher and Jeffrey (2007). By conducting interview among research funders and managers, they identified these three dimensions as the main success determinants in collaborative Ph.D. projects. In the following, we will follow the framework by Butcher and Jeffrey. The question that now follows is how to measure the success of collaborative Ph.D. projects.

We should stress that in this study, success refers to the extent to which the collaboration's goals 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 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).

In the extant literature, there is currently no agreement on how to assess the success of collaborative PhD projects. For instance, Jeffrey and Butcher (2007) investigated the correlation between collaboration success factors such as supervisor, project management and communication and the perceived collaborative research success (from the Ph.D. candidate's perspective). In doing so, these researchers did not consider different components when measuring collaboration success. Other studies have also measured success from a single component only, such as knowledge transferring ability between partners, development and commercialization of a new product (Bekkers and Bodas Freitas, 2011). Siegel et al. (2003a) identify how technology as one output of university-industry collaboration is successfully transferred and the strategies for improving technology transfer.

Other researchers mention different components for the success of university-industry collaboration without considering these different components in their analyses. For instance, Santoro (2000) mentions that tangible technological outcomes (e.g. publication, patent, patent application) along with knowledge sharing are components of success in university-industry collaborations. Barnes et al. (2002) identified success as a construct with multiple components. They evaluate six collaborative research projects between university and industry and identify different components for collaboration success. They evaluated the

projects' outcomes based on two types of components: subjective and objective. For their subjective evaluation, they relied on the main participant's perception to the extent their expectations were met. In terms of objective success components, they considered the number of publications, patents, new product, new process and technology development. However, their work is a conceptual study based on six case studies.

As success is a multi-dimensional concept, we choose to investigate the effects of success determinants on different components of success. While focusing specifically on collaborative Ph.D. projects and studying the existing literature, we aim to consider all the relevant components of success. Our starting point is to recognize the complex nature of joint PhD projects in that not two, but three partners need to be distinguished: the PhD student, the university supervisor and the supervisor at the partner organization. Moreover, the type of collaboration is specific in its long duration (typically four years or longer) compared to contract research which generally has a much shorter duration. And, the type of knowledge central to these collaborations - new scientific knowledge - makes collaborative Ph.D. projects different from other types of collaboration (Salimi et al., 2014). By reviewing the literature on the Ph.D. candidates, Thune (2009) found that scholarly productivity (i.e. publications and presentations), commercial productivity (i.e. patent and trade secrets), and future career of Ph.D. candidates are variables that are considered as outcomes of collaborative Ph.D. projects. In line with Thune's study, we measure a project's success using multiple components. We look at formal outputs including publications and patents as well as whether the relationship between the university and its partner has been continued and whether the PhD candidate was offered a job. In addition to these variable resembling Thune's study, we also specifically look at knowledge transfer using a progressive scale (explained below) as to be able to assess how valuable the knowledge transfer has been for the receiving partner.

3. Data and Methodology

3.1. Data collection

We conducted a survey in order to examine how university and industry build their relationships through collaborative Ph.D. projects and how different collaboration dimensions impact on different collaboration success measurements. In our study, the collaborative Ph.D. project is the unit of analysis. Our population is defined as Ph.D. projects involving Eindhoven University of Technology (henceforth indicated by TU/e) and a firm or public

research organization (PRO) that resulted in a published Ph.D. thesis between the years 2000 and 2011.[1] Here, it is important to stress that in The Netherlands, most of the public research organizations rely heavily on contract research and other sources of commercial funding, and have very limited public funding, quite differently from PROs in many other countries that are much closer to government agencies.[2] There is a specific 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 universities play in fostering economic development. Therefore we are much more likely to find this type of collaboration (industry-university) in technical rather than other universities.

Looking at all 1783 doctoral theses published between 2000 and 2011 at Eindhoven University of Technology, we determined that 496 (28 percent) of all PhD theses resulted from a collaboration with a firm or public research organization (in this paper we call these 'collaborating partner' or simply 'partner').[3] For 408 of these, we were able to retrieve up-to-date contact details of the former Ph.D. candidate. We then approached the full population of 408 former PhD candidates. 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 with public research organizations, bringing our overall response rate to 47 percent.

Collaboration success can be measured by collecting data from one of the collaboration partners (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 considered all the partners' perspectives. Barnes et al. (2002) show that a Ph.D. candidate's opinion and experiences as a main actor in the collaborative project give us access to both the industry and academia perspective. In addition to the Ph.D. candidate's pivotal role in the collaboration, the easier accessibility of Ph.D.

[1] We include all departments of the university, which include Applied Physics, Chemical Engineering & Chemistry, Electrical Engineering, Mathematics & Computer Science, Mechanical Engineering, Built Environment, Biomedical Engineering, Industrial Design, and Industrial Engineering & Innovation Sciences. In the analysis, we grouped the latter four into a single category "Management or Design department".

[2] 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 public research organizations differ from those for firms (see Section 3.2).

[3] A collaboration was derived from reading the preface of each PhD thesis, which – in the Dutch PhD system – typically acknowledges all collaboration partners.

candidates is also relevant from a practical viewpoint.[4] As if we would require all the partners' opinions on a specific project, the response rate would decrease dramatically, thus hampering the data analysis.[5] Therefore in terms of subjective evaluation for this study, the measurement of collaboration success depends on the Ph.D. candidate's perception and experience.

Still, measuring from a single source may cause concern in terms of common method variance. To reduce such bias as much as possible, we implemented measures as suggested by Podsakoff et al. (2003). Among other things, 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 suggests that our study does not suffer from common method bias.

Finally, to check for non-response bias, we used the projected respondent method offered by Armstrong and Overton (1977). This method assumes that non-respondents are more similar to late respondents. We compared non-respondents with two waves of respondents and found no indications of non-response bias.

4 Finding the supervisor(s) at a university and the contact person in industry is very difficult compared to tracking down 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 worked 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 it is the Ph.D. candidate who actually conducted the research rather than the supervisors, the data obtained from a Ph.D. candidate are likely to be more reliable than data obtained from supervisors (Behrens and Gray, 2001). Other studies like those of Butcher and Jeffrey (2007) also evaluated collaborative projects in terms of being successful or unsuccessful from the Ph.D. candidate's perspective due to considerations about response rate and quality of responses.

5 If the probability of getting a response from each actor (Ph.D. candidate, university and collaborating partner supervisors) is independent, the overall response rate would be given by the product of individual response rates. For example, for a response rate of each actor of 40 percent, the overall response rate would drop to 0.4 * 0.4 * 0.4 = 0.064, which is obviously too low to obtain reliable results.

3.2. Variables

Table 1 provides an overview of the dependent variables for this study. Wherever possible when evaluating collaboration, we used factual, objective measurements by considering all relevant success measurements. The first – and perhaps the most important – measurement was of the level of knowledge actually transferred to and used by the partner (Bekkers and Bodas Freitas, 2011). The extent to which the knowledge Ph.D. candidates developed in their theses has been adopted by industry is measured in a progressive scale. In the early preliminary stages, this knowledge may not be transferred at all. The next stage, knowledge transfer, makes that knowledge effectively available to industry staff working in this field and for instance accessible in libraries or being presented to staff. Once industry researchers have studied and mastered the transferred knowledge, absorption has taken place. The next stage occurs when the absorbed knowledge is applied in a business context. The final step is commercialization, which can be a small part or form the basis of a product or process. This measurement uses a progressive, ordinal scale as specified in Table 1, for which we applied the ordinal logit model in analysis.

Our other success variables are dichotomous variables. Whether a project resulted in academic publication whether knowledge was patented (Barnes et al., 2002) are two of dichotomous variables. Furthermore we measured whether the relationship between university and partner was continued (van Gils, 2012). Because the Ph.D. candidates can form and maintain the relation between university and its partner, after finalizing the Ph.D. project, the university and the partner can become engaged in a new collaboration (Thune, 2009). Other consequences of collaborative Ph.D. projects can be whether the university or partner offered the Ph.D. candidate a job after graduation. As such, we considered a job offer to a Ph.D. candidate from a university or its partner a proxy of a successful collaboration. We used a binary logit model to analyze these dichotomous variables. Details on our dependent variables, including the phrasing of the underlying question in our survey, are in Table A in the appendix.

Table 1 goes about here

Table 2 reports the correlation between dependent variables. For the 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 we can see from the table, almost all the correlations are very low, suggesting a high discriminate validity (Hair et al., 2006).

Table 2 goes about here

Table 3 is 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". Based on the first dimension of collaboration, we identified project management characteristics such as which partner(s) is responsible for funding the project, managing the coordination, making decisions on the content of project, and if any publication is prohibited due to industry restrictions.

Because of the important role that supervisors play in collaborative Ph.D. projects, we considered supervision characteristics as a second dimension of collaboration. This aspect is measured by various characteristics such as both the university supervisor and its partner supervisor's level of knowledge on the Ph.D. topic, the enthusiasm of both supervisors to be involved in the project, their level of openness to any new ideas and similar opinions between both supervisors on the Ph.D. topic. Further factors are: the effect of the university supervisors' academic position, the industry supervisors' academic degree and the replacement of any of the supervisors during the Ph.D. project.

With respect to the third dimension of collaboration, we considered the communication characteristics between partners in a collaborative Ph.D. project. We measured this aspect by considering the quality and frequency of meetings between Ph.D. candidates and their supervisors both at the university and at the partner as well as between the supervisors in both locations.

All continuous variables were measured on a five point Likert-type scale. Details on our independent variables, including the phrasing of the underlying questions in our survey, can be found in Table B in the appendix.

Table 3 goes about here

We further considered the effect of five control variables for an alternative explanation of the phenomena measured. These control variables are: (1) whether the partner's office is in the same city as the university, (2) whether the collaboration is with a public research organization (as opposed to a firm), (3) whether the Ph.D. candidate is a former employee of the partner, and (4) whether TU/e and the partner have a prior relationship. All these variables reflect a form of proximity between partners (Boschma, 2005; Ponds et al., 2007; Balland, 2012), including geography proximity (1), institutional proximity (2) and social proximity (3 and 4). In all cases, one can expect that proximity is supportive of trust, which benefits the

complex coordination process. Hence, one expects positive signs for all four control variables. Finally, we use dummies for each university department to control for structural differences across disciplines. Details on our control variables, including the phrasing of the underlying questions in our survey, can be found in Table C in the appendix. Table D (also in the Appendix), which provides the correlation between all the independent and control variables, shows that these correlations are quite low. We assessed the potential multicollinearity between independent variables in each of the three regression models. In the first model below (the effect of project management on success), the variance inflation factor (VIF) is between 1.035 and 2.009. That is, the tolerance (1/VIF) is greater than 0.4, well above the critical value of 0.2 (Menard, 1995). With respect to our second model (the effect of supervisors on success), VIF is between 1.091 and 1.884 (equivalent to tolerances greater than 0.5). For the last model (the effect of communication on success), VIF is between 1.186 and 1.466, which means that the tolerance is greater than 0.6. These results suggest that our study does not suffer from multicollinearity. Furthermore we investigated the multicollinearity between all independent variables (see Section 4.4).

4. Results and discussion

As discussed above, we distinguished three collaboration dimensions: project management, supervision, and communication. Our main results for these groups are shown in Tables 4, 5 and 6 respectively (and discussed Section 4.1, Section 4.2 and Section 4.3 respectively). In each table we have two columns for every dependent variable, one without the control variables (see previous section), and one with these variables. Our discussion of the results will be solely based on the regressions including the control variables, as these are most reliable.

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).

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 found that knowledge transfer is supported by joint decision-making suggesting that joint involvement in the content part of a project is indeed helpful for knowledge transfer through Ph.D. candidate. This result is in line with what is found in the literature that emphasizes on the role of collaborative Ph.D. candidates as knowledge transferor from university to the

industry (Mangematin 2000; Mouge´rou 2001). Knowledge transfer is also supported by a publication restriction imposed by the partner. Arguably, this is because such cases represent strategic knowledge that the partner is keen to obtain (and keen to patent). In terms of our control variables, we find that a former employee of the partner is more effective in transferring knowledge than other PhD candidates, probably because of the familiarity of the candidate with the organizational context in which (she) he operates.

Table 4 goes about here

For our second outcome variable, *academic publications* (Table 4, Columns 3 and 4), we found no significant relationships. Apparently, project management aspects do not affect the likelihood of Ph.D. candidates having their results published in academic journals.

Our third outcome variable considers whether the developed *knowledge is patented* (Table 4, Columns 5 and 6). We found that the likelihood of patents is: (a) positively related to the partner funding the project. Arguably, this might be because the partner sees more commercial potential in the project, or has more control of the scientific direction. This finding is in agreement with Czarnitzki and Fier (2003), who found that if a project is funded by a firm, the likelihood of patents increases because of the focus on commercialization activities; (b) the likelihood of patents is negatively related to joint management; (c) the likelihood of patents is positively related to a publication restriction imposed by the collaborating partner. This result is expected since a publication 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. In the control variables, we see that patenting likelihood increases if the 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 TU/e, 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 highly patent-intensive company and this may affect our results. We also observed that the positive effect of funding by a 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 public research organization as opposed to a firm 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). Interestingly, a job offer by a university is less likely

if the partner was involved in managing the relationship, either alone or together with the university. Although we have no exact 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 included that as a control variable and it remains insignificant. A job offer by the partner is not related to any project management aspects, yet, unexpectedly, it is negatively affected by prior relationship between the university and the partner.

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 observed that such a follow-up is more likely if the partner funded the project. This result still remains significant after adding control variables showing the robustness effect of this independent variable. We also observed that this is more likely if the project was also preceded by other collaboration. Thus, we observe evidence of long 'chains' of subsequent collaborations indicative of long-term partnerships

4.2. How do supervisors affect collaboration success?

Table 5 shows our regression results of the effect of supervisors' characteristics on the six different success measurements.

Table 5, Columns 1 and 2 show that the *level of knowledge transfer*: (a) is negatively related to the level of university supervisor knowledge. Indeed, a supervisor with a high knowledge level may well be more interested in publications than in facilitating knowledge transfer; (b) is positively related to both supervisors having similar opinions as can be expected; and (c) is negatively related to supervisor replacement during the project, again, as can be expected. Knowledge transfer is also more likely if the Ph.D. candidate is a former employee of a partner; again, this effect most probably reflects the candidate's familiarity with the organizational context.

Table 5 goes about here

Regarding having an *academic publication* as outcome of a collaborative Ph.D. project (Table 5, Columns 3 and 4), we found that the likelihood of academic publications is negatively related to the university professor's academic position. University supervisors with a higher academic position are likely to have more managerial responsibilities as well as fewer incentives to publish compared to less senior colleagues. Consequently, the probability of publication might decrease. By adding control variables, the publication probability decreases if the partner's office is located in the same city as the university, which is

unexpected. Prior relations between university and partners – indicative of trust between partners – 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 found that patenting is supported by a university supervisor enthusiasm. In terms of control variables, co-location in Eindhoven increases the likelihood of patents. Note again that this effect is likely to be, at least partially, the result of collaborations with the Philips research in Eindhoven, which is very productive in terms of patenting.

For our fourth outcome variable, *job offer to Ph.D. from university* (Table 5, Columns 7 and 8), we found 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 found that *a job offer by partner* is less likely is the university supervisor is very knowledgeable. This may be because a knowledgeable university supervisor is likely to be more research-oriented and the partner focuses more on the commercialization aspects of knowledge. As expected, we also observe that it is more likely if the Ph.D. candidate is a former employee of the partner.

Finally, for the sixth outcome variable, whether *the collaboration was followed up by a new one* (Table 5, Columns 11 and 12), we found that such a follow-up is more likely if the partner supervisor's has a high academic degree, possibly cognitive proximity can facilitate new collaboration. Moreover, follow-up collaboration is less likely if the original collaboration is with a public research organization than with a firm.

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.

Regarding *the level of knowledge transfer* (Table 6, Columns 1 and 2), we found: (a) it is positively related to the frequency of meetings between the Ph.D. candidate and 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 at the 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 partner supervisor disappears. Besides, we observed that a high level of knowledge transfer is less likely if collaboration is with a public research organization as opposed to a firm. Moreover, it is more likely if the Ph.D. candidate is a former employee of the partner.

Regarding the second outcome, *academic publications* (Table 6, columns 3 and 4), we find no significant relationships.

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 public research organization compared to a firm reduces the likelihood of patents.

Table 6 goes about here

For our fifth outcome variable (Table 6, Columns 9 and 10) we found that *offering job to Ph.D. from partner* is: (a) positively related to the high frequency of meetings between Ph.D. and 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. Regarding the control variables, we observe again that the Ph.D. candidate is more likely to receive a job offer from a partner if the candidate is a former employee and less likely if the university already collaborated with the partner in question.

For the last outcome variable, *following-up of collaboration by a new one* (Table 6, Columns 11 and 12), we found that a high frequency of meetings between both supervisors more often results into a follow-up collaboration. Arguably, this indicates that both sides find each other helpful in solving other problems, which could lead to new collaboration. By adding control variables, we observed that such a follow-up is more likely if the Ph.D. candidate is a former employee of the partner and both partners have a prior mutual relationship. These results show the importance of social proximity in generating the trust and commitment, which in turn inspire to continue collaboration.

4.4. An integrated model

The regression analyses we presented so far on the effect of project management, supervision and communication on project performance, suffer from two limitations. First, each of the analyses assesses the effect of only one set of collaboration dimensions (project management, supervision, and communication). To assess the robustness of the results of the three separate regressions concerning these three dimensions, an additional analysis is required using a full model including all variables. Indeed, the results may change if the management, supervision and communication variables are inter-related in such a way that their joint inclusion would render some effects insignificant. Yet, given the number of observations (N=191), we were compelled to reduce the number of independent variables for such a combined analysis. A second limitation is that some variables, both dependent and independent, are based on the subjective assessment of the Ph.D. candidate in question. Hence, some findings may be based on unobservable individual characteristics (such as ability or personality) and could affect both their engagement in the Ph.D. as measured by collaboration dimensions and the performance outcomes of the Ph.D. project. We aimed to tackle both issues, albeit partially, by constructing an integrated model including project management, supervision and communication variables but excluding those variables most likely to suffer from individual candidate bias. We constructed an integrated model including all independent variables from the three separate analyses, but excluding the independent variables related to decision making, levels of enthusiasm, similarity of opinions, openness and quality of communication. We also excluded the variable supervisor replacement because this is not just collaboration dimension but can also be regarded as a performance indicator. Entering the remaining independent variables in a single model may raise new multicollinearity issues between these variables. With VIF values between 1.055 and 1.638, however, we can safely conclude that the integrated model does not suffer from multicollinearity.

Table 7 presents the regression results of the integrated model. This model includes 11 independent variables plus control variables. By comparing the results of the three separate regressions (Tables 4-6), we found that the significant results in the three previous analyses, remain significant except for three variables. Concerning funding by partner, its positive effect on follow-up collaboration found in Table 4, is still positive but insignificant in Table 7. For what regards the knowledge level of the university supervisor in Table 5, we no longer find any significant effect in Table 7. And finally, the positive effect of a high academic

degree of the partner's supervisor on follow-up collaboration in Table 5, is no longer significant in Table 7.

Table 7 goes about here

Looking at the control variables in the integrated model, we recognize the effects observed before. Co-location in Eindhoven is associated with more patents indicative of a Philips effect. Interestingly, geographical proximity also favors follow-up collaboration suggesting that the Eindhoven region is supportive of long-term relationships. If we look at the difference between collaboration with a Public Research Organizations versus a firm, we find that knowledge is more easily transferred to a Public Research Organization than to a firm, indicative of the benefits of institutional proximity. However, the negative effect of collaboration with a public research organization on patenting in Tables 4 and 6, becomes positive in Table 7. That is, patenting is more likely if a Public Research Organization rather than a firm is the partner. A PhD candidate who previously worked as an employee for the partner, i.e. who is socially proximate to the partner, is better able to transfer knowledge and more likely to get a job offer from the partner after the project. Finally, we find no effect of prior relationships between the university and the partner.

Hence, we conclude that, based on the full model, the main conclusions of the separate analyses remain intact.

5. Conclusions, discussion, and limitations

This paper studied the factors that impact the success of collaborative Ph.D. projects. We did so by three empirical analyses, focusing on potential explanatory success factors related to project management, characteristics of supervisors, and communications, respectively. To test the robustness of our results, we also tested one single model, including all possible success factors. We believe our study contributes to the existing literature, which rarely focused on collaborative Ph.D. projects (Perkmann et al., 2013). And, the few studies done so far mostly compared the outcomes of collaborative Ph.D. projects to non-collaborative projects rather than focusing on understanding success. We believe our study also has significant value for practitioners, as both universities and their collaborative partners may use our results to improve the likelihood of success of their joint projects. The latter is important because (1) there has been an increasing tendency to get involved in university-industry collaboration (Thursby and Kemp, 2002), and (2) collaboration is inherently costly and risky activities for partners (Thomson and Perry, 2006), making it pivotal to maximize the probability of

achieving substantial benefits from the collaboration. In fact, quite a few of the factors we found to impact success in a positive way, are factors that are in the range of control of the partners. In the reminder of this section, we discuss our main findings in relation to the existing literature, and discuss some limitations of our study.

Decision-making. Gemme and Gringas (2004) as well as Wallgren and Dahlgren (2005) suggested that students' experiences are influenced by different collaboration arrangements such as resource exchanges and features of the decision-making process. Our results show that, to promote collaboration success, implementing joint decision-making on the content of the project is appropriate. In fact, involving all partners in this decision-making process not only increases the synergy between them, but also provides a situation in which collaboration partners contribute to determine their responsibilities and roles in collaboration. This allows partners of collaborations to follow and promote their beneficial expectations mutually (see also Artz and Brush, 2000). Regarding the source of project funding, our findings suggest that likelihood of success is increases when the partner organization funds the project (instead of the university).

Supervisor's attitude, supervisor replacement. Our study confirms the earlier findings of Butcher and Jeffrey (2007), among others, that the university supervisor's enthusiasm is one of factors affecting the success of collaborative Ph.D. projects. Our study now adds to this the (not so obvious) finding that this enthusiasm also increases patenting likelihood. This result that both university and their partner should select / look for truly committed academic staff when entering a collaborative project. Furthermore, supervisors in both university and its partner are a vital asset in collaboration (Thune, 2009) and can provide an effective learning environment for the students. Therefore, replacing a supervisor is a challenging issue for every partner during a project, and is best avoided whenever possible. So, should a supervisor leave university, it might be wise to try to agree that he or she will nevertheless continue to supervise the collaborative Ph.D. student. Furthermore, we advise the collaborating partner to oversee the frequency and quality of communication with the Ph.D. candidate during the project. In fact, more frequent meetings facilitate the creation of mutual trust among partners and transferring knowledge (Bouba-Olga et al., 2012). Therefore, this finding emphasizes the importance of frequent face-to-face meetings between Ph.D. candidates and supervisors.

Publication restrictions. Our findings concerning the effects of publication restrictions by partners may warrant additional discussion and perhaps call for future research. Publications restrictions are – as expected – positively related to patenting. But we also find

that they render knowledge transfer more effective. Arguably, restrictions help in this respect, because companies might be more open to absorb and adopt the outcome of the project if they have better changes obtain exclusive rights in its use. Finally, we also find that publication restrictions do *not* negatively affect the likelihood of publication. This is an intriguing and perhaps puzzling outcome. It may be that there is some selection effect: studies with such restrictions may have been more promising in the first place, and have had even more publications if the same study was performed without that restriction. Another possible explanation is that there is a negative effect on the *scope* of publications – making them less valuable or lowering their impact from what it could have been absent the restriction. Since we did not study the scope of publications, this might be a topic for further research.

Previous collaboration experience. Finally, having worked together on similar projects helps partners to achieve a higher level of success. We found that if the Ph.D. candidate is a former employee of the university's partner, (s)he has more chance to be offered a job by the partner after graduation. This result confirms the earlier findings of previous studies (Mangematin, 2000; Mouge´rou 2001), that the industry involvement in PhD projects leads to higher job opportunities. Having experience with collaboration, and partners' differences facing them, also facilitate the success of collaboration (Thune, 2009). Hence, aiming at long-term partnerships rather than one-off projects is likely to pay off. Our study also adds to this finding that if both partners (university and its partner) have a prior mutual relationship, continuation of collaboration in terms of a new project increases.

Our study has several limitations that could encourage researchers to continue work on collaborative Ph.D. projects. One obvious limitation holds that we studied only Eindhoven University of Technology. As a technical university with closely historical links to local industry, results may be to some extent specific to this regional context of Eindhoven. We think more empirical studies are needed to examine the effect of collaboration dimensions on the success of collaborations in other technical universities, as well as other types of universities, to better validate the proposed 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 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). However, gathering sufficient data for statistical analysis is problematic. Alternatively, case studies could be done to include the three perspectives in the analysis. Finally, an open question remains whether the success factors we have determined for collaborative Ph.D. projects also hold for non-collaborative projects. A final limitation is that this study specifically looked at university-industry collaborations in the form of Ph.D. projects. Other forms of collaborations might be quite different, and more diverse in nature. They may last very short or very long (whereas Ph.D. collaborations are always approx. 4 years), they may have large research teams and high level academic staff involved in carrying out the tasks (whereas in Ph.D. collaborations the primary work is always carried out by a single Ph.D. candidate). There may also be selection differences: in some cases (desire for fast answers, very high confidentiality, very uncertain types of research, etc.) companies may chose other forms of collaborations. Hence, our results are not necessarily generalizable to other forms of university-industry collaborations.

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Appendix:

Tables A, B, C, D go about here