How to Capture the Impact of the Engineering Doctorate (EngD) programme to Industry? – Conceptual and Methodological issues related to Skills for innovation

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Abstract

Recent studies show an increase in the number of doctoral students who interact with firms, receive funding form firms and work in the private sector after graduation. However, relatively little is known how the industrial collaboration experiences influence their careers, how the collaborative research experiences are perceived, and how to capture the impact of such interactive experiences over the years. This paper examines the Engineering Doctorate (EngD) programmes, one of the collaborative doctoral programmes in the UK and discusses conceptual frameworks with regard to how to capture the impact of such programmes, and assess the value of enquiry methodologies to analyse such impact, to better understand the performance of the Triple Helix approach, especially related to various forms of innovation and skills development, including management, leadership and entrepreneurial skills. It is argued that The EngD model of collaborative doctoral programmes build open innovation relationships, implying new conceptualisation of S&T human capital.

Introduction

The needs of the knowledge economy have increased the demand for doctoral-level ‘highly skilled personnel’ in governments, research institutes and private industry alike. Doctorate holders are trained to produce new knowledge and serve as an important channel for knowledge exchange between academia and industry, especially if they enter industry after their doctoral education (Mangematin, 2001; see also, Cruz-Castro and Sanz-Menéndez 2005). Recent studies show an increase in the number of doctoral students who “interact with firms, receive funding form firms and work in the private sector after graduation” (Thune 2009). Governments have promoted ‘people-based partnership’ (Butcher and Jeffrey, 2007) schemes using students and researchers as ‘agents of change’ (Stewart, 1999), who are able to realise the benefits of cooperation, hence, creating spill-over effects from the collaborative relationships (Howells, 2000; Gertner, et al, 2011). Public schemes for such collaborative programmes have taken different shapes within different national policy contexts and the national labour market conditions.

Doctoral research training is evolving in response to the changing nature of research (Gibbons et al., 1994; Rip, 2004), increase in the engagement with wider industry/society (D’Este and Patel, 2007; Thune, 2009), and, changes in professional career structures both in the academic and broader labour market (Enders, 2005; Lee et al., 2010). However, relatively little is known how the industrial collaboration experiences influence their careers, how the collaborative research experiences are perceived (see Butcher and Jeffrey, 2007), and how to capture the impact of such interactive experiences over the years. The career trajectories and training mechanisms for doctoral students, post-doctoral scientists and R&D personnel need to be investigated with longitudinal data, set in broad and diverse organisational, labour market and industrial landscapes (see Lee et al., 2010). However, the mobility and exchange of people, and the impact of such relationships on various forms of innovation and skills development has been the understudied area in recent innovation literature.

Bozeman and Corley (2004) define 'Science and Technology (S&T) human capital' as 'the sum of scientists' and engineers' scientific and technical knowledge, work relevant skills and social ties and resources*'* (Bozeman and Corley, 2004, p. 604). The S&T human capital literature has focused on scientists' career trajectories and their sustained ability to contribute and enhance their capabilities. It is argued that the new scientific labour market is characterised by the formation of competences on a collaborative basis between academia and industry, through the creation of a "hybrid space" (Lam, 2007, p. 1005). Authors have called such human capital as "the linked scientists" (Zucker et al., p. 2002), whose work roles and careers straddle the world of the university and the firm. Based on a view that knowledge creation is a collective process, S&T human capital can be seen as 'professional network ties and their technical skills and resources' (Bozeman et al., 2001, p.636), including human capital and social capital that enables researchers to create and transform knowledge and ideas in ways that would not be possible without these resources.

This paper examines the Engineering Doctorate (EngD) programmes, one of the collaborative doctoral programmes in the UK and discusses conceptual frameworks with regard to how to capture the impact of such programmes, and assess the value of enquiry methodologies to analyse such impact, to better understand the performance of the Triple Helix approach (see Etzkowitz, 2002), especially related to various forms of innovation and skills development, including management, leadership and entrepreneurial skills. The paper presents extensive review of literature on conceptual and methodological issues capturing the impact of such collaborative partnerships. A case study is presented to illustrate and highlight social and relational dimensions of university-industry links, which are sometimes “messy” in nature, with mixed outcomes and impacts. The evaluation of the impact of collaborative doctoral programmes needs to be contextualised in light of these complexities. It is argued that The EngD model of collaborative doctoral programmes build open innovation relationships, implying new conceptualisation of S&T human capital.

Collaborative doctoral programmes as part of Triple Helix Relationships

Innovation is shaped by the sets of relationships and organisations that interact, including firms, universities, research institutes and governments, as well as broader sets of institutions such as labour markets, the education and training systems and their relation to systems of corporate governance (Lorenz and Lundvall, 2006, p.6). The inter- and intra-organisational management of university-industry relationships and the impact of such relationships on various forms of innovation have been documented in recent literature focusing on the building of Triple Helix relationships. This is accompanied by the growing recognition that tacit, informal relationships and personal interactions are the key for successful collaborations between university and industry through inter-organisational people mobility and exchanges (Agrawal, 2001; Howell, 2000; Perkmann and Walsh, 2007; Gertner et al., 2011).

There is an assumption that there is a significant “cultural divide” (Butcher and Jeffrey, 2007) between universities and industry as two separate knowledge production systems. Today universities are encouraged by various policy and funding instruments to actively engage in the diffusion of research-based knowledge by multiple routes, including commercial channels − licensing patents, consulting, or implementing knowledge through spin-off companies, as well as more relationship-based knowledge transfer activities (Perkmann and Walsh, 2007) − collaborative research, commissioned research, consultancy, equipment sharing, advisory roles, joint supervision, joint publication and student placements. Along with an increased expectation of the role of universities for innovation (Mowery and Sampat, 2005), and economic development from research and commercialisation of the knowledge they generate (Geiger and Sa, 2008), universities have come to be re-appreciated for the traditional role as producers of well-educated human capital – whose collective impact outstrips the economic value related to direct ‘knowledge-transfer’ and commercialisation.

Following the study conducted by EAU (Borrell-Damian, 2009, 27), in this paper, the collaborative doctoral programmes are identified as follows: “the doctoral theses carried out with interaction between a university, a company and a doctoral candidate. A distinctive characteristic is that industry experts take part in the supervisory committee, officially or informally. Industry can play several roles, but being in the supervisory committee is what effectively reflects the specific nature of the collaborative doctoral project. ” Collaborative doctoral programmes serve as part of the university-industry interface in a variety of ways. Different contexts of collaborations need to be distinguished, including mechanisms of funding and the time required to spend within industry. Collaborative doctoral programmes are sometimes funded solely by industry/employer (e.g. industry sponsored internships/fellowships), whilst there are different types of publicly supported collaborative doctoral programmes between university and industry, partly supported by employers/industry. In some cases, the students spend substantial part of the programmes within industry. In other cases, the collaboration does not require the doctoral student to spend period of time physically in the industry/employer.

Thune (2009, 642-645) identifies three key categories of empirical research on doctoral student- industry collaborations. The first group of works focuses on "characteristics of the nature of collaborations". The characteristics include preconditions such as the type of firms, students, disciplinary characteristics and prior experiences. The characteristics of interactions include organisational arrangements, supervision arrangements, resource exchange, and routines developed during the course of collaboration, and how these factors influence students' learning experiences. The second group of literature highlights "study experience and outcomes" of doctoral student-industry collaboration. Outcomes include scholarly productivity, commercial productivity, students' perceptions of future careers, successful collaboration and academic freedom (see, Bucher and Jeffrey, 2007; Salminen-Karlsson and Wallgren, 2008). The third group of research concerns another types of outcomes - career trajectories and labour markets for doctoral graduates, but many of the works are limited to career destination right after the graduation (e.g. Mangematin, 2000). It is important to identify the natures of different collaborative arrangements between the university, doctoral students and industry, and to examine the educational impact of such relationships, forms of knowledge exchanges and implications for research experiences and training (Stephan, 2001; Chiang, 2011). It is also pertinent to ask what forms of impacts are identified at the industry partners through such collaboration.

Forms of Collaborative Doctoral programmes and public supports

Public schemes for collaborative doctoral programmes have taken different shapes in different national contexts. The US and Australia have invested in "research centres" that enable such partnerships. The US National Science Foundation (NSF) has funded a number of university-industry cooperative research programmes, including the recent Industry-University Cooperative Research Centres (I/UCRC). In Australia, the Cooperative Research Centre (CRC) program has been running since the 1990s focusing on the production of "industry-ready" research graduates (Harman, 2004; Manathunga et al., 2012).

In Europe, different types of collaborative doctoral "research programmes" and collaborative schemes have been developed (see CEC, 2006). For instance, in France, *Industrial Agreements for Training Through Research* (CIFRE) is a programme to develop "public-private research partnerships based on these jointly financed by firms and the National Association for Research and Technology (ANRT)". The CIFRE programme not only gives firms access to cutting-edge public research, but also helps the students to get a foothold in the firm in terms of their future job prospects (Giret, and Recotillet, 2004). In Denmark, an Industrial PhD programme has been established over decades, conducted jointly by a private company, an Industrial PhD student, and a university (The Danish Agency for Science, Technology and Innovation, 2009). The European Commission has recently launched a pilot “European Industrial Doctorate” programme.

The case of the UK illuminates *the co-existence and co-evolution* of different publicly supported collaborative doctoral programmes over years. These schemes provide funding for doctoral students who work on projects jointly supervised by an academic and industrial (or public sector organsiations), including CASE studentships, EngD programmes and the Faraday Partnerships. Following the white paper “Realising out potential: a strategy for science, engineering and technology” (1993), the Collaborative Awards in Science and Engineering (CASE studentship) were established in 1994. The CASE award involves a partnership between an academic supervisor, an external organisation and a jointly supervised doctoral student. CASE awards have been expanded from original science and engineering focus across all the UK Research Councils including medical, bioscience, arts and humanities, economic and social sciences. These programmes are now variously called funded by the different research councils (e.g. Industrial CASE studentships, Case studentships and Collaborative Doctoral Partnerships). The CASE models, still based on traditional PhD model, provide opportunities to conduct industry/user relevant research, which may lead to successful commercialisation of the doctoral research. More recently, there are new “professional doctorates” (PDs), providing vocationally-oriented doctoral programmes (Fell et al., 2011). In this paper, however, due to the differences in history and the nature of research, PD is treated separately from collaborative doctoral programmes.

The EngD scheme provides distinctive collaborative doctoral programmes as it is based on pre-dominantly demand-driven research in nature. The scheme is one of the long established forms of collaborative research programme, introduced nationally in 1992. The Engineering and Physical Sciences Research Council (EPSRC) funded 22 EngD centres prior to the 2007 EPSRC review (EPSRC, 2007). The EngD is a four year full time doctoral programme and those students enrolled on EngD degree are called “Research Engineers (REs),” who receive “higher stipend” than other doctoral students. The aim of the EngD scheme was to provide postgraduate engineers with “an intensive, broadly based, research programme incorporating a taught component, relevant to the needs of and undertaken through sponsorship with industry” (EPSRC, 2007). In 2009, 19 Industrial Doctorate Centres (IDCs) were created, replacing the EngD scheme, as a subset of EPSRC’s new Centres for Doctoral Training (CDTs). As of 2011/2012, £19 million is spent on 29 IDCs, and the number of students trained amounts to about 1400, and the number of company partners under the scheme amounts to some 600 over time (Golby, 2012). In 2013, the new call for CDTs has been made, in which IDCs are integrated.

Conceptualising the Impact of EngD programmes

The EngD/IDC scheme can be seen as a response to “multiplication of the links” between the academic sector and the industrial R&D sector (Beltramo, et al., 2001) and as an evolution of a type of doctoral programme to meet new labour market conditions. Firms need to solve industrial problems and need “state of the art” scientific knowledge for their R&D needs. Firms also need to develop employees with highly developed research and analytical skills. Individual REs look for career progress, and aspire to progress in research with industrial relevance whilst they pursue academic degree. The company commits to support the research project over the duration of the EngD programmes and the doctoral students (REs) attend the taught modules within the university whilst they work within the company as employees. There are some financial incentives for firms to participate in the EngD/IDC schemes as it is relatively cheaper to have doctoral students supported by the research council. The research project is identified by the sponsoring employer and confirmed as appropriate by the university (Vitae, 2012). In order to ensure these agendas are shared, EngD/IDC management committees typically consist of a mixture of academics and industrialists who have some projects with the university. They try to optimise training opportunities for doctorate students under the EngD/IDCs. The programme is seen as a route to achieve "fast-track" progression to senior management positions in industry (Barnes and Neailey, 2011) as the EngD/IDC scheme aims to provide students with industry ready skill sets.

As an analytical framework, Bozeman's (2000) identified five dimensions of the diverse technology transfer environment, which can be adopted to the understanding of broader knowledge transfer (KT) and knowledge exchange (KE) activities and processes as part of the collaborative relationships. Following Sahal (1981, 1982), Bozeman (2000, 629) sees that simply focusing on the "product" is not sufficient to the study of transfer and diffusion of technology- "it is not merely the product that is transferred but also knowledge of its use and application". Bozeman (2000, 637) identified five dimensions of technology transfer environment as follows:

- *The transfer agents:* individual, institution or organization seeking to transfer knowledge.

- *The transfer object:* contents and form of what is being transferred (tacit or codified knowledge in the form of a product, a method, a process, a design, etc.).

- *The transfer media:* means through which transfer occurs, that is, whether knowledge is transferred through formal or informal mechanisms or collaborations, including the influence of IP policies.

- *The transfer recipient:* individual, organisation or institution receiving the *transfer object* (private individuals, firms, public sector organizations, etc.).

- *The transfer demand environment:* factors related to *the demand environment* such as market, social, cultural and economic need for the transferred object.

Several underlying assumptions within this technology transfer framework need questioning, in particular the conceptualisation of *transfer agents* and *recipients*. In this conceptualisation, ‘transfer’ and ‘receipt’ of knowledge is only on one-side – Kitagawa and Lightowler (2013) argue that in the knowledge transfer/exchange environment, all actors and agents are recipients of knowledge, and the process is more interactive and reciprocal than linear. Despite this limitation, these five dimensions identified of transfer environment offer a useful starting point for discussion of the relationship between public policy, collaborative doctoral programmes and industry R&D activity.

The nature of the market, availability of private investment and public resources available for industry R&D, support for training and mobility; and characteristics of the industry sector, and policy measures including the information and brokerage support and networking measures, particularly targeting Small and Medium Enterprises (SMEs), and regulation are key factors that condition the whole *transfer demand environments.* National and international policy objectives are often presented in general and broad terms sometimes with 'ambiguity' – for example, to increase the contribution of universities in meeting industry needs; to improve the demand and availability of STEM skills (e.g. DIUS, 2009); or to enhance innovation in specific national strategic key technology areas. These are then interpreted and applied in different policy contexts through the funding distribution and the policy implementation stage (Molas-Gallart and Casto-Martinez, 2007).

The characteristics of the *transfer agents* affect the interpretation and implementation of transfer policies and strategies conditioned by the institutional values and culture of individual organisations. In the case of universities, institutional missions, strategies, resources and the nature of the institution's business (Kenny and Goe, 2004; Jongbloed and Zomer, 2010; Vorley and Nelles, 2008;) as well as individual academics' experiences, motivation and perceptions of opportunities as well as barriers related to their academic work environment (Abreu et al., 2009; Goldstein, 2010) and their behaviours condition transfer processes and effectiveness (see Slaughter and Rhoades, 1996). There are still a number of perceived "barriers" between university and academia, especially the mobility of existing staff in academia and industry (Howells, 2000). We do not know how these perceived barriers affect individual career strategies and decision making processes - "how the perceived barriers shape subsequent collaborations" (Bruneel et al., 2010) and how individuals may overcome such barriers.

The EngD model of collaborative doctoral programmes influences *transfer agents* , the *transfer object* as well as *transfer demand environments.* The scope of the human and social capital will condition not only new scientific and technological knowledge production but also routes and capabilities to bring the knowledge to the market. This includes new sets of competences and capability such as developing new organisational strategies, management, entrepreneurial and leadership skills. Such broader conceptualisation of the S&T human capital reflects use and translation of technology and knowledge - the *transfer object* - in a variety of organisational forms (Lam, 2004). This includes knowledge in both manufacturing and service sectors including knowledge intensive businesses.

Evaluative frameworks and methodologies

This paper aims to develop a conceptual and methodological framework in order to evaluate the multi-dimensional impact of the EngD collaborative projects, especially on the industry partners. The key objective is to define and understand what is the 'impact' of EngDs and identify how it can best be evidenced. There are a number of conceptual and methodological frameworks that have been developed over years to measure the impact of various R&D policy interventions. These methodologies range from pure quantitative, pure qualitative and mixed techniques.

The quantitative approaches include those based on econometrics (Solow et al., 1958). Other evaluative approaches include models based on 'return on investment' (Griliches, 1995) or 'research payback' (Buxton and Hanney, 1996), and various efforts to evaluate the impact of basic research or private sector investment, such as knowledge production, research capacity building, networks and interactions, policy or product development and wider societal benefits including increased productivity (see Salter and

Martin, 2001). Based on the theoretical discussion on recent innovation policy evaluation, the concept of "behavioural additionality" emerged based on the observation that that in early evaluations of collaborative R&D programmes did not capture the effects on firms, in particular the 'dynamics of behavioural change' (Buisseret et al., 1995; Gok and Edler, 2010). Qualitative case study methods are often employed in order identify detailed processes of organisational, social and cultural impacts. Other qualitative methods include expert testimony, ethnographic study, longitudinal historical studies, documentary analysis, sociological analysis, tracking approaches and logic models (Boaz et al., 2009; Georghiou et al., 2002).

Based on the existing literature, first, the paper develops a framework to characterise the forms of EngD collaboration and different types of *input*, *output* and *outcomes* of such collaborative activities. Secondly, the questions are developed if the EngD programme has changed each of the participants in terms of behavioural additionality. For example, for industry partners the change would include

i) patterns of collaboration (i.e. if the firm collaborated differently, with some other firm that it would not have collaborated with university without support),
ii) rate and trend of collaboration (i.e. if the changed collaboration is a persistent one, if the EngD scheme triggers an ever increasing collaboration or it will gradually decrease sometime after the scheme) and
iii) internal dynamics of collaboration (if the collaboration is extended to other parts of the firm because of the EngD programme)
iv) strategy of firm in terms of moving into any new technological areas, new end markets, expanding an area of R&D where new recruits have been added.

The nature of the EmgD impacts may be schematically presented in Table 1:

Table 1: Input, output, outcome and Impact of the EngD project

	Project input	**Project activity**	**Project output**	**Project outcome**	**Impact**	**Behaviour Change**
University	New industry doctoral project	Collaborative R&D Training Solving industry problems Skills development	Joint publications New technology; IP secured; IP exploited in the firm; IP Licensing Portfolio Thesis	New technology knowledge about technology Networks Consultancy Industry access	*Impact on academic performance*	New R&D strategy New curriculum New interdisciplinary collaboration
Industry	Industry contribution RE (stipend or employee) Scientific knowledge			New technology/ products / processes / services delivered to market. Spin-off firm (numbers and revenue (actual/forecasts)	*Impact on industry performance* - turnover - profitability competitiveness - new jobs created - societal impact	New firm strategy New R&D activity New technology New market New recruit
RE	Industrial sponsorship			Industrial experiences EngD degree Qualification Networks Management and leadership skills	*S&T Human capital* Career opportunity/ progression	Boundary spanning

Contextual Case Study Methodology

The empirical research has been conducted by combining different methodology and data-sets over the duration of 3 years. The initial pilot study, the result of which is presented here, was conducted between May 2010 and January 2011, through a mixed qualitative methodology: interviewing academic staff; participating in workshops with industrial doctorate students, and in a focus-group meeting; and by carrying out a survey of industrial doctorate students asking about their experiences of "learning and skills formation" both at the university and in industrial settings. The exploratory pilot study aimed to be illustrative of the variety of experiences and perceptions of RE's 'learning' within the EngD/IDC, including opportunities, barriers and challenges; and how they have overcome these, rather than generalising the results. Many of the interactive processes of individual and collective learning, networking and other institutional processes, can be better understood through examining what happens at the level of individuals and the specific organisational contexts. To that end, the case study method (Yin, 2003) of a specific IDC was chosen in order to gain contextually nuanced information, that may not be captured in quantitative studies.

A pilot case study was conducted at one of the IDCs[1], in collaboration with the research and management team at the Centre at the University. The aim of the study is

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[1] The IDC was originally established in 2006 as EngD Centre between two universities, with £3.4 million funding from the EPSRC. In the first three years, 31 EngD projects were established, sponsored by more than 20 different companies. In April 2009, the Centre was awarded a further £5.3 million from the EPSRC to establish a new Industrial Doctorate Centre (IDC).

to illustrate “learning experiences” and “strategies” of individual doctoral students who work between the two “knowledge production systems” and who move across two spaces, namely academia and industry. In order to gain a set of systematic data sets on REs’ attitudes and perceptions and benavioural changes, an on-line survey with REs who were enrolled on the programme was developed in collaboration with the research and management team of the IDC. The following key questions were asked in the survey:

- How do doctoral students learn through industry-based collaborative doctoral programme experiences?; and
- How would the learning experiences of doctorates be embedded within an industrial context?
- What are the perceived barriers and constraints for the REs through the industrial collaborative doctoral model and how can they be overcome?

The following section gives an overview of the observations from the survey results. Where appropriate, comments from the REs are quoted to highlight the diversity and complexity of their experiences, especially in terms of perceived challenges and “barriers” to knowledge exchanges across organisational boundaries. As of October 2010, the number of REs was 62 (80% were “stipend REs” who were receiving a grant of £15,000 a year from the EPSRC, and 20% were “employed REs” sponsored by their companies). The fee for the EngD degree (£7,400 a year) was covered by the EPSRC. The survey targeting the REs was launched on 24 August, and by 15 October, twenty-five responses were collected out of the targeted fifty students (excluding the first year intake in October 2010).

The survey asked individual EngD students about their strategies in carrying out research projects between academia and industry. “Which of the following factors do you think influence your strategies to carry out your research?” (Figure 1). “Individual and direct relationships with industrial and academic supervisors” was identified as a factor that strongly influence students’ research strategies. In particular, REs perceived the influence of the industrial supervisor as being greater than the academic one. There are other relational factors that influence research strategies including, “existing collaboration between the company and the University” and the “relationship with peers at the IDC.”

In response to the questions about their perceptions of the “impact” of their research projects, most of the REs answered “new ideas” and “innovation” (e.g. “new products” and “processes”); followed by “collaboration with the university” and other networks and contacts; and commercial impacts such as “increase in client base” and “sales”. The perceived impact also includes “organisational change” and “future leadership” (Figure 2). With regards to the knowledge exchange and organisational change, there appear to be complex organisational contexts REs are embedded in. In response to the open question about the main challenges of being an RE, several comments pointed to the different needs between academia and the business world and the difficulty of balancing and managing the needs of the two worlds and these between two supervisors.

Some of the comments reflect the structural issues of EngD programmes. The following comment from one of the REs highlights the issues concerning the industrial supervisor and broader organisational context:

> *"Industrial supervisor was not made aware of the reason why senior management decided to go for the EngD. Also industrial supervisor is more focused on meeting short term objectives; he does not appreciate the length and benefits of research. He just needs to be educated on this"*

A senior academic staff at the IDC also pointed out that whilst the firm's top level management appreciates having an RE, the day-to-day manager, the industrial supervisor, may not necessarily share this strategic view.

There seems to be a difference in terms of *autonomy* and *embeddedness* of REs –between those REs who are on a stipend, and those who have been employed by the same company prior to the EngD enrolment. It seems that REs, in particular "stipend REs," could see "radical innovation" in terms of changes in organisations, whereas "employed REs", who have worked at the company and are likely to continue after the EngD programmes, may be better positioned to induce an "incremental" innovation process within the workplace. If combined with their career strategies, these may lead to new leadership and innovation in the specific organisational contexts.

Figure 1 Factors affecting EngD students' research strategies

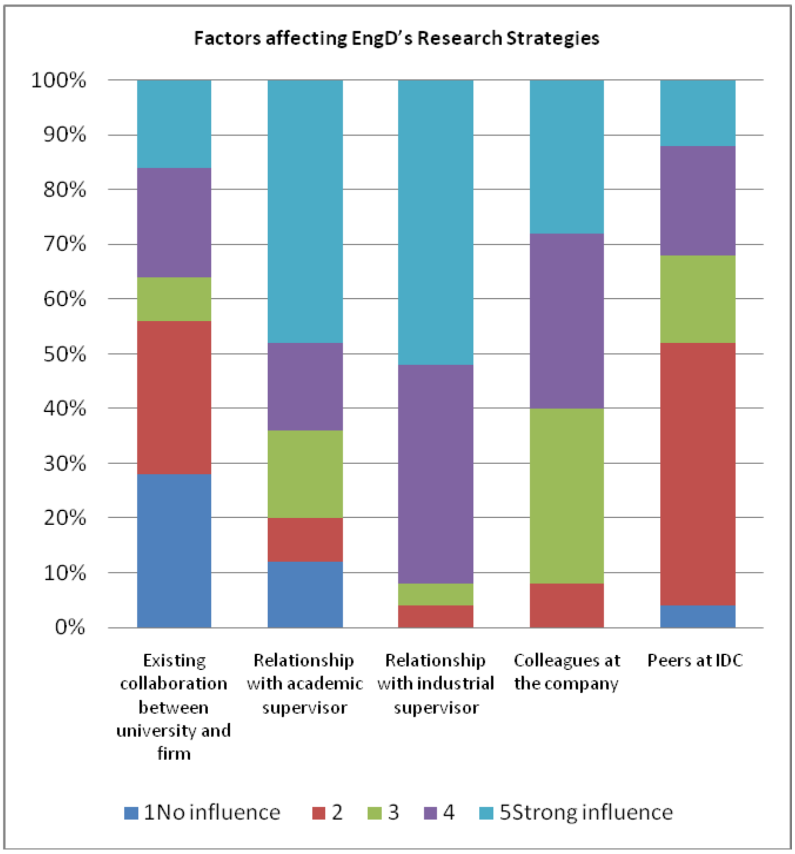
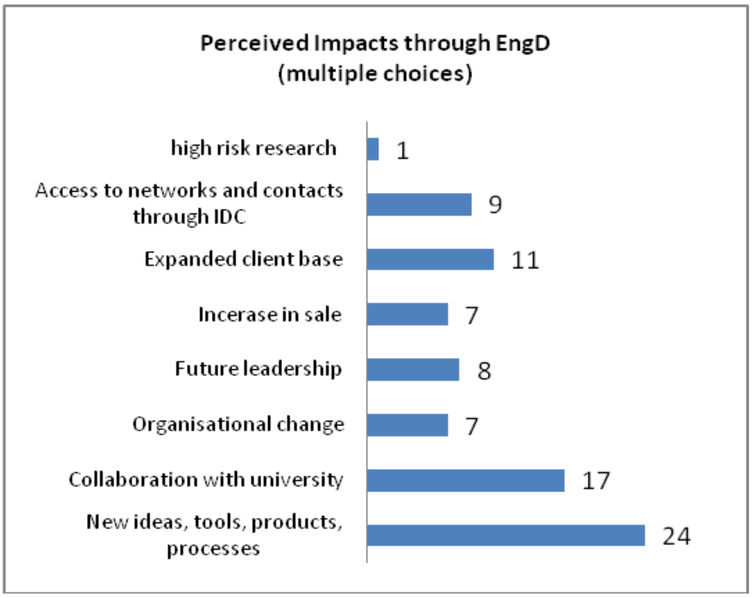


Figure 2 Perceived Impacts through EngD to the company



Discussion

IDCs are designed to create "hybrid spaces" for doctoral students to be placed in both industry and academic institutions, conducting research which is of relevance to the industry's needs. Industrial doctorate students are often expected to become future managers/leaders of their organisations as agents of change with new scientific knowledge production as well as developing management and leadership skills. The small qualitative study highlights the complex nature of learning, power and identity within a workplace and throughout different stages of doctoral training encompassing both higher education and workplace. The survey with the REs at the IDC illustrates the institutional complexity of working within "hybrid spaces," managing different expectations and solving industrial problems with academic inputs and support, as well as acting as "change agents" within organisations. One of the industrial doctorate students described the challenge of being an RE is:

> *"to gain a compromise between what the different stakeholders want from the project, i.e. me, my company, my industrial supervisor, the University"*.

These "experiential dimension" (Butcher and Jeffrey, 2007, p. 1248) of research collaboration and knowledge exchange is understudied. REs work across the two modes of knowledge production systems (Gibbons et al, 1994). Such individuals, who span across "diverse knowledge communities" act as knowledge brokers or boundary spanners, or develop "dual identities" (Gertner, 2011, p.642). However the findings in earlier studies point out several constraints and problems about the communication between the supervisors and the student/RE (see Butcher and Jeffrey, 2007; in a different national context, see Salminen-Karlsson and Wallgren, 2008). As

Starbuck (2001) suggests, students should be involved in project planning and in setting up agreements on objectives and timelines, with both academic and industrial supervisors. This would need to be shared at the appropriate level of the hierarchy within the partner organisations. The current study echoes the point that "the personal experience of research collaboration is necessarily imperfect, noisy, messy and ultimately one of mixed emotions and outcomes" (Butcher and Jeffrey, 2007, 1248).

Through these experiences of "learning to share common norms" (Bruneel et al, 2010, 860), all the *transfer agents* and *transfer recipients*, not only the REs, but also, industrial and academic supervisors and the university and industry managers share experiences and objectives, and learn how to better work together. These social and relational dimensions of university-industry links coexists with different types of knowledge flows, such as dissemination of scientific codified knowledge and commercialisation of property rights. Qualitative personal experiences of REs including intangible dimensions of impacts and processes needs to be investigated further (e.g. Carayannis, 2004). For example, the career directions of industrial doctorate students are diverse, and their career pathways cross over not only academic-university boundaries, but also boundaries between firms, and within the firm, and between scientific and management careers (Mason and Nohara, 2010). They translate knowledge not only *between university and industry*, but also face the challenge of translating different types of knowledge *within the firm* where they work.

Understanding the perceived barriers to university-industry collaboration from point of view of individuals is important because it uncovers the problems and challenges that have emerged in the processes of mobility experience and knowledge exchange. Qualitative study of personal experiences illustrates such processes and contexts. As a small scale research with a qualitative nature, the explanatory power of this pilot case study is limited and it only provides a snapshot of opinions and practices. Despite methodological limitations in this study, it highlights complexity and relational processes that can be overlooked in the evaluation studies of collaborative R&D activities. The methodological and conceptual frameworks of the evaluation of impacts of the EngD need to be developed in light of such contextual diversity and complexities.

Conclusion

This paper contributes to the current policy discussions on the forms of industry engagement in higher education, in particular, collaborative doctoral programmes as university-industry interface. Based on the framework developed by Bozeman (2000), the paper aimed to understand the forces shaping forms of S&T human capital development, forms of research collaboration and their impacts, including incentives, internal organisational structures and external environments that condition the nature of collaborative relationships. S&T Human Capital refers to impact of collaborative activities on the 'enhanced scientific and technical skills', social capital derived from interactions, and the development of networks and infrastructure, which constitutes key part of the Triple Helix relationships.

The case of Engineering Doctorate (EngD) is examined as one of the long established forms of collaborative research programme in the UK. Whether the EngD/IDC model provides new forms of doctoral training and new pathways for non-academic careers remains a big question to be investigated and evidenced further.

The recent development of Centres for Doctoral Training (CDTs) is still in its early days, and it is too soon to determine the specific impact of these. In terms of the measurement of the impact, specific contexts of the collaborative relationships and institutional settings and changes over time need to be considered. Programme characteristics and the diversity of industry sectors of the EngD Centres/IDCs deserve further consideration. For example, some IDCs focus on specific industrial sectors, such as life sciences, nuclear engineering, photonic technologies while some has broader engineering and manufacturing focus cutting across different industrial sectors. Throughout its history, the number of EngD degree holders is already high. The nature of industry partners (e.g. large multinationals, SMEs) and the nature of the doctoral students (e.g. stipend or existing employees) are other factors that influence the impacts of doctoral projects to industry partners. Long term career pathways of REs need to be investigated by conducting a comparative study across IDCs, and with other collaborative and non-collaborative doctoral programmes.

The EngD model of collaborative doctoral programmes influences *transfer agents* as well as *transfer demand environments* building "open innovation relationships" (Johnson et al 2010), enabling individual REs create collaborative relationships which lead to industrial and academic achievements and further impacts. This underlies new conceptualisation of S&T Human Capital, going beyond scientific and technological capability development. The collaborative model not only creates new scientific and technological knowledge but also it takes the knowledge to the market. Such process nurtures individuals' entrepreneurial and management skills, and also enables them to act as change agents within and across the organisation. This resonates with the objectives of the EngD scheme - to nurture industry relevant skills, including future leadership and management.

The study of collaborative doctoral programmes may contribute to the broader field of R&D policy evaluation. Different dimensions of impacts with respective methodological challenges of evaluation need to be further investigated. Further conceptual, theoretical and methodological consideration would contribute to the development of evaluative frameworks of R&D public policy measures, especially surrounding the concept of behavioural additionality and links to skills, innovation and corporate technology strategies.

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