How does working on university-industry collaborative projects affect science and engineering doctorates' careers? Evidence from a UK research-based university[1]

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Abstract

This paper examines the impact of industrial involvement in doctoral projects on the particular nature of the training and careers of doctorates. We draw on an original survey of job histories of doctorates in physical sciences and engineering from a research-based university in the UK. Using multivariate probit analysis and linearised (robust) and resampling (jackknife) variance estimation techniques, we found that projects with industrial involvement are associated with higher degree of socialisation with industry. There is some evidence showing that these projects are also more likely to focus on solving firm-specific technical problems or developing firm-specific specifications/prototypes, rather than exploring high-risk concepts or generating knowledge in the subject areas. Crucially, these projects result in fewer journal publications. Not surprisingly, in line with existing literature, we found that engaging in projects with industrial involvement (in contrast to projects without industrial involvement) confers advantages on careers in the private sector. Nevertheless, there is also a hint that engaging in projects with industrial involvement may have a negative effect on careers in academia or public research organisations. While acknowledging that the modelling results are based on a small sample from a research-based university and that therefore the results need to be treated with caution, we address implications for doctorates, universities and policymakers.

Keywords science and engineering; doctoral students; careers; knowledge transfer; university-industry relations; scientific productivity

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1. Introduction

The rise in university–industry collaborations has drawn attention to the changing nature and dynamics of academic knowledge production (Gibbons et al., 1994; Stoke, 1997). Debates tend to centre around the balance between basic and applied research, the governance of resulting intellectual property and the quality of scientific outputs from university-industry collaborations (Blumenthal et al., 1997; Campbell et al., 2000; Geuna & Nesta, 2006; Gluck et al., 1987; Hong & Walsh, 2009; Kenney, 1987; Wash et al., 2007). A particular strand of literature focuses on the academic scientists involved in university-industry collaborations, including their motivations (Lam 2011), different norms (Shibayama, 2012; Tartari & Breschi, 2012), determinants of funding success and commercial activities (Aschhoff & Grimpe, 2014; Chang et al., 2009; Melkers & Xiao, 2012), the nature of their research (Goel & Grimpe, 2012; Landry et al., 2006; Landry et al., 2010) and their scientific productivity (Abramo et al., 2012; Ambos et al., 2008; Calderini et al., 2007; Chang & Yang, 2008; Estabrooks et al., 2008; Gulbrandsen & Smeby, 2005; Haeussler & Colyvas, 2011; Louis et al., 2001; Shibayama, 2012; Van Looy et al., 2004). Overall, the evidence points to positive impacts of university-industry collaborative activities on the careers of academic scientists. There is some agreement that the most able academics are successful at conducting both traditional research and activities with industry involvement. Indeed, although academic researchers involved in university-industry collaborations may find a clash of expectations for practical applications from industrial partners and their own expectations of scientific excellence, they can bridge this gap in expectations by building broad research portfolios (Estabrooks et al., 2008; Gulbrandsen & Smeby, 2005; Haeussler & Colyvas, 2011; Louis et al., 2001; Lowe & Gonzalez-Brambila, 2007; Van Looy et al., 2004; Siegel et al., 2007).

Nevertheless, the focus on faculty members´ research and careers rather on the particular research projects they undertake can obscure some important aspects of knowledge production. This is because faculty members can be engaged simultaneously in projects with industrial involvement and in projects without industrial involvement. Also, this focus obscures the effects on other parties involved in the research projects, such as doctoral students, for whose careers the changing nature of knowledge production and funding may have very important implications. While faculty members will be involved in several projects, doctoral students are typically engaged in only one project. Furthermore, in science and engineering (S&E), doctoral students´ research is more or less directly tied to supervisors' grants. Faculty members build their research portfolios through obtaining grants from various sources. As scientific experiments are labour intensive and often involve much tacit knowledge, supervisors often play the role of directing the projects, rather than conducting them, and doctoral or post-doctoral students directly conduct the research as part of their training. Also, scientific equipment is expensive and scientific expertise is highly specific. It is likely that the doctoral students´ work will draw almost exclusively on the equipment and specific expertise embedded in a particular laboratory and research team. Therefore, the changing nature of knowledge production and industry involvement will have profound impacts on doctoral students and their training. While some studies show that engagement in projects with industry involvement helps smooth transitions of doctoral students from academia to industry (Dany & Mangematin, 2004; Giret & Recotillet, 2004; Mangematin, 2000; Martinelli, 1999; Robin & Cahuzac, 2003), less is known about which aspect of university-industry collaborations might contribute to that advantage. Moreover, there is little knowledge of how doctoral students' ambitions to pursue careers in academia or other public sector organisations may be affected if they engage in projects involving industry.

We draw on an original survey of job histories of doctorates in the fields of physical sciences and engineering from a research-based university in the UK. By studying job histories of doctorates, we are able to assess the effects of the nature of doctoral projects not only on those who eventually have a career in the private sector, but also on those who eventually become academics or work in the public research organisations. Using multivariate probit analysis and linearised (robust) and resampling (jackknife) variance estimation techniques to triangulate the findings, we found that projects with industrial involvement are associated with higher degree of socialisation with industry. There is some evidence showing that these projects are also more likely to focus on solving firm-specific technical problems or developing firm-specific specifications/prototypes, rather than exploring high-risk concepts or generating knowledge in the subject areas. Crucially, these projects result in fewer journal publications. Not surprisingly, in line with existing literature, we found that engaging in projects with industrial involvement confers advantages on careers in the private sector. However, there is also hint that engaging in projects with industrial involvement may have a negative effect on careers in academia or other public sector organisations. We acknowledge that the modelling results are based on a small sample from a research-based university and that therefore the results need to be treated with caution. Nonetheless, the exploratory research points out several directions for further research to enhance our understanding of the dynamics of university-industry collaborations. Policy implications for doctorates, universities and policymakers are addressed.

The paper is organised as follows. Section 2 and 3 review existing literature on the various attributes of university-industry collaborative research and careers of S&E doctorates. Section 4 outlines data and methods. Section 5 presents the results. Discussion and conclusions follow in Section 6.

2. Attributes of university-industry collaborative research

The period since the early 1990s represents a time of major changes in science policy. In the case of the UK, the science policy agenda change reflected in the 1993 White Paper "Realising Our Potential" (HMSO, 1993) outlined that public science should contribute to wealth creation through closer links to industry. Academic researchers considered to be operating in the ivory tower were asked officially to identify potential users of their research output and channels of knowledge transfer when submitting projects to research councils and other grant funders. Similarly, the Sainsbury's Science and Innovation Investment Framework 2004-2014 explicitly stated that to achieve the ambition of the UK's public funding in science and innovation, publicly funded academic research would be "*strongly influenced by and delivered in partnership with end users of research*" (HM Treasury, 2004, pp.6). To further realise this ambition, in the 2014 Research Excellence Framework, UK academics' research "impact" beyond academia will be explicitly evaluated.[2] At the same time, this period has also seen the emergence of more "open" approaches to innovation by firms, with many firms opening up their boundaries to access external sources of knowledge and technology (from other firms but also from university) and bringing innovations developed in-house to market through external organisations (Chesbrough, 2003).

Scholars from different countries and from different theoretical backgrounds see the growing policies that foster interactions between universities and industry in different ways. Literature on knowledge production has come to recognise that universities play a key role in the systems of innovation (Freeman, 1987; Lundvall, 1992; Nelson, 1993). This has provided, at the policy level, the rationale for encouraging universities to contribute to national competitiveness through broader interactions with external and diversified organisations, particularly direct interactions and collaborations with industry (Larédo, 2007). Others argue that university-industry collaborative research represents a new mode of knowledge production (Gibbons et al., 1994), which operates in a context of application, in which problems are set in an interdisciplinary framework and is carried out in collaboration by non-hierarchical groups and not exclusively in the context of universities. This is also seen as facilitating a trend

[2] The allocation of UK higher education core funding is based on the number of students and the performance of the competition based Research Excellence Framework (REF), which was first introduced in 1985. Details of how the impact beyond academia will be assessed in the 2014 REF are outlined in the REF website: http://www.ref.ac.uk/media/ref/content/researchusers/REF%20guide.pdf.

to develop basic research that seeks to extend the frontiers of understanding but is also inspired by considerations of use (Pasteur's quadrant) (Stoke, 1997). Some indicate that while many welcome the extra resources and theory-testing benefits associated with industrial projects, academics who see the "Mertonian" norms of open science (Merton, 1973) as the main responsibility for academic research might be reluctant to engage in research collaborations with industry (Haeussler & Colyvas, 2011; Tartari & Breschi, 2012). In any case, there is a consensus that the call for academic research to draw more attention to application and to the transfer of the research to serve social and economic needs (and in the particular context of the UK, the focus on "impact") has become formal and institutionalised (Lawton Smith, 2006; Larédo and Mustar, 2004). Given the increasing trend in university-industry relations, and in particular, the involvement of industry in academic (and especially doctoral) research projects, our expectation is that the nature of academic research projects will differ between those with and without industrial involvement. This difference may be largely accounted by a number of attributes, namely, industrial relevance, research productivity and social networks, which we describe below.

2.1. Industrial relevance

We have seen a rise in university-industry collaboration, which can comprise a range of activities, from direct academic research commercialisation such as university spin-off companies and licensing of university held patents, to technical consultancy by universities, with academics conducting contract research commissioned by firms to solve specific technical problems independently, by means of joint research with firms, or by the creation of research consortia targeting more general industry-related problems so that a whole group of companies/members can benefit from the research outcome. These activities may be associated with different outputs. For instance, Landry and colleagues (Landry et al, 2007; Landry et al, 2010) found that the lower the novelty of research, the more likely it is associated with consulting activities and that the higher the novelty of research, the more likely it leads to scientific publications. With the emergence of these different university-industry collaborations, we also witness the emergence of what are called "entrepreneurial academics", academics who do not necessarily want to set up their own venture, but who follow alternative paths (other than grants from research councils and other charitable or public bodies) to pursue their research interests (Meyer, 2003).

This is in line with literature on incentives behind different collaborative activities. Perkmann and Walsh (2009) found that, for projects initiated purely by firms, the objectives of such research are generally to "seek a solution to a technical problem arising within a firm's R&D, manufacturing or other operations", to "develop design significations or prototypes for new or improved products or processes, or to "provide advice on R&D projects and develop projects pursued within firms". The objective of "exploring a high-risk concept on behalf of a firm – outside the firm's main stream activities" is generally initiated by both academia and industry. On the other hand, the objective of "generating knowledge in general - carrying out research on topics of broad interest to a firm"- is often mainly the interest of academics. Given that the academic reward system highlights the importance of scientific publications, academics would be more likely to initiate university-industry collaborative projects that also have greater publication potential.

Similarly, Schmoch (1999) reported that, in Germany, firms prefer to initiate collaborative contract research that is short-term, with specific and foreseeable results. Furthermore, such research is normally characterised by one-way knowledge transfer from academia to industry. In contrast, professors prefer collaborative projects with potential for two-way knowledge transfer and that are funded through the programmes of the Federal Ministry for Science, Education, Research and Technology (BMBF) or European Commission Framework programmes. Based on an analysis of 46 university-industry collaborations in several European countries, Carayol (2003) also showed that industrial partners usually prefer research with lower risk and with higher potential for developing concrete applications within a reasonable time frame. Even when firms decide to go for risky research, the rationale for this still lies in the potential applicability of the research into their product or process development. By contrast, academics often try to exploit synergies between industrial partners' and their own research agendas. Carayol (2003) suggested that the balance may depend on the distance between the academics' own research and their industrial partners' research objectives (i.e. how basic or applied the academics' research is). These contributions therefore suggest that projects with and without industrial involvement may have different objectives. Consequently, we would expect projects with industrial involvement to be more industrially relevant.

2.2. Research productivity

University-industry collaborations involve the collision between two different worlds, where different norms and practices prevail (Sauermann & Stephan, 2013). While the world of science is governed by search for first principles, emphasis on robust methods, peer review, reputation and openness, the world of business is driven by the intention to develop commercially feasible products and processes, search for profits, secrecy and knowledge and value capture to gain market competence and market share (Kenney, 1987; Pisano, 2006). Therefore, when there is industry involvement in academic research, academic researchers might be requested by firms to delay scientific publications in order to secure patent applications (Blumenthal et al., 1997; Geuna & Nesta, 2006; Gluck et al., 1987), or might not be allowed to conduct scientific communication regarding the content of the commissioned research to appropriate otherwise that investment (Gluck et al., 1987). Indeed, Chang and Yang (2008) showed that when scientists themselves are involved in licensing, they delay the disclosure of their research. Hong and Walsh (2009) found that industrial funding is positively associated with academics' feeling of not being able to have free scientific communication. Walsh et al. (2007) also showed that academics' commercial activities resulted in restricted access to research materials, data and unpublished information. Interestingly, academics with histories of commercial activities are more likely to be denied access to scientific data and information by others (Campbell et al., 2000), perhaps due to the fact that these entrepreneurial academics do not share knowledge freely with others. This implies that research dissemination may be harmed by industrial involvement, as researchers' publications might potentially be delayed or limited through contractual agreements with industrial partners or due to their own direct commercial activities. A study by Thune (2010), however, based on 25 interviews of doctoral students working in projects with industrial involvement, showed that there was no evidence that these students encountered publication delay or problems with intellectual property rights.

Other studies show a positive relationship between university-industry collaborations and academics' scientific productivity. Estabrooks et al. (2008), Gulbrandsen and Smeby (2005), Louis et al. (2001), Van Looy et al. (2004) and Haeussler and Colyvas (2011) reported that academics that receive industrial funding are as productive as or even more productive than those who do not. Others show that entrepreneurial academics are in general more productive in terms of publication rates and impact of publications (Abramo et al., 2012; Chang & Yang, 2008; Lowe & Gonzalez-Brambila, 2007). They are also more likely to obtain further research funding (Melkers & Xiao, 2012). Indeed, research has shown that industry is more inclined to work with academics that already have a good track record in securing research grants (Link et al., 2007). There is also evidence of great heterogeneity in the productivity of academic research with industrial involvement. For instance, Calderini et al. (2007) reported that scientists in the applied fields are more likely to patent than in theoretical fields. Ambos et al. (2008) also found that scientists in UK departments with higher scientific excellence (based on the UK research assessment result) have higher likelihood of commercial output (a patent, a licence or a spin-off company) from collaborative projects with industry. Academics with strong personal motivations and commercial links are more likely to be involved in patenting, licensing or academic spin-offs (Chang et al., 2009).

That is, industry tends to pursue academics in prestigious departments/universities and in the fields that are more likely to produce research with useful applications. This may explain why scientists who fall in these categories may be more productive scientifically and commercially. There is little empirical evidence at project level, however, as to whether projects with industrial involvement are as scientifically productive as projects without industrial involvement. It is thus unclear whether different levels of scientific productivity may be expected between projects with and without industry involvement.

2.3. Social networks

Scientists with greater social network assets are more likely to achieve higher commercial productivity (Grandi & Grimaldi, 2003; Harvey et al., 2002; Landry et al., 2006; Landry et al., 2010). Harvey et al. (2002) stressed the role of strong leadership in their research on high performing medical and medical-related research groups in the UK universities. One of the most important functions of research group leaders is to provide network connections within the research community and with practitioners, both to access resources and trustworthy research partners. Therefore, Grimpe and Fier (2010) found that German academics who are group leaders are more likely to be involved in commercial activities. Harvey et al. (2002) also showed that departments with strong external connections through their key players place themselves better in the “mode 2” (Gibbons et al., 1994) environment. Similarly, Grandi and Grimaldi (2003) found that, while new ventures’ external connections are regarded as a key determinant for success, academic spin-offs’ intensity of external connections is positively associated with that of the academics’ original research groups. This shows the network contribution of the original research groups to the academic spin-offs. Landry and colleagues also showed that academics with greater network assets (connections with private firms, government departments and university media relations/public affairs offices) result in greater commercial knowledge transfer activities in patenting, in spin-offs and particularly in consulting (Landry et al., 2006; Landry et al., 2010). Network assets may also be an important determinant of successful university-industry collaborative research. Niedergassel and Leker (2011) found that close contact and relationship between academics and industrial partners is associated with success of project outcome of university-industry collaborative research.

Aiming at a smooth knowledge transfer from successful university-industry collaborative research, industrial partners might also take advantage of the social networks built through the collaboration to further acquire human resources involved in the projects. Indeed, based on in-depth interviews, Lam (2007) demonstrated how private firms access strategically the young bright candidates through collaborations with academia. Sometimes earlier industrial links for doctorates with industrial projects has wider impacts. The 2003 UK PPARC survey of the Council funded doctorates (DTZ Pieda Consulting, 2003) revealed that, among the respondents who reported that their sponsorship had been the CASE studentship, a UK Research Councils' scheme where research students working for a doctorate in collaboration with an industrial partner, 6-8 years after graduation, 20% were still working with the organisations that sponsored them, and 40% had continued to have collaborations with their sponsors. Indeed, Fritsch and Krabel (2012) also found that German PhD students who cooperate with industry are more likely to show their preference for working in the private sector.

Thus, there is evidence in the literature that faculty members who have greater social network assets are more successful in building collaboration with industry. Industry seeks academic knowledge and talent through these links. Doctoral students and post-doctoral researchers might benefit form training through projects with industrial involvement as it may provide them with earlier industrial contact that might not only be useful for their initial employment, but also have positive effects throughout their careers.

3. Research training in the university-industry interface

Doctoral training has always been one of the vital aspects of higher education. Doctoral researchers are, one the one hand, producing academic knowledge, and, on the other hand, receiving research training as competent researchers. Their research training and hence competences are often defined through the doctoral research projects.

The nature of doctoral research is closely linked to the funding mechanism of academic research. Any change in science policy could redefine the landscape of doctoral research projects. Returning to the UK case, the changes reported in section 2 above are also reflected in changing views on academic training. The 1997 Dearing Report[3] (HMSO, 1997) clearly stated the need to replace the rationale for academic research training in order to "*promote the power of mind…*" or to "*search for truth…*" (pp. 71) outlined in the earlier White Paper on higher

[3] The Dearing Committee was appointed by the government to make recommendations on how the purposes, shape, structure, size and funding of higher education should develop to meet the needs of the United Kingdom for the next 20 years (HMSO, 1997).

education, i.e. the 1963 Robbins Report, with objectives to "*increase knowledge and understanding both for their own sake and for their practical applications"* to *"serve the needs of a knowledge-based economy"* (pp. 72).

Thus, in parallel with the discussion of how academic research with industrial involvement might affect the nature of academics' research, policy emphasis on fostering university-industry collaboration and impact on users affects doctoral students' projects. In science and engineering, academics who have greater industry involvement also support more post-graduate students (Bozeman & Boardman, 2013). While faculty members progress hand in hand with their collaboration with industry, less is known about how the interface of university-industry collaborations affects the future of doctoral students. Doctorates are special types of academic personnel as many will go to industry after graduation, enabling direct knowledge transfer from academia to industry (Mangematin, 2001). However, they may also continue to pursue academic careers. This means that doctoral research training must meet the dual challenge of preparing future academics and industrial scientists at the same time.

For those who enter industry, doing projects that involve industry may help for a smooth transition to employment in industry. The open innovation rationale for academic research has been widely adopted and many studies in different countries reported its usefulness for the career outcome of S&E doctorates in the private sector (Dany & Mangematin, 2004; Giret & Recotillet, 2004; Mangematin, 2000; Martinelli, 1999; Robin & Cahuzac, 2003). It is argued that research labs' competences have direct influence on doctoral students' competences and hence their careers. For instance, Dany and Mangematin (2004) pointed out that French life science doctorates from research labs that are well connected to industrial and academic communities have an advantage in private research careers. Mangematin (2000) showed that in physical sciences, doctoral students with projects without industrial collaborations are less likely to be in private sector research positions. Similar results also appear in the study of Giret and Recotillet (2004), where they showed that doctoral students sponsored by the French CIFRE grant (Industrial Agreement for Training Through Research, the French Ministry of Research's attempt to foster collaborations between universities and firms to train young doctorates to meet the needs of the private firms) are more likely to be employed in the private sector and to earn higher salaries. In line with all these studies, Martinelli (1999) reported that French doctorates who were sponsored by CIFRE programme not only received higher pay, but were also more likely to get permanent positions and less likely to be unemployed. Using survival analysis, Robin and Cahuzac (2003) found that doctoral research in partnership with industry increases the propensity of gaining open-ended contracts in the private sector for French doctorates in life sciences. There is also evidence showing successful job transitions from academia to industry in the UK's "Power Academy", where graduates are sponsored by power companies to bridge the knowledge gap between academia and industry (Bell et al., 2012).

In line with existing studies, our expectation is that doctoral students who are involved in research projects without and those who are involved in research projects with industrial involvement are provided with different kinds of academic research training. Consequently, they leave university with different skills for their careers. Our study intends to unfold the many aspects of university-industry collaborative projects and explores the specific features that facilitate (or hinder) the career advantage of doctorates. In particular, this study examines the impact of university-industry collaborative research on S&E doctorates who actually wish to pursue a career in the public sector, an aspect that is rarely discussed in the existing literature on university-industry collaboration. Using novel data based on individual doctorates' research projects and their job histories, this paper addresses the questions of whether there is empirical evidence on differences in academic training between doctoral students involved in projects with and without industrial involvement and how the difference may confer advantages or disadvantages to S&E doctorates for careers in the private and the public sectors.

4. Data and methods

The research setting is a UK research-based university, the University of Manchester. The University of Manchester is among the top universities in the UK in attracting industrial funding, government funding, EU funding and the highly privileged UK Research Council EPSRC funding (around 25% of the University's total income in 2009/2010 is from contract research). Its high dependence on contract research means the shift in funding rationale should be well reflected in its faculty members' research profiles. Moreover, it is one of the leading research universities in the UK (ranked as the third place in the 2008 UK research assessment in terms of the number of full-time equivalent staffs that are judged to be "world leading" or "internationally excellent").[4] Its leading position in research means that it is at the centre of the on-going debate over the changing context of science and makes it an excellent example to examine the impact of industrial involvement in academic (doctoral) projects. A survey on doctoral training and retrospective employment history of doctorates (covering

[4] Data from The University of Manchester Facts and Figures 2009; on-line available at: http://www.manchester.ac.uk/medialibrary/aboutus/facts_figures.pdf

7-10 years employment history) was conducted between April and July 2008. The sampling frame is a list of doctoral students graduated during the period 1998-2001 by the University of Manchester in physical sciences and engineering disciplines[5] with UK and other EU addresses. The advantages of using such sampling frame are:

1. Each doctorate represents a research project. By looking at doctoral projects, we are using each "project" as an analysing unit. Attributes of projects associated with university-industry collaborations could thus be measured directly. This measure is an advantage in analysing attributes of university-industry collaborations when compared to other studies that use measures such as the individual academic as an analysing unit, as an individual academic could be involved in different projects funded from various sources at the same time.
2. By tracing career histories of doctorates, we are able to have a longitudinal view of the effect of being involved in projects with industrial involvement on doctorates' careers. This approach is more powerful than a simple cross-sectional analysis.

A postal survey strategy was applied. With the help of the alumni office, a total of 512 questionnaires were sent to UK addresses and 84 to other EU addresses. A self-addressed return envelope with a stamp was provided for each UK address and without a stamp for each other EU address. The strategy of using the postal survey method, rather than interviews, was due to the UK 1998 Data Protection Act, which does not allow direct access to alumni information for researcher. The survey resulted in a total of 91 UK and 11 other EU responses. Excluding 38 UK and 7 other EU undelivered returned questionnaires, the survey is estimated to have response rates of 19.20% for UK addresses and of 15.3% for other EU addresses. The overall response rate is 18.51%. Taking into the account the fact that these doctorate graduates have left the University for 7-10 years and, and as young people are particularly mobile, the exact response rate should be higher. Non-response bias is assessed and no significant bias is found.[6] After missing data are excluded, 101 valid responses are used for factor analysis and 92 valid responses are used for the rest of the analysis.

[5] PhDs graduated between 1998 and 2001 from the Faculty of Engineering and Physical Sciences were surveyed. Subject areas include chemical engineering and analytical science, chemistry, computer science, earth, atmospheric and environmental sciences, electrical and electronic engineering, materials, mathematics, mechanical, aerospace and civil engineering and physics and astronomy.

[6] Details in Lee et al. (2010).

The analysing method is the recursive multivariate probit model. The reason for choosing this model is that it is ideal for estimating a discrete choice model with more than two alternatives. That is, in our case, after leaving doctoral training, in their 7-10 years of working life (see definition of jobs in Appendix A), respondents may experience promotion (to or within) the private sector (P_1), promotion (to or within) the public sector (P_2) or both. Public sector comprises positions in universities (majority), government departments and other public sector organisations. These different types of promotion opportunities are the dependent variables. Since the objective of the study is to assess the impact of doing projects with industrial involvement on their careers, whether doctoral projects have industrial involvement or not (I) is an explanatory variable. Moreover, from the literature, it is also understood that a project with industrial involvement may be associated with a set of variables that characterise industrial projects (X_3). Therefore, the model specification is as follows:

$P_1^*= \beta_1 X_1+\gamma_1 I+\varepsilon_1$; $P_1=1$ if $P_1^*>0$ and 0 otherwise

$P_2^*= \beta_2 X_2+\gamma_2 I+\varepsilon_2$; $P_2=1$ if $P_2^*>0$ and 0 otherwise

$I^*= \beta_3 X_3+\varepsilon_3$; $I=1$ if $I^*>0$ and 0 otherwise

That is, $P_1=1$ indicates that promotion to or within the private sector is experienced. $P_2=1$ indicates that promotion to or within the public sector is experienced. Similarly, $I=1$ indicates that doctoral training has industry involvement. The first two equations, outcome of promotion, are structural equations with projects with industrial involvement as an explanatory factor. The third equation, projects with industrial involvement, is modelled as a reduced form equation.

X_1 and X_2 represent a set of constant variables (as control variables) and they are the number of journal publication from the doctoral project, gender, discipline, and the geographical location of respondents' given addresses. Also, classical discussions on career outcome of scientists emphasise the effect of success orientation. It is suggested that those who are scientifically-oriented are more likely to be satisfied by their contribution to the scientific community and view this as success, while those who are commercially-oriented are more likely to pursue a managerial career in order to gain greater power, influence, financial rewards or higher status (e.g. Allen & Katz, 1986, 1992). For public sector research institutions including universities, Mallon et al. (2005) also found a clear distinction between UK scientists who mainly enjoy the passion for research and those who strategically plan their careers for progression. Therefore, success orientation is used as a control variable for career outcome. X_3 represents a set of variables that might characterise projects with industrial involvement. These variables include industrial relevance of the doctoral project, social network dimensions of the project and the number of journal publication from the doctoral project. A potential underlying factor that affects students' choice of projects might be due to their difference in success orientation. That is, those doctorates that went for projects without and those who went for projects with industrial involvement may be qualitatively different in their success orientation. Commercially-oriented students may be more likely to choose projects with industrial involvement because of their greater interest in useful commercial applications. Thus, measures of success orientation are also added in this equation as they may affect a doctorate's choice of project. Additional considerations for the recursive multivariate probit model is followed by having at least one of the exogenous variables in the reduced form equation excluded from the structural equations (Maddala, 1983).

β_1, β_2, β_3, γ_1 and γ_2 are unknown coefficients to be estimated. ε_1, ε_2 and ε_3 are error terms that are joint normally distributed with means of zero and variance-covariate matrix V, where V has the values of 1 on the diagonal and non-zero off-diagonal elements ρ_{12}, ρ_{13} and ρ_{23} (where $\rho_{12}=\rho_{21}$, $\rho_{13}=\rho_{31}$ and $\rho_{23}=\rho_{32}$). This means that the multivariate probit model allows error terms ε_1, ε_2 and ε_3 to be correlated. Although the above three probit regressions might be modelled separately as independent equations, the estimated coefficients might be inconsistent because the correlation between error terms has not been taken into account (Maddala, 1983).

For each year of the respondent's working history, information about whether the respondent got promoted and about the respondent's working sector was given. Therefore variables of whether a respondent has ever experienced promotion to or within the private sector (yes=1; no=0) or promotion to or within the public sector (yes=1; no=0) can be derived. They are meaningful measures for career outcome (i.e. whether the respondents have experienced any promotion since graduation) in that around 42% of the respondents had never encountered any job promotion at all at the time of survey. Questions about each respondent's doctoral project and training such as whether the project had industrial involvement (yes=1; no=0), industrial relevance of the doctoral project, the number of journal publications, the number of meetings with/presentations to industry and whether the laboratories that respondents were working in had any contact with industry were asked. Industrial relevance of the doctoral project is a constructed variable. Adopting measures by Perkmann and Walsh (2009), we asked respondents whether their projects focus on the goal of "seeking a solution to a specific technical problem identified within a firm's or a group of firms' operations", "developing design specifications or prototypes for new or improved industrial products or processes", "generating knowledge on topics of broad interest to Doctorate subject area" or "exploring a high-risk concept identified by a firm or a group of firms – outside the firms' mainstream activities". The first two categories ("seeking a solution…." and "developing design…") can be regarded as objectives with direct industrial relevance, while the latter two categories ("exploring a high-risk concept…" and "generating knowledge…") are more distant from the market and have low industrial relevance. We also adopted Allen and Katz's (1992) measures of scientists' success orientation. The measures comprise six types of experiences and respondents were asked to score from 1 (the least) to 4 (the most) the extent to which each of the six experiences provides them with a sense of success. The six types of experiences are: 1) contributing to a product of high commercial success, 2) publishing a paper which adds significantly to the technical literature, 3) developing concrete answers or solutions to important technical problems, 4) developing new theoretical insights or solutions, 5) contributing to a product of distinctly superior technical quality and 6) coming up with a highly innovative idea or solution. Factor analysis (using principal component factors as the factor extraction method) shows that two main factors with eigenvalue greater than 1 are identified and these two factors alone explain 68% of the variance. For the two factors, one corresponds to commercial-orientation and the other corresponds to scientific-orientation; the results are fully in line with that of Allen and Katz (1992). Factor analysis results are shown in Table 1. That is, two latent variables that represent respondents' success orientation towards commercial success or scientific success are constructed through factor analysis. Demographic information such as gender, doctoral subject area and location (UK or other EU) was also included in the questionnaire. Description of variables and descriptive statistics are in Table 2 (see correlation in Appendix Table B).

Table 1 and 2 here

To ensure the robustness of the model specification, further considerations are taken. First, we explored the influence of prior working experience before doctoral training on doctoral students' career choice between the public and the private sectors after the completion of doctoral training (e.g. Fritch and Krabel, 2012). Nevertheless, we found that the average age of our respondents when they completed their doctoral training is 27.5 and therefore had limited work experience. We also found that there is no difference in the completion age between those who entered the private sector and those who pursued the public sector for their first jobs.

Secondly, we explored the impact of different types of projects with industry involvement. Out of the projects with industrial involvement, 68% were joint research with industry, 20% were projects solely commissioned by industry and the remaining 12% were projects founded through an industrial consortium. None of our respondents reported that their projects were associated with university spin-offs. This implies that collaborative research between individual academics and a single industrial partner on a specific project appeared to be the dominant mechanism that provided the respondents with their research training. Long term collaboration between university departments and industry through an industrial consortium was not a significant channel for doctoral training. For this reason, the variable of projects with industrial involvement is not further divided into detailed types of projects.

Thirdly, studies have suggested that research groups' leadership may affect academic scientists' careers or collaboration in the private sector (e.g. Fritsch and Krabel, 2012). While the number of years in tenure does not affect academics' commercial activities, industry is more likely to work with tenured academics and group leaders for knowledge transfer (Grimpe and Fier, 2010). In the UK context, however, the organisation of academic research groups is often quite organic. Each faculty member establishes his/her own research group through the appointment of doctoral students and postdoctoral fellows. Normally only the faculty members, and thus, the group leaders, who are also most likely to be tenured, are able to apply for research funding. As our analysing units are doctoral projects, and each doctoral project is supervised by a faculty member who effectively is also the group leader, this means that in our study, all the doctoral projects are supervised by group leaders. Therefore, we do not assess specifically the effect of group leadership.

Finally, it is suggested that the contribution of academic research to small and medium enterprises (SMEs) needs special consideration (Meyer, 2003). It is possible that in our model, the effect of the heterogeneity of firms with which academics collaborate is overlooked. However, following the conceptual framework developed by Perkmann and Walsh (2008), we assume that if the objectives of academic collaboration with industry are for specific problem solving, the projects are likely to be relatively more short-termed and associated with SMEs. On the other hand, if the objectives are research-driven and aiming at general knowledge production, the projects are likely to be more long-term and associated with larger firms. Therefore, the effects of collaboration with different sized firms on research projects are likely to be captured by our survey question that asked respondents about the goals of their research projects and is used to construct the variable about projects' industrial relevance. Hence, overall, we can conclude that the result of further considerations taken to assess the robustness of the model specification is satisfactory.

The estimation is executed through the STATA's mvprobit command that applies the simulated maximum likelihood (SML) using the Geweke-Hajivassiliou-Keane (GHK) simulator to estimate the joint multivariate normal distribution. Increasing the number of draws for the GHK simulator reduces simulation bias and increases accuracy of the results (Cappellari & Jenkins, 2003). Due to the small sample of the study, we carry out the modelling using draws of 100 and 150 to ensure that the estimations are consistent. Robust and jackknife standard errors are estimated and intra-cluster correlations are taken into account. The analysing tool is STATA® 10.

5. Empirical findings

The modelling results are illustrated in Table 3. We use GHK simulator with draws of 100 and 150 and the results are consistent. The results of draws of 150 are reported as the model is a better fit (lower AIC). The three estimated equations result in three correlation coefficients ρ_{12}, ρ_{13} and ρ_{23}. There is significant evidence rejecting the null hypotheses that ρ_{12} and ρ_{23} are zero (robust estimation), or $\rho_{12,}$ ρ_{13} and ρ_{23} are zero (jackknife estimation). This confirms that three equations are stochastically dependent. This also implies that modelling the three equations separately as if they were independent would lead to inconsistent estimations. Key findings are as follows.

Table 3 here

5.1. Doctoral projects with industrial involvement confer social network advantage

Table 3 shows that doctoral projects with industrial involvement might be associated with research objectives that aim at solving firm-specific technical problems or developing firm prototypes or specifications; that is, these projects are more industrially-relevant. What makes industrial projects different is that doctorates doing these projects are a lot more likely to have close interaction with industry through meetings and presentations during their doctoral training. It is also more likely that these doctorates will be working in labs that already have contact with industry. This confirms that social networking with industry during doctoral training provides opportunities for doctoral students to familiarise themselves with the industrial environment and working practices of industry and may consequently lead to a smoother transition to a career in industry.

Not surprisingly, respondents who were engaged in projects with industrial involvement experienced on average six meetings/presentations with industry, while such interaction was almost non-existence for those who engaged in projects without industrial involvement. Furthermore, we also asked whether respondents' labs had any connections with industry and whether they used such contact to get their first jobs. 73% of our respondents reported that their labs had some sort of connections with industry; this implies that about half of the doctoral students engaged in projects without industrial involvement worked in the labs where their supervisors conducted other work with industry. 12.5% of doctortal students engaged in projects with industrial involvement and 6.8% engaged in projects without industrial involvement reported that they used the connections that their labs had to obtain their first jobs. This indicates that as long as the labs have connections with industry, the propensity of using existing lab's industrial connections to find the first job may be similar for both groups of doctoral students. However the difference is that by definition, being engaged in a project with industrial involvement means working in a lab with industrial connections, while this is not necessarily the case for projects without industrial involvement. Therefore, although not the most common channel to obtain first jobs, being engaged in projects with industrial involvement seems to increase the chance of securing first jobs through such connections. Furthermore, there is evidence that the influence of interaction with industry during doctoral training does not end with finding first jobs but has a more profound effect. We asked whether the respondents had ever worked or collaborated with their doctoral labs' industrial contact since graduation. Around 31% of those who were engaged in projects with industrial involvement said yes, while the figure for those who were engaged in projects without industrial involvement was 11%. While these figures do not answer directly why working with industry during doctoral training enhances promotion in the private sector, however, they provide interesting insights of the social network advantage that is associated with doctoral training with industrial involvement.

5.2. Doctoral projects with industrial involvement have reduced scientific productivity

What also marks projects with industrial involvement is the reduced number of journal publications resulting from those doctoral projects (see also Figure 1 graphical presentation). There could be many possible reasons for this. An obvious explanation is that the projects with industrial involvement may be designed to solve specific industrial problems and therefore the research results from these projects may be less publishable. Our modelling results show some evidence, but not conclusive, that projects with industrial involvement are more likely to aim at solving firm-specific technical problems or developing firm prototypes or specifications. Another hypothesis is that those who decided to do projects with industry involvement might be less scientifically-oriented and more commercially-oriented and thus produce fewer journal publications. The hypothesis however is rejected as the modelling results show that there is no significant association between project choice and individual success orientation. A further plausible hypothesis is that respondents who were engaged in projects with industrial involvement might be requested by industrial partners to delay publications from their doctoral projects to allow for patents. If this was the case, the reduced scientific productivity associated with projects with industrial involvement should be accompanied with an increase in commercial productivity, such as patents. However, only two respondents engaged in projects with industrial involvement and one respondent engaged in a project without industrial involvement reported that they obtained patents from their doctoral training. There is no evidence to support this hypothesis. It is well acknowledged that not all firms will pursue patents to protect their intellectual property. Notably firms often try to exercise secrecy, i.e. to prevent know-hows from leaking out of the firms rather than publish them for temporary monopoly rights (e.g. Arundel, 2001 and Cohen et al., 2000). Hence one further direction open for exploration is the extent to which projects with industrial involvement may restrict open scientific communication due to secrecy exercised by industrial partners or by the academics themselves.

Figure 1 here

5.3. Doing projects with industrial involvement confers advantage in the private sector but there is continuing value attached to scientific productivity in the public sector

With the advantages of earlier socialisation with industry and possibly also more firm-specific knowledge, modelling results reveal that compared to doctoral students engaged in projects without industrial involvement, doctorates who were engaged in projects with industrial involvement are more likely to have at least one promotion in the private sector (see also Figure 2). On the other hand, there might be evidence, though not conclusive, implying that doctoral training connected to projects involving industry has a negative effect on promotion in the public sector (see also Figure 3).

Also, what is valued and hence affects promotion in the public sector appears to be the number of journal publications resulting from doctoral training (Figure 3). Indeed, the propensity of experiencing promotion in the public sector increases as the number of journal publications resulting from doctoral training increases. Furthermore, bearing in mind that our regression model is recursive and nonlinear, the number of journal publications would have a further indirect effect on respondents' promotion propensity through whether their doctoral projects involved industry. Indeed, graphical presentation shown in Figure 2 reveals that in particular for those who were engaged in projects without industrial involvement, the propensity of promotion decreases as the number of journal publications increases. This effect is not observable for those who were engaged in projects with industrial involvement. Therefore, in contrast to promotion opportunities in the public sector, the number of journal publications resulting from doctoral training has a negative or no effect on promotion opportunities in the private sector. This confirms that scientific excellence remains the most important value attached to work in the public sector. Also, this reaffirms that reward systems attached to the public and the private sector are distinctly different in S&E doctoral labour markets. Indeed, scientific publications do not appear to be appreciated by industry.

Figure 2 and 3 here

The modelling results are based on a small sample from a research-based university and the results need to be treated with caution. Nonetheless, these results provide rich insights for further exploration. Projects with industrial involvement seem to provide career advantage in the private sector and might have a negative effect on careers in the public sector. This implies that, to make the most of doctoral training, candidates must decide his/her career choice before choosing the type of doctoral project. In reality, it is unclear whether potential or existing S&E doctoral students are aware of this. If respondents who intend to pursue careers in the private sector would intentionally choose projects with industrial involvement, a clear distinction of respondents' sectors of their first jobs between those who were engaged in projects with and those who did projects without industrial involvement should be observed. We tested this hypothesis using a chi-square test for independence and found that there is no evidence suggesting any association between respondents' likelihood of working in the private sector for their first jobs and the likelihood of being engaged in projects with industrial involvement (Table 4). This indicates that while industry involvement in doctoral projects has profound effects on careers of S&E doctorates, it is likely that most S&E doctoral students are not aware of these effects. Indeed, unknowingly, at the time they choose their doctoral projects, they may have partly determined their chance of success in different sectors for their future careers.

Table 4 here

6. Discussion and conclusions

This paper has examined the impact of industrial involvement on academic research projects and on careers of doctorates. Three significant results are found. First, projects with industrial involvement result in fewer numbers of journal publications. Second, there is some, but inconclusive, evidence indicating that being engaged in projects with industrial involvement may compromise the careers of doctorates in academia or other public sector organisations. Third, although being engaged in projects with industrial involvement confers advantages in the private sector and may have negative effects on careers in the public sector, doctoral students seem to be unaware of this.

Interestingly, we found that projects with industrial involvement are associated with fewer journal publications. We have rejected the hypothesis that doctoral students who went for projects with industrial involvement were less scientifically-oriented and thus produce less academic articles. Projects with industrial involvement are also not particularly linked with commercial productivity such as patents (there is therefore no significant evidence suggesting that journal publications may be delayed to allow for patents). We however have presented some evidence that industrial projects are positively associated with the objectives of solving firm-specific problems or developing firm-specific specifications/prototypes. Industrial partners may therefore limit scientific communication regarding the content of the commissioned research (Gluck et al., 1987) to protect their trade secrets. This is in line with Hong and Walsh's (2009) finding that academics who have industrial funding feel less free to communicate their research. Industrial partners might in general be happy to allow academics to publish their collaborative research. But when the research is involved with firm-specific knowledge such as production processes and products, academics are likely to be asked not to publish the experiment in true scale of the processes/equipment used by firms but to scale up/down them. Sometimes, academics may also be requested not to reveal the exact substances/materials used in the experiment, or even the objectives or applications of the research or the technologies developed. These limitations do not necessarily suggest any intellectual property rights conflicts, as most likely the projects would be accompanied by contracts that detail the intellectual property arrangements. Rather, what industrial partners might impose to academics is the type of content that academics can publish or disclose openly. Sometimes when academics are directly tied to commercial activities, they themselves might hold scientific discovery secret. There have been studies showing the problem of denied access of information or materials in the scientific community (Campbell et al., 2000). Yet, we have very limited knowledge about how, why and what secrecy is exercised in the scientific community due to industrial involvement. Further research may look systemically at this specific aspect of university-industry collaborative research and its impact.

Another question raised from this study is what is the impact for S&E doctorates who wish to pursue academic or public research organisations careers but are engaged in projects with industrial involvement. The modelling results show two scenarios. Doing industrial projects reduces scientific productivity and might also have a negative effect (robust estimation) on promotion opportunity in the public sector (see also Figure 3). While policymakers are eager to promote university-industry collaborative projects, and doctoral students are most likely to be the researchers who conduct them, the question of how being engaged in projects with industrial involvement may affect academic careers has not been properly addressed. Another scenario is that being engaged in projects with industrial involvement may have no negative effect on promotion opportunity in the public sector (jackknife estimation). Given the fact that collaboration with industry is increasingly encouraged in academia, familiarity with industrial environment and working practices could be a further advantage. Could it be possible that being engaged in projects with industrial involvement might benefit not only someone who wishes to enter the private sector, but also someone wishing to obtain an academic position? Therefore, for doctorates' careers in the public sector, the disadvantage of having fewer publications associated with industrial projects might be neutralised through the advantage of industrial connections and familiarity with industrial practices. That is, these doctorates could work as 'boundary spanners' because they understand both the languages of academics and businessmen (Siegel et al., 2007). If this was the case, does it mean that there might be a new breed of academics that is qualitatively different from the traditional one? Both scenarios indicate that further research and policy considerations are necessary.

A third question is whether doctoral students are fully aware of the impact of doing different types of projects in general. We have pointed out that a key dimension associated with doctorates' later career outcome in terms of promotion in the private sector is the industrial contact they built during doctoral training. The result is in line with Lam's (2007) observation that firms recruit talent strategically through interaction with universities. For doctoral students, a more direct contribution to their career outcome in the private sector through projects with industrial involvement is earlier familiarity with the industrial environment such as meetings, presentations and project management. There is also some evidence showing that projects with industrial involvement are more relevant to industry. It would not be a surprise that firms may be more inclined to employ doctorates who had experience in these projects. The test of whether the doctorate respondents are aware of the consequence of choosing certain type of projects indicates that, in spite of the distinctive advantage of doing projects with industrial involvement for careers in the private sector, respondents seemed to be unaware of it. Future research could examine how doctoral students may select strategically their projects and plan their careers (if they actually have these ideas in mind when pursuing a doctoral qualification).

In short, doctoral training is an integral part of academic research and doctoral students are important human resources of universities. Nevertheless, in discussions regarding university-industry collaborations, very few studies have examined how the nature of doctoral research, which represents a very large part of academic research in science and engineering, and hence careers of the doctoral students, may be affected. This study addressed these issues. Not surprisingly, industrial projects provide advantages in private sector careers. What is surprising, however, is that through the shift of focus to the analysis of doctoral projects, we have derived insights on university-industry collaboration that are overlooked in the existing literature. Firstly, we found that projects with industrial involvement result in fewer journal publications. Secondly, despite these projects resulting in fewer scientific journal publications, and despite that journal publications remain the key advantage for careers in the public sector, we did not find a conclusive disadvantage of doing industrial projects on careers in the public sector. The implication that the disadvantage of fewer publications associated with industrial projects may be overcome by the advantage of having industrial connections suggests that the landscape of academia could be evolving dramatically. Thirdly, while the impact of being involved in projects with industrial involvement on careers in the private sector is profound, doctoral students do not seem to be fully aware of it. The rationale for having diversified routes to doctorates might be clear, but the problem is that doctorates may not be fully aware about the impacts of the different routes. There are many faces of university-industry collaborations and they have different effects on a variety of actors involved in such activities. Policymakers might need to consider a more dynamic and differentiated approach to research and science policy. Although fostering university-industry collaborations contributes to research diversity, too much reliance on projects with industrial involvement might actually reduce research diversity.

Finally, the research draws on the UK case of the University of Manchester only. The inference does not go beyond the sample and time frame studied. The small sample size implies that the results need to be treated with caution. A further larger scale investigation is welcome. Moreover, we only investigate doctoral students from engineering and physical sciences. It is possible that a study of students in biomedicine or life sciences might result in different patterns. Furthermore, the proxy used for career outcome considers only the propensity of promotion. Subjective considerations such as job expectations and satisfaction are not captured in this paper. Nonetheless, we believe the study contributes some interesting insights into university-industry collaborative research and on the effects on careers of S&E doctorates. These results shed light on further directions for in-depth research.

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Table 1: Factor analysis result (rotation method: varimax rotation) (N=101)

Experiences Survey items	**Factor loadings**	
	Commercial-orientation	Scientific-orientation
Contributing to a product of high commercial success	0.845	-0.107
Publishing a paper which adds significantly to the technical literature	0.127	0.795
Developing concrete answers or solutions to important technical problems	0.679	0.366
Developing new theoretical insights or solutions	-0.051	0.898
Contributing to a product of distinctly superior technical quality	0.863	0.095
Coming up with a highly innovative idea or solution	0.488	0.581
Variance explained	0.363	0.321

Table 2: Description of variables and descriptive statistics (N=92)

	Category		Coding	Mean	Standard deviation
Dependent variables					
Ever experienced promotion to or within the private sector	Yes		1	0.413	0.052
	No		0		
Ever experienced promotion to or within the public sector	Yes		1	0.217	0.043
	No		0		
Project with industrial involvement	Yes		1	0.522	0.052
	No		0		
Project variables					
Industrial relevance	Seeking a solution to a specific technical problem identified within a firm's or a group of firms' operations Developing design specifications or prototypes for new or improved industrial products or processes	With direct industrial relevance	1	0.380	0.051
	Exploring a high-risk concept identified by a firm or a group of firms – outside the firms' mainstream activities Generating knowledge on topics of broad interest to PhD subject area	With low industrial relevance	0		
Paper	The number of journal publications resulted from PhD; interval variable			2.348	0.220
Project's industrial communication	Estimated number of meetings with or presentations to industry during PhD; interval variable			3.272	0.599
Lab has industrial contact	Yes		1	0.728	0.047
	No		0		
Individual variables					
Commercial-orientation	Constructed variable; details in Table 1; continuous variable			*	*
Scientific-orientation	Constructed variable; details in Table 1; continuous variable			*	*
Female	Female		1	0.228	0.044
	Male		0		
Engineering	Engineering disciplines		1	0.272	0.047
	Physical science		0		
UK	UK addresses		1	0.902	0.031
	Other EU addresses		0		

* Factor analysis using principal component factor as factor extraction method produces scores with mean 0 and variance 1.

Table 3: Estimation results of the recursive multivariate probit model

	Project with industrial involvement		Promotion in the private sector		Promotion in the public sector	
	Coefficient (Robust Std. Err.)	Coefficient (Jackknife Std. Err.)	Coefficient (Robust Std. Err.)	Coefficient (Jackknife Std. Err.)	Coefficient (Robust Std. Err.)	Coefficient (Jackknife Std. Err.)
Project with industrial involvement			0.901(0.362)**	0.935(0.428)**	-0.583(0.321)*	-0.567(0.372)
Industrial relevance	0.657(0.531)*	0.632(0.404)				
Paper	-0.223(0.103)**	-0.246(0.126)*	-0.028(0.067)	-0.030(0.079)	0.253(0.079)***	0.255(0.096)**
Project's industrial communication: Meeting/presentation	0.499(0.370)***	0.466(0.126)***				
Lab has industrial contact	0.998(0.370)***	0.767(0.335)**				
Commercial-orientation	-0.073(0.1830	-0.064(0.280)	0.062(0.161)	0.062(0.187)	-0.166(0.171)	-0.170(0.200)
Scientific-orientation	-0.123(0.167)	-0.112(0.255)	-0.340(0.165)**	-0.340(0.197)*	-0.093(0.151)	-0.101(0.171)
Female			-0.923(0.351)***	-0.909(0.393)**	0.782(0.335)**	0.783(0.360)**
Engineering			-0.017(0.340)	-0.010(0.393)	0.435(0.328)	0.446(0.413)
UK			0.748(0.515)	0.724(0.679)	1.074(0.653)	0.996(3.912)
Constant	-1.072(0.312)***	-2.240(0.959)**	-1.141(0.564)**	-1.140(0.717)	-2.472(0.707)***	-2.417(3.824)
N	92					
Log pseudo likelihood						
Robust estimation	-112.911					
Jackknife estimation	-111.784					
Correlation coefficients						
Robust estimation	ρ_{12} = -0.574***, ρ_{13} = -0.534, ρ_{23} = 0.670***					
Jackknife estimation	ρ_{12} = -0.574***, ρ_{13} = -0.621*, ρ_{23} = 0.654***					

*** significant at the 1% level

** significant at the 5% level

* significant at the 10% level

Table 4: Respondents' first job sectors and projects

	First job sector		
Project with industrial involvement	Private	Public	Total
Yes	26	21	47
No	24	21	45
Total	50	42	92

Pearson $chi^2(1) = 0.0365$ Pr = 0.848

Figure 1: Predicted propensity of engaging in a project with industrial involvement by the number of journal publications (based on robust estimation)

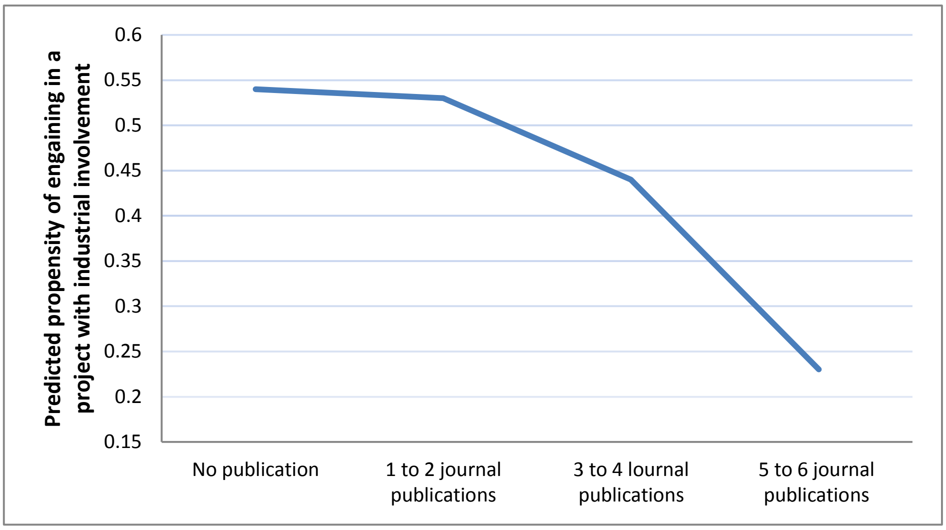


Figure 2: Predicted propensity of experiencing promotion in the private sector by the number of journal publications by industrial involvement of the project (based on robust estimation)

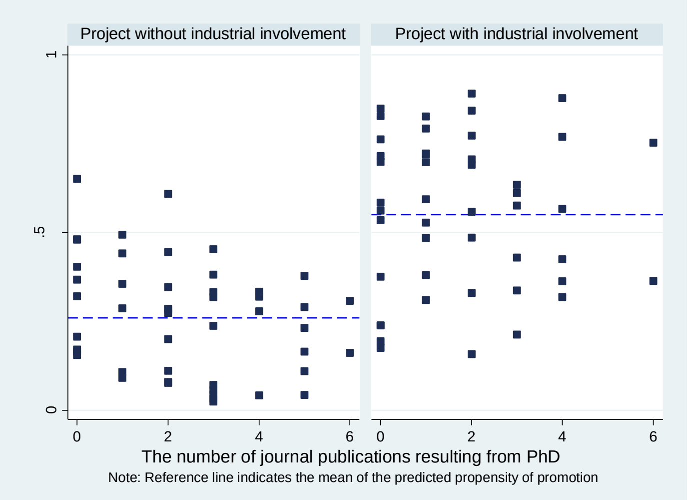
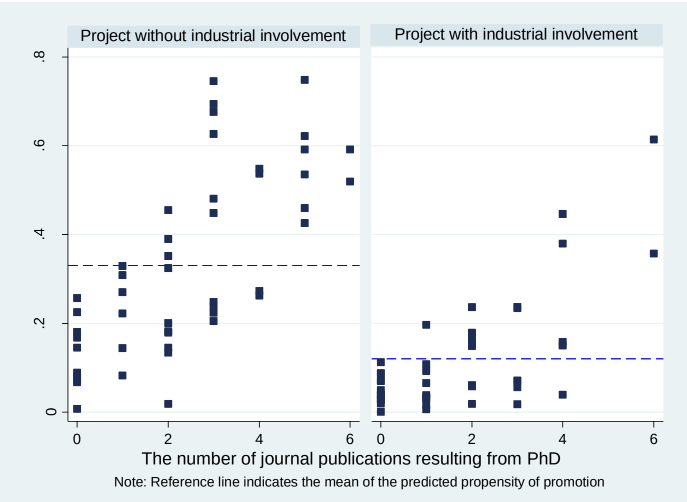


Figure 3: Predicted propensity of experiencing promotion in the public sector by the number of journal publications by industrial involvement of the project (based on robust estimation)



Appendix A: Definition of a job

- Include any job (including self-employment), full-time or part-time, which you did for at least six months (or which you expect to last for at least six months).
- Don't count jobs or work experience that you did while registered as a full-time PhD student.
- If you **changed the kind of work you did, rank or job title** while working for **the same employer**, count it as a **change of job**.
- If you have worked in a Government Department, school or hospital, count any move from one Government Department, school or hospital to another, as a change of job.
- Contract researchers in academic institutions or other employment on short-term contracts: if your contract was renewed count this as an extension of the same job.
- If you had a period of "temping", free-lancing, consultancy or self-employed contract work, count the whole period as one job.
- If you went on maternity leave or sick leave and went back to the same employer for the same kind of work, rank and job title, count the whole period as one job.

Appendix Table B: The correlation matrix for the data

	Industrial relevance	Papers	Project's industrial communication	Lab has industrial contact	Commercial-orientation	Scientific-orientation	Female	Engineering	UK
Industrial relevance	1.000								
Paper	-0.188	1.000							
Project's industrial communication	0.368	0.035	1.000						
Lab has industrial contact	0.294	0.126	0.168	1.000					
Commercial-orientation	0.154	0.047	0.114	0.161	1.000				
Scientific-orientation	0.029	0.108	0.066	0.057	-0.013	1.000			
Female	-0.114	0.078	0.113	-0.424	0.135	0.144	1.000		
Engineering	0.284	-0.052	0.030	0.223	-0.157	0.187	-0.219	1.000	
UK	-0.020	-0.043	0.043	-0.160	-0.044	-0.054	0.192	-0.261	1.000