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Career patterns and competences of PhDs in science and engineering in the knowledge economy: The case of graduates from a UK research-based university

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ABSTRACT

Based on data collected through a complex survey of science and engineering PhD graduates from a UK research-based university, this paper examines the different types of careers and to what extent different types of competences acquired from doctoral education are regarded as valuable in the different career types. The results show that employment outside the conventional technical occupations is the main destination for the survey respondents. This career type is not only successful at retaining its members, but is also the destination of the other career types. Moreover, different types of competences from doctoral education are regarded as relatively more valuable in different career types: knowledge directly tied to subject areas is regarded as more valuable in academia/public research; both knowledge directly tied to subject areas (but more general type of knowledge rather than specialist knowledge in PhD topics) and the more general and transferable skills are regarded as valuable in technical positions in manufacturing; and the general and transferable skills are regarded as more valuable in employment outside the conventional technical occupations. In absolute terms, general analytical skills and problem solving capability acquired from doctoral education are perceived as valuable in all three career types.

1. Introduction

In the early 1990s, in the publications "Science and Technology Policy" (OECD, 1991) and "Technology-Economic Programme: Technology and the Economy" (OECD, 1992), the OECD was concerned with the prediction among several member countries of a future shortage of scientists and engineers and its possible impact on the economy. This prediction was based on both the belief that there would be an increased demand for scientists and engineers and the perceived decline in students' interests in science and engineering.

This concern about a future shortage of scientific labour force was echoed in policy reports in a number of countries. In the UK, the 1987 Department of Education and Science White Paper stated that the demand for highly qualified manpower outstripped supply and called for an increase in the number of graduate scientists and engineers (Department of Education and Science White Paper, 1987). In the USA, in 1991, the Bureau of Labour Statistics developed a projection of the labour force covering 1990–2005. The projection indicated that for scientists, engineers and technicians as a group, demand could increase by up to 59% (Braddock, 1992). Alternatively, a 1990 study by the National Science Foundation projected that there would be a shortfall of 675,000 graduates in natural science and engineering by the year 2006 (Finn and Baker, 1993).

The concern raised during this period about the future shortage of scientists and engineers and the possibility that their technical knowledge and talent may not be properly exploited was justified by the belief that having qualified scientists and engineers working within the boundaries of the conventional scientific and engineering occupations was a key factor contributing to national technological competitiveness and economic growth (Dosi et al., 1994; Freeman, 1992). Consequently, policy responses included a series of programmes for training scientists and expanding the number of PhDs in science and engineering in member countries (OECD, 1991).

More than a decade later, policymakers are still concerned about the shortage of scientists and engineers due to the continued lack of interest in science and engineering among students, but this time the concern is not just about how to keep science and engineering graduates in their conventional occupations. The contemporary argument is that, in the new economy, the basis of competition has changed and is increasingly driven by knowledge and intangible assets, with knowledge production becoming more widespread and widely distributed across a host of new places and actors, in many cases outside conventional technical occupations (David and Foray, 2002). Therefore, in contrast to the

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attitudes in the late 1980s and the early 1990s, policymakers have begun to recognise that one of the reasons for supporting the production of larger numbers of science and engineering graduates is that, in the new economy, with more and more sectors adopting new technologies, the demand for scientists and engineers is increasing outside the conventional boundaries of science and engineering occupations in order to adopt, produce and diffuse knowledge efficiently (The Dearing Report, 1997; Foray and Lundvall, 1996; OECD, 2000). Moreover, with structural change in the economy, including the decline of manufacturing and the increasing importance of services, the amount of highly skilled personnel such as scientists and engineers in the service sector is becoming increasingly significant (Cervantes, 2001; Lavoie and Finnie, 1998; Lavoie et al., 2003), as many jobs and functions are displaced or outsourced from traditional manufacturing sectors (Miozzo and Grimshaw, 2006). Indeed, the 2002 Sir Gareth Roberts' review of supply of science and engineering skills in the UK, entitled "SET for Success", clearly stated that many scientists and engineers make contributions to the economy through employment in many sectors, not only through working in industrial R&D.[1]

Hence, regardless of the change in rationale, the demand of scientists and engineers has been increasing over the last decade. In the UK, such demand has been re-affirmed in the 2008 White Paper entitled "Innovation Nation" (Department for Innovation, Universities & Skills, 2008). However, most of the discussions in existing policy statements or reports are based on science and engineering (S&E) graduates. Whether scientists and engineers at doctoral level are experiencing the same trend is a matter of empirical research. Traditionally, doctoral education was regarded as a passport to academia or public research organisations. This is visible in the Harris Report (1996) in the UK which stated that because many postgraduate research students might go to work in higher education institutions, higher education institutions should provide them with proper training related to teaching. However, with the huge increase in the number of people with doctoral qualifications, many studies have expressed concerns about the lack of job opportunities for science and engineering (S&E) PhDs in academia or public research organisations (Dany and Mangematin, 2004; Enders, 2002, 2005; Fox and Stephan, 2001; Giret and Recotillet, 2004; Mangematin, 2000; Martinelli, 1999; Robin and Cahuzac, 2003; Stephan et al., 2004). Whether this traditional career type is the dominant one for S&E PhD graduates is a question open to empirical research. Thus, given the change in the rationale for the demand of scientists and engineers and the implications for S&E PhDs, this paper intends to explore empirically the career types of S&E PhDs and to investigate whether S&E PhDs are most likely to be employed within or outside the conventional S&E PhD occupations. Also, the paper studies to what extent the different types of knowledge and skills acquired from S&E doctoral education are perceived as valuable in different occupations.

The paper is organised as follows. Section 2 reviews the types of careers for S&E PhDs. Section 3 explores the knowledge and skills acquired from doctoral education and to what extent they might be relevant to different career types, paying particular attention to the distinction between the conventional S&E PhD occupations and the potentially increasingly significant employment outside the conventional S&E PhD occupations. Section 4 discusses the data used in the analysis, which is based on a complex survey, the analysing methods and measures. Section 5 presents the results and Section 6 summarises the discussion and conclusions.

[1] Document online available at: http://www.hm-treasury.gov.uk/ent_res_roberts.htm (accessed 24 January 2010).

2. Careers of S&E PhDs

Scholars in innovation studies have pointed out the contributions of S&E PhD personnel to the economy. Pelz and Andrews (1966) stressed that PhD and non-PhD personnel differ significantly in their motivations and the quantity and quality of their output. Mangematin (2001) also pointed out the special nature of doctoral manpower because its members, on the one hand, are trained in universities and contribute to production of new knowledge and, on the other hand, serve as an important channel for knowledge transfer from academia to industry if they enter industry after doctoral education. Indeed, it has been argued that one of the most significant benefits to the economy from public funded basic science is highly trained manpower for industry and government through S&E doctoral education (Larédo, 2007; Martin and Irvine, 1981; Mowery and Sampat, 2005; Pavitt, 1991). These arguments suggest that PhDs may bring either the most up to date scientific knowledge they have produced or their capabilities in producing such knowledge into industry and result in knowledge spillovers through mobility across different employment contexts (Almeida and Kogut, 1999; Madsen et al., 2003; Rosenkopf and Almeida, 2003). This means that the extent of S&E PhDs' employment in industry has an impact on how academic research is transferred to industry.

The extent to which S&E PhDs are employed in industry shifts over time and seems to become increasingly significant. Martin and Irvine (1981) surveyed PhDs trained in two UK radioastronomy observatories (Jodrell Bank and Cambridge) between 1945 and 1978. Their data revealed that at the time of survey, first jobs for respondents were 55% in academia, 22% in government and 17% in industry and the most recent jobs were 46% in academia, 29% in government and 20% in industry. This indicates that throughout the period, career patterns for radioastronomy PhDs in the UK were rather stable. Stephan (1996) showed that in the US, up to 1991, academia remained the largest employment sector for doctoral scientists although the proportion was decreasing. Industry was the second largest employment sector for doctoral scientists and the proportion was increasing. Stephan et al. (2004), based on data from the US Survey of Doctorate Recipients from 1973 to 1999, further pointed out that for those who have left graduate schools for more than 5 years in all science and engineering fields, employment in industry grew so rapidly that by 1989, industry surpassed the tenure-track academic sector as the most common employment sector for S&E PhDs and by the mid-1990s, it surpassed all types of academic employment. A UK survey targeting the PPARC (Particle Physics and Astronomy Research Council) sponsored PhD students (DTZ Pieda Consulting, 2003) estimated that 6–8 years after awards ended, in 2003, 15% of the sponsored students were either in permanent university research positions or in government/public sector research positions and 54% were in the private sector. Ender's (2002) German case, based on a survey of three cohorts of German doctorates (1979/1980, 1984/1985, 1980/1990) in 1999, reported that in the long run (15–20 years after graduation), only 40% of mathematics graduates and 20% of electrical engineering graduates were in higher education. These studies imply that in many counties, academia is becoming the secondary employment sector for S&E PhDs, while industry is gaining its dominance as the major PhD employment sector.

Because these observations may indicate an employment pattern that diverges from the traditional expectation that PhDs are trained to become academics, this has led scholars to discuss a number of issues. These include: the incentives for doing a PhD (Mangematin, 2000), expectations and realities regarding employment (Fox and Stephan, 2001; Mangematin, 2000), value of the doctoral research training (Enders, 2002, 2005), employability of people with a doctoral degree (Dany and Mangematin, 2004), determinants of S&E PhD career outcome (Giret and Recotillet, 2004; Mangematin, 2000; Robin and Cahuzac, 2003), and how S&E PhDs may contribute to research activities in industry (Mangematin, 2000; Stephan et al., 2004), particularly their role in the commercialisation of academic results (Lam, 2007; Murray, 2002, 2004; Stephan et al., 2007; Zucker et al., 2002a,b).

Despite all these developments, two areas remain largely unexplored. First, given the change in the rationale for the demand of scientists and engineers and the change in industrial structure, there is scope to explore the resulting changes in careers of S&E PhDs. While academia and government may be traditionally regarded as the main sectors for employment for S&E graduates, many universities and government organisations might be employing more S&E PhDs for non-research tasks such as for developing strategies or policies. These are some examples of unconventional S&E PhD jobs within the conventional S&E PhD sector. Similarly, it is often taken for granted that many S&E PhDs will occupy research positions in industry, and these positions have traditionally been associated with R&D laboratories in large firms in industries such as chemicals, pharmaceuticals, aerospace, semiconductors, etc. It is unclear whether modern S&E doctorates are more likely to be employed in these conventional research positions just mentioned or in banks or consultancy firms. Indeed, the UK PPARC case (DTZ Pieda Consulting, 2003) showed that for those PPARC sponsored PhDs who worked in the private sector, 29% were in software design/solutions/management, 24% were in financial services and 24% were in business services. Therefore, to address these changes, apart from bearing in mind the academia/non-academia and the research/non-research distinctions, in this paper, we pay special attention to S&E PhD jobs within and outside the conventional PhD occupations, i.e. academic or public research positions and technical positions in manufacturing, and how they may evolve through time. Hence, this leads to our first research question:

(1) Where are S&E PhDs employed and have they changed jobs/sector?

3. Knowledge and skills acquired from doctoral education

3.1. Purposes of doctoral education

In the UK, the official purpose of doctoral education can be traced back to the report by the Committee of Vice-Chancellors and Principals (CVCP) (1988). This report, entitled "The British PhD", stressed two main purposes of doctoral education: the first is to enable graduates to make original contributions to their respective disciplines and the second is to provide professional research training enabling them to become independent researchers.

These two purposes or dimensions of modern doctoral education, scholarship and professional training, which are regarded by some as competing (Burgess, 1997; Leonard, 2000; Pole, 2000), reflect the dual nature of the PhD as a "product" and as a "process" (Park, 2005). The scholarship dimension is rooted in the general perception and requirement that a PhD thesis has to be original and advance disciplinary knowledge. This implies that the purpose of scholarship in doctoral education is assessed by a final "product", a thesis; a thesis has to demonstrate that some original knowledge has been produced. On the other hand, the dimension of professional training places emphasis on the "process", the development of the procedure and the capability to conduct research independently. As PhD projects are open-ended scientific investigations in nature, without in-depth understanding of knowledge in the discipline to make an elegant argument and the ability to frame proper research questions and then to execute the research, an original contribution to knowledge in the discipline is implausible. Hence, to a certain extent, it is reasonable to assume that if a PhD award is granted, it is a guarantee that the receiver is equipped with in-depth knowledge in a specific discipline and has the capabilities to design and implement an independent piece of research. This implies that the process of a PhD study is a journey of individual learning, both to acquire knowledge in the discipline and procedures to construct knowledge, and that successful post-graduates should leave university with knowledge and skills, some of which are subject-specific and others that are more general and transferable.

Using a competence-based perspective in discussing career development, DeFillippi and Arthur (1994) stressed that there is a broader dependence of organisational competences on individual career behaviour and from a career standpoint, an individual's competences are defined through matched employment settings that recognise their potential contribution. That is, the relative importance of a specific type of knowledge or skills in a specific employment sector can be defined through the extent to which the type of knowledge or skills are perceived as valuable by individual employees in the sector, and the employees' perception is based on the characteristics of how the use of knowledge in the sector is rewarded. Indeed, this resonates with the idea that social knowledge is embedded in individual relationships that are structured by organising principles, i.e. a "shared template" (Kogut, 2008; Kogut and Zander, 1992). Hence, what distinguishes S&E PhDs' competences acquired from doctoral education from one type of career to another is largely due to the difference in the structures of the use of knowledge and how use of knowledge is rewarded in different types of career.

3.2. Characteristics of the use of knowledge by different types of career

The reward system in academia has been largely based on Merton's (1973) universalism argument, stressing that professional recognition and rewards are given to those who are the most productive or able to demonstrate the most significant contribution to their fields. In the academic setting, professional recognition means quality publications, peer recognition (especially recognition from renowned scholars) and reputation within the scientific communities. However, Merton (1973) further pointed out the Matthew effect in science. That is, recognition in science is often disproportionate; eminent scientists gain disproportionately greater credit while unknown scientists gain disproportionately little credit for their contributions. Another interpretation is that the more a scientist's contribution has been recognised, the more the scientist's later work will be appreciated. The recognition of scientific contribution is skewed in favour of established scientists (Merton, 1988). Therefore, in order to be recognised at early stage of their career, young academics have to establish a sizable lab with a reasonable number of research students to carry out the research and to devote themselves to more publications in renowned journals. To achieve this, partly because of the need for a convincing track record, partly because of the efficiency to carry out further research, academic scientists normally cannot afford to switch subject areas/disciplines suddenly away from their PhD work. This naturally results in a significant importance in knowledge in specific subject areas for academic scientists.

Nevertheless, in recent years, there is increasing concern with the changing world of science. There is a consensus that public science is increasingly assessed by accountability and social responsibility and in many public research organisations, entrepreneurship and networking with a range of actors from different sectors are enormously encouraged (Funtowicz and Ravetz, 1993; Gibbons et al., 1994; Nowotny et al., 2001; Slaughter and Leslie, 1997; Ziman, 1996). As a result, researchers in public organisations, in addition to their roles as scientists, are at the same time becoming project managers and administrators to coordinate actors across sectors. These changes might challenge the traditional reward system in public science and the competences that research scientists should gain from their doctoral education might be expected to partly shift over time from substantive to more general and transferable skills as management and administration become a larger part of scientific life.

Industrial scientists generally work with very different expectations and demands from the academic/public sector. It is argued that industrial scientists often face tensions between professional science and industrial organisation (Kornhauser, 1962). Professional science concerns mainly contributions to knowledge, quality research and long-term program. On the other hand, industrial organisation favours profits, cost savings and normally short-term results. In industry, the key goal (a final target or product) is clear, teamwork is essential and deadlines are often very tight. Because manufacturing industry is highly product-oriented and because of the high uncertainty and risks involved in developing new products, firms normally adopt parallel strategies (Abernathy and Rosenbloom, 1969) for product development. This implies that an industrial scientist is likely to be involved in several research projects at the same time. As the success or failure in controlling new products' time to market will eventually translate into the performance of individual scientists, industrial scientists' abilities to handle research projects are vital. This reveals a crucial dimension differentiating the use of more general and transferable skills between industrial researchers and academic or public sector researchers.

However, this is not to say that the competences of industrial scientists lie mainly in transferable skills. Firms do basic research for many reasons. In some cases, basic research is the unplanned by-product of the attempt to solve specific industrial problems. Sometimes firms such as biotechnology companies do basic research that is near market to have first-mover advantages. In some other cases, large firms, due to their market power, might be confident enough to conduct basic research and expect, with their diversified products and resources, that at some point, findings from their basic research activities will eventually have good commercial uses (Rosenberg, 1990). Firms might also do basic research in order to cultivate capabilities to absorb research findings from other scientists (Cohen and Levinthal, 1989). Furthermore, in some companies, there is a strong culture of publishing. Stephan (1996), based on 1991 data, pointed out that, in the US, industrial journal publications accounted for around 16% of total publications for both the fields of chemistry and physics. In engineering, nearly a quarter of scientific and technical articles came from industry. Globally, Godin (1996), based on the 1989 data, reported that chemicals and pharmaceuticals were placed in first and second place in terms of numbers of industrial publications. The literature indicates that in the pharmaceutical industry, firms' reputation for openness and commitment to publication are important in postgraduate industrial scientists' employment decisions, both in the UK (Jones, 1992) and in the US (McMillam and Deeds, 1998). This implies that the practice of publication in industries such as chemicals and pharmaceuticals, where UK manufacturing industry is strongly based, is long established. This shows that a certain amount of substantive knowledge in related subject areas is necessary for industrial scientists to be seen as competent. However, as industrial scientists often work in product-oriented projects and race with time to launch new products, figuring out what works for product development is normally more important than understanding deeply why the solution works. Therefore, substantive knowledge used by industrial scientists is more likely to be general in certain subject areas rather than specific (as are PhD topics).

Many industrial scientists turn into dedicated managers gradually through career progression (Biddle and Roberts, 1994; Lavoie and Finnie, 1998). Such role transformation indicates that there are career moves for industrial scientists from the conventional technical occupations to employment outside the conventional occupations. Dedicated managers very often do not conduct scientific research any longer but are involved with company strategies and coordination among internal and external divisions. As the success or failure in controlling new products' time to market in product development may have become these dedicated managers' direct responsibility, this type of career move is likely to require greater emphasis on analytical skills, project management skills and problem-solving capability.

Apart from turning from research scientists into dedicated managers, many PhD-trained scientists enter private sectors in jobs other than research or technical departments in manufacturing. They often serve as consultants in knowledge-intensive business firms. The nature of their jobs is interdisciplinary, cross-organisational and international, as demonstrated by the study of Hargadon and Sutton (1997), who illustrated how one product design firm acts as a technology broker serving product design for several hundred different firms in over 40 industries. Furthermore, according to Creplet et al. (2001), experts and consultants play different roles in consultancy firms. Consultants often work in well-defined problems and their know-how lies in their ability to apply a particular toolbox in well-known contexts. However, in some situations, consultancy firms encounter problems that are unknown to their clients as well as to the firms and new solutions need to be developed. The capability needed is not the ability to provide analogy between known problems and solutions but to propose new patterns of interpretation. This knowledge production process often involves operation of a new panel of knowledge and interaction with epistemic community. This capability leads some consultants to be regarded as experts. Indeed, a team leader from a large international engineering consultancy firm pointed out the similarity between experts and doctoral students in their knowledge production process (preliminary interview conducted to prepare the survey):

> "Most of the projects come to my team because nobody in my company has a clue of how to solve the problems. It means that every time I look at new problems, I know that I do not know the answers and I also know that nobody in the company knows the answers. So you need to go through the process that only the PhD training can really teach you in order to solve these problems. . .Because you have been through the process of defining a problem and analysing it, next time when you encounter a completely different but equally challenging problem, you are not that scared. You know how to break the problem into pieces, to analyse it and come up with some answers."

In some other instances, S&E PhDs might even choose jobs that are outside the conventional technical occupations and outside occupations such as dedicated managers or consultants/experts. In any case, for jobs outside conventional PhD occupations, regardless of whether they are in management, in knowledge brokering or in other non-research tasks, knowledge in specific subject areas is less likely to be more important than general and transferable skills; these jobs are likely to need knowledge that is transferable and requires greater emphasis on the procedural dimensions to serve very diverse clients and situations.

The above discussion suggests some ideas of how knowledge may be used in different types of careers. The discussion is in line with Lam' (2004) typology of use of knowledge in different organisational forms. She argues that the professional bureaucracy organisational form is based on embrained knowledge, which is formal and theoretical, while the operating adhocracy (such as professional partnerships, software engineering firms and management consultancies) is based on embodied knowledge, which draws its capability from the know-how and problem solving skills embodied in individual experts. Drawing on Lam's (2004) typology, we suggest that different competences acquired from PhD training may have different values for S&E PhDs working in different career types: the conventional technical occupations, which correspond to the professional bureaucracy, may be likely to emphasise more formal knowledge in subject areas, while employment outside the conventional technical occupations, which is more close to the operating adhocracy, may be more likely to emphasise knowledge that is general and transferable. As a result, the usefulness of knowledge directly tied to subject areas and of knowledge that is more general and transferable may be perceived differently in different career types. This leads to our second research question:

(2) To what extent are competences developed through S&E doctoral education relevant for different career types?

4. Data and measures

4.1. Data

We explore the research questions through a complex survey of graduates from a UK research-based university, the University of Manchester. One of the main considerations of our research design is to overcome difficulties in accessing personal information due to the UK 1998 Data Protection Act. For exploratory purposes, our strategy was to adopt a single university setting to avoid the effects and complexities caused by different universities and regions. There are other benefits of studying S&E PhD graduates from the University of Manchester. Firstly, it is the largest single-site university in the UK and has renowned and well-developed engineering and physical science departments. Practically this provides a reasonable size sample from engineering and physical science disciplines. Second, it is a member of the UK Russell Group, which represents the top 20 leading universities in the UK (the University of Manchester was ranked in 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"). Its leading position in research means that it should offer attractive doctoral training and thus it is an academic environment where students, regardless of whether they aim at academic careers or simply want to have degrees that are respected by industrial employers, would like to obtain their doctoral degrees from. We also adopt the strategy of selecting home (UK and other EU) PhD students graduated from specific years to minimise culture and cohort effects.

The survey conducted comprises retrospective employment history (covering 7–10 years employment history to address the change in the distribution of career types but not too long to minimize non-response), types of knowledge acquired from doctoral education and how they are perceived as valuable in different jobs. It was conducted between April and July 2008. The population sampled for this survey includes all the home PhD students that graduated between 1998 and 2001 in science and engineering disciplines. The sampling frame comprises 512 names with UK addresses and 84 names with other EU addresses. The sampling strategy is a single stage clustered sampling (individuals as primary sampling units [PSUs] and jobs as secondary sampling units), and as all names in the sampling frame have the same selection probability and all jobs from individuals have the same selection probability, the sample is self-weighted. Such sampling strategy allows jobs to be clustered into individuals. It is assumed that individuals are independent from each other, while jobs are correlated with individuals to whom they belong.

The survey was conducted by post through the Alumni Office to preserve confidentiality. Our first wave of survey resulted in 82 responses in 4 weeks just before the response deadline. If e-mails were available, e-mail reminders were sent to encourage responses. After the deadline, 20 more respondents returned the survey questionnaires. A total of 91 UK and 11 other EU responses were obtained. There were 38 UK and 7 other EU undelivered returned questionnaires. The overall response rate is 18.51% at individual level (19.20% for UK addresses and 15.3% for other EU addresses).

As the sample is self-weighted, bias mainly comes from non-responses. At the individual level, the distributions of survey population according to gender, discipline, year of graduation and location (UK or other EU) are known. A characteristic comparison between respondents and non-respondents in these dimensions using chi-square tests for independence (Armstrong and Overton, 1977; Lawton and Parasuraman, 1980; Lambert and Harrington, 1990) indicates that there is no evidence showing that respondents and non-respondents at individual level are different in gender ($X^2=0.29$; df = 1; $p=0.590$), discipline ($X^2=1.073$; df = 1; $p=0.300$), year of graduation ($X^2=0.528$; df = 3; $p=0.913$) and location ($X^2=1.113$; df = 1; $p=0.291$) (Table A1). A total of 282 jobs are obtained (Table A2). As there is no information about the number of total jobs held by the surveyed PhDs, a comparison of the mean number of jobs held by each individual between the concurrent waves (Armstrong and Overton, 1977; Lambert and Harrington, 1990) indicates that there is no significant difference ($t(97)=1.134$; two-tailed $p=0.260$) between the number of jobs held by respondents from the first wave (mean = 2.92; SE = 0.130; $N=79$) and the number of jobs held by respondents from the second wave (mean = 2.60; SE = 0.245; $N=20$).

Based on the results of the characteristic comparison between respondents and non-respondents and the comparison of concurrent waves (between the first and the second waves), non-response bias appears to be insignificant. Therefore, as the average number of jobs held by our participants is 2.8, the total number of jobs in our survey population is estimated to be around 1669. Based on Cochran's sample size formula (Cochran, 1977), the obtained 282 jobs are adequate for running regressions for categorical data, with an alpha level of 0.1, 5% margin of error and the standard deviation of the scale as 0.5 for maximum variability (the estimated minimum sample size is 234). The final valid number of jobs for analysis is 268. There are very few cases of missing data due to information not given. Attrition due to such cases is assumed to be insignificant.

4.2. Analysing methods

The analysis in this paper is based on both individual level analysis and job level analysis. In Section 5.1, analysis is based on un-weighted descriptive data analysis at individual level. In Section 5.2, when jobs are used as analysing units, the analysing approach adopted is design-based (Cochran, 1977; Lehtonen and Pahkinen, 2003; Skinner et al., 1989). The design-based survey data analysing approach takes the complexity of sampling design and the existence of intra-cluster correlation into account and uses non-parametric variance estimators. Such non-parametric variance estimators are generally unbiased and consistent but result in higher variances and inefficiency (Skinner et al., 1989). The design-based approach estimates marginal effects of explanatory variables and serves for research aiming at exploratory purpose. This approach is different from the model-based approach which seeks to establish precise models, to estimate independent effects and to have predictive power.

Table 1
Career types of S&E PhDs, the University of Manchester's 1998–2001 home S&E PhD graduates, 7–10 years after graduation.

	First job (%)	Most recent job (%)
Academic/public research	42	30
Technical positions in manufacturing	21	12
Employment outside the conventional technical occupations	37	58
Total	100	100

As the sampling design is self-weighted and although it appears that there is no significant non-response bias, a post-stratification adjustment is applied to weight the gender-discipline-year of graduation-location subgroups so that they will be identical to those in the population. Analysing methods comprise design-based descriptive data analysis and design-based logistic regressions. The analysing tool is STATA Release 10.1. For survey data analysis, by default, the STATA svy command uses the linearisation method based on a first-order Taylor series linear approximation for covariance matrix estimation (Wolter, 1985) and the pseudolikelihood estimation to fit the model (Lehtonen and Pahkinen, 2003). For design-based logistic regression models, weighted version of the Hosmer–Lemeshow tests (Hosmer and Lemeshow, 1980) run through the STATA svylogitgof command developed by Archer et al. (2007) are applied to assess the goodness-of-fit for the models. The jackknife method based on sample reuse techniques for covariance matrix estimation is also available under the STATA svy command. Hence, logistic regression results using the linearisation method for covariance matrix estimation are compared with results using the jackknife method.

4.3. Measures

4.3.1. Career types

Each respondent was asked to provide information about the type of each job held after PhD training. Each respondent was also asked to provide information about tasks in each job held after PhD training. The variable "career type" is then constructed based on information given by respondents' job type and job tasks (details in Table A3). The academic/public research career type is restricted to PhDs conducting research tasks in academia or government/public/non-profit organisations. The technical positions in private sector manufacturing career type is restricted to PhDs conducting research, development, design or production in manufacturing; PhDs who have become dedicated managers in manufacturing are not considered as being engaged in this career type. The academic/public research and technical positions in private sector manufacturing career types are regarded as the conventional technical occupations. All other jobs are defined as employment outside the conventional technical occupations. This classification intends to explore the difference in the use of S&E PhD competences between the conventional technical occupations and the increasingly significant employment outside the conventional technical occupations. According to this measure, the distribution of our respondents' first jobs was 42% in academia/public research, 21% in technical positions in manufacturing and 37% in employment outside the conventional technical occupations. The distribution of the respondents' most recent jobs is 30% in academia/public research, 12% in technical positions in manufacturing and 58% in employment outside the conventional technical occupations (Table 1).

4.3.2. Types of knowledge/skills acquired from doctoral education

The discussion in Section 3.2 implies that different PhD competences may be more or less relevant in different career types. It is likely that PhD knowledge/skills directly tied to subject areas and PhD knowledge/skills that are more transferable are appreciated differently in jobs within and outside the conventional technical occupations. Within the conventional technical occupations, it is also likely that, compared to industrial scientists, scientists in academia or public research organisations rely on a quite different set of knowledge/skills acquired from doctoral education. With regard to knowledge/skills directly tied to subject areas, academic scientists, particularly in science and engineering, often start their career by extending their PhD work, while although knowledge in subject areas normally are important for industrial scientists as well, it is less likely that their work will be an extension of their PhD research.

When we refer to transferable skills, however, it is argued that the notion of transferability remains ambiguous because it is highly bounded with the context of application (Craswell, 2007). Pole (2000) argued that apart from substantive knowledge, doctoral students also gain more transferable skills such as technical skills and craft knowledge during their study. Technical skills are techniques that are required to conduct research effectively. They could be programming skills, the effective use of software and the ability to design a research and analyse the results. We classify them as application of information technology and data processing skills and general analytical skills. Craft knowledge, although closely linked to technical skills, emphasises the capability to make a research project work. This will involve project management skills, report writing and presentation skills and experimentation and fieldwork. Delamont and Atkinson (2001) reported shocks and uncertainties encountered by PhD students in biochemistry, earth science and physical geography when they realised that to make an experiment work is far more than the capability of being able to apply theories and techniques needed for the experiment. We therefore refer to this particular dimension of craft knowledge in making things work as problem solving capability.

Based on these distinctions, in the questionnaire, we asked respondents to rank the three most valuable types of knowledge/skills that they gained from their PhD and used in each of their jobs. That is, we were interested in measuring the perceived usefulness of a specific type of PhD knowledge/skills in a job. The most valuable knowledge/skills is given 3 scores; the second most important one is given 2 scores and the third is given 1 score. The knowledge/skills gained from doctoral education to be ranked are: (1) specialist knowledge in PhD topic; (2) general knowledge in PhD subject area; (3) application of information technology and data processing; (4) general analytical skills; (5) report writing and presentation skills; (6) project management skills; and (7) problem solving capability. Based on the same measure, for each job, each type of knowledge/skills acquired from doctoral education can be distinguished further by whether it has been selected as one of the three most valuable PhD skills in the job or not. To highlight the differences, a variable "important competence", which indicates whether a specific knowledge/skill has been selected as one of the three most variable PhD knowledge/skills in a job (coded as "yes" if it has been selected and "no" if not been selected), was created. At the level of jobs, it appears that "general analytical skills" and "problem solving capability" are perceived as one of the three most valuable PhD competences in more than half of the survey jobs in all three career types. "Specialist knowledge in PhD topic" and "general knowledge in PhD subject area" are perceived as at least somewhat important in more than half of the survey jobs in academic/public research. In general, perceived usefulness in "specialist knowledge in PhD topic", "general knowledge in PhD subject area" and "project management skills" appears to have greater variation by career types (Table 2).

Table 2
Perceived usefulness of PhD competences by career types, the University of Manchester's 1998–2001 home S&E PhD graduates, design-based descriptive data analysis. The number of observations is 268.

	Distribution in score (row percentage)				Selected as among the three most variable PhD competences (%)	Mean score	Linearised standard error
	3	2	1	0			
Specialist knowledge in PhD topic							
Academic/public research	40	17	6	37	63	**1.597**	0.199
Technical positions in manufacturing	10	10	0	80	20	0.515	0.188
Employment outside the conventional technical occupations	6	2	4	88	12	0.254	0.081
General knowledge in PhD subject area							
Academic/public research	18	38	2	42	58	**1.310**	0.175
Technical positions in manufacturing	18	21	4	57	43	1.006	0.255
Employment outside the conventional technical occupations	8	8	4	80	20	0.430	0.109
Application of information technology and data processing							
Academic/public research	2	7	8	83	17	0.279	0.105
Technical positions in manufacturing	6	13	4	77	23	0.482	0.187
Employment outside the conventional technical occupations	5	13	11	71	29	0.528	0.111
General analytical skills							
Academic/public research	6	24	25	45	55	**0.917**	0.165
Technical positions in manufacturing	15	25	24	36	64	**1.188**	0.221
Employment outside the conventional technical occupations	28	34	10	28	72	**1.624**	0.139
Report writing and presentation skills							
Academic/public research	7	11	18	64	36	0.603	0.139
Technical positions in manufacturing	2	14	27	57	43	0.610	0.152
Employment outside the conventional technical occupations	9	12	20	59	41	0.714	0.121
Project management skills							
Academic/public research	0	5	8	87	13	0.186	0.063
Technical positions in manufacturing	6	13	15	66	34	0.587	0.174
Employment outside the conventional technical occupations	10	5	29	56	44	0.690	0.114
Problem solving capability							
Academic/public research	13	25	18	44	56	**1.059**	0.175
Technical positions in manufacturing	28	33	11	28	72	**1.612**	0.244
Employment outside the conventional technical occupations	27	38	11	24	76	**1.695**	0.131

5. Results

5.1. *Dominance of employment outside the conventional technical occupations*

For the University of Manchester's 1998–2001 home S&E PhD graduates, academic/public research appears to be the most popular career option for their first jobs (42%) (Table 3). However, among those who were in this career type for their first jobs, only one quarter (27%) secured permanent positions initially (Table 4). The other three quarters were in fixed term contracts, mostly in post-doctoral research positions. Whether this choice is viable for long-term career development is uncertain. Indeed, 7–10 years after graduation, only around 67% of those who initially were in this career type remain in academia/public research. For those who are most recently in this career type, 36% are still in fixed term contracts. 28% of those who initially were in this career type have moved to employment outside the conventional technical occupations. Overall, 7–10 years after graduation, the percentage of PhDs in this career type has decreased from 42% to 30%. Over one third of those who remain in this career type (36%) do so even though they have not been able to secure permanent positions, a fact highlighting the lengthening of stages for many academic careers. Moreover, the alternative for respondents who move out of this career type seems to lie in employment outside conventional technical occupations (Table 3). Thus, in a long-term perspective, this career type cannot be seen as the dominant one for our survey respondents.

Technical positions (research, development, design or production) in manufacturing were neither initially nor currently the main alternative of academia/public research. The proportion of University of Manchester' 1998–2001 home S&E PhD graduates in this career type has decreased from 21% when first graduated to 12% 7–10 years after graduation. For those who initially were in this option, 60% have moved to positions outside conventional technical positions. In a case-by-case investigation, 7 out of 12 of such moves are due to the promotion from researchers to dedicated managers.

Table 3
Distribution of career types, tabulation by first job and by the most recent job, the University of Manchester's 1998–2001 home S&E PhD graduates, 7–10 years after graduation.

First job	The most recent job			
	Academia/public research	Technical positions in manufacturing	Employment outside the conventional technical occupations	Total *N*
Academia/public research	26 (67%)[a]	2 (5%)[a]	11 (28%)[a]	39 (42%)[b]
Technical positions in manufacturing	1 (5%)[a]	7 (35%)[a]	12 (60%)[a]	20 (21%)[b]
Employment outside the conventional technical occupations	1 (3%)[a]	2 (6%)[a]	32 (91%)[a]	35 (37%)[b]
N	28 (30%)[a]	11 (12%)[a]	55 (58%)[a]	94 (100%)

[a] Row percentage.
[b] Column percentage.

Table 4
Distribution of career types by employment condition, first job and the most recent job, the University of Manchester's home 1998–2001 S&E PhD graduates, 7–10 years after graduation. Percentage shown is row percentage.

	First job		The most recent job	
	Fixed term	Permanent	Fixed term	Permanent
Academia/public research	29 (73%)	11 (27%)	10 (36%)	18 (64%)
Technical positions in manufacturing	2 (9%)	20 (91%)	0 (0%)	11 (100%)
Employment outside the conventional technical occupations[a]	2 (6%)	33 (94%)	1 (2%)	50 (98%)
N	34 (35%)	64 (65%)	11 (12%)	79 (88%)

[a] The number used in the distribution excludes cases of those who are self-employed; the career type of those who are self-employed is classified as employment outside the conventional technical occupations; there is one self-employed case in terms of first job and are four self-employed cases in terms of the most recent job.

Table 5
Employment sectors of S&E PhDs, the University of Manchester's home 1998–2001 S&E PhD graduates, 7–10 years after graduation.

	First job		The most recent job	
	Sector percentage	Percentage of unconventional jobs within sector	Sector percentage	Percentage of unconventional jobs within sector
Academia/public organisations	47	15	41	28
Private sector	53	59	59	80

More than one third of our respondents (37%) initially took employment outside the conventional technical occupations when they first graduated. 7–10 years after graduation, there is little sign of our respondents in this career type moving out, as 91% of them still remain in this career type; that is, those who initially were in this career type continue to stay (Table 3). This career type is not only the most stable one, but also the main destination for many respondents moving from the other two career types. Indeed, for our respondents, 7–10 years after graduation, this career type accounts for 58% of all employment.

Therefore, academia/public research cannot be regarded as the main career type for the University of Manchester's 1998–2001 home S&E PhD graduates. Similarly, very few of our surveyed S&E PhDs are actually working as industrial scientists in large corporate R&D laboratories in manufacturing, although many of them are working in industry. These results highlight the significance of jobs outside the conventional technical occupations for S&E PhDs. Indeed, although employment outside the conventional technical occupations might not account for the largest proportion of the survey respondents' first employment, it was however only 5% behind the largest employment sector. Moreover, 94% of initial employment in this career type was permanent and 91% of those who were in this career type remain in this sector. Furthermore, over time, it appears to be the main destination for movers from the other two career types. Thus, it is not surprising that 7–10 years after graduation, this career type accounts for 58% of total employment of our respondents and has become the dominant career type. The employment dynamics inside and outside the conventional technical occupations is invisible if the discussion mainly focuses on employment dynamics inside and outside academia/public organisations. Table 5 shows the stable career patterns of our S&E PhDs over time when the analysis is based on the latter case and the significant increase in unconventional jobs within the sectors over time.

To highlight the heterogeneity of the unconventional technical S&E PhD jobs, a detailed investigation looking into our sample case by case shows that among individuals' most recent jobs that fall outside the conventional technical occupations, 29% are private sector dedicated managers, 34% are technical positions in services, mainly in programming, software development or consultancy, 20% are academic/public non-research positions, 11% are school teaching or other types of lecturing positions, and the rest are private sector marketing positions, patent attorneys, sales positions, technical writers, business analysts, etc.

5.2. *Different competences mix for different career types*

Overall, based on scores (Table 2) given by the survey respondents, knowledge directly tied to subject areas, particularly "specialist knowledge in the PhD topic", is regarded as of great importance in academia/public research. It is less important in technical positions in manufacturing, although "general knowledge in PhD subject area" is quite important in this career type. It is of limited significance in employment outside conventional technical occupations. In general, knowledge/skills acquired from doctoral education related to general and transferable skills receive higher scores by respondents working in employment outside the conventional technical occupations, lower scores by respondents in technical positions in manufacturing and even lower scores by respondents in academia/public research positions. However, "general analytical skills" and "problem solving capability" are important in all career types, but to different degrees.

Design-based logistic regressions are applied to test whether perception of the relative importance of each specific competence in different career types is significantly different. In this way, we are able to identify specific PhD competences for different career types. For each type of knowledge/skills acquired from doctoral education, a logistic regression using "important competence" as dependent variable and "career type" (comprising the three possible career types as categories and the career type of academic/public research as reference category) as explanatory variable is applied.[2] The regression aims at evaluating how the propensity of S&E PhDs' ranking of a specific type of knowledge as "among the three most valuable PhD knowledge/skills in a job", compared to the propensity to rank this type of knowledge as "not among the three most valuable PhD knowledge/skills in a job", varies in different career types. The analysing units are individual jobs, and thus the total valid 268 jobs are all used in the analysis. Whether the respondents are from engineering or science disciplines might affect their perception of usefulness of knowledge in jobs and therefore, the variable "engineering" (science disciplines as reference category) is used as control variable. Results are shown in Table 6. Additional control variables such as gender, year of graduation and location (UK or other EU) are explored, but they do not change the impres-

[2] An alternative approach is to compare several means of the original scores by career types (such as Tukey's test). Using this approach does not change the results presented in this paper.

Table 6
Relative perceived usefulness of PhD competences by career types. Comparison uses academic/public research as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as "among the three most valuable types of PhD knowledge/skills in a job" rather than not been selected at all by career types using design-based logistic regressions based on the University of Manchester's 1998–2001 home S&E PhD graduates with 7–10 years job histories.

	The linearised method		The jackknife method	
	Odds ratio	90% CI	Odds ratio	90% CI
Specialist knowledge in PhD topic				
Career type				
Technical positions in manufacturing	0.130***	0.052–0.322	0.130***	0.049–0.344
Employment outside the conventional technical occupations	0.071***	0.031–0.159	0.071***	0.029–0.170
Engineering	2.968**	1.315–6.699	2.969**	1.238–7.116
General knowledge in PhD subject area				
Career type				
Technical positions in manufacturing	0.540	0.238–1.227	0.541	0.226–1.292
Employment outside the conventional technical occupations	0.171***	0.090–0.326	0.171***	0.087–0.335
Engineering	1.639	0.799–3.364	1.693	0.764–3.520
Application of information technology and data processing				
Career type				
Technical positions in manufacturing	1.623	0.557–4.730	1.623	0.481–5.484
Employment outside the conventional technical occupations	2.139	0.946–4.833	2.139	0.894–5.114
Engineering	0.442	0.174–1.122	0.442	0.157–1.264
General analytical skills				
Career type				
Technical positions in manufacturing	1.369	0.557–3.363	1.369	0.529–3.545
Employment outside the conventional technical occupations	2.091*	1.056–4.140	2.091*	1.029–4.247
Engineering	1.498	0.756–2.969	1.498	0.724–3.098
Report writing and presentation skills				
Career type				
Technical positions in manufacturing	1.369	0.591–3.171	1.369	0.565–3.319
Employment outside the conventional technical occupations	1.258	0.656–2.410	1.258	0.642–2.464
Engineering	0.795	0.395–1.599	0.795	0.381–1.659
Project management skills				
Career type				
Technical positions in manufacturing	3.501**	1.334–9.189	3.502*	1.216–10.085
Employment outside the conventional technical occupations	5.173***	2.462–10.871	5.173***	2.341–11.432
Engineering	0.527	0.226–1.226	0.527	0.205–1.356
Problem solving capability				
Career type				
Technical positions in manufacturing	2.151	0.861–5.374	2.151	0.800–5.780
Employment outside the conventional technical occupations	2.672**	1.366–5.266	2.672**	1.330–5.370
Engineering	0.613	0.308–1.221	0.613	0.296–1.269

N observations: 268.
* Significance (two tailed): .1.
** Significance (two tailed): .05.
*** Significance (two tailed): .01.

sion of the association between career types and the perceived usefulness of each specific type of PhD knowledge/skills in a job. The results from the linearised methods and the jackknife methods are very similar but the jackknife methods result in wider range of confidence intervals (CI). All regressions pass the STATA svylogitgof goodness-of-fit tests.

Compared to the survey respondents working in academia/public research, respondents in technical positions in manufacturing are more likely to select "project management skills" as valuable PhD knowledge/skills in their jobs rather than not select it at all, but less likely to select "specialist knowledge in PhD topic" as valuable PhD knowledge/skills in their jobs. Compared to the survey respondents working in academia/public research, respondents employed outside the conventional technical occupations are more likely to select "general analytical skills", "project management skills" and "problem solving capability" as valuable PhD knowledge/skills in their jobs rather than not select them at all, but less likely to select "specialist knowledge in PhD topic" and "general knowledge in PhD subject area" as valuable PhD knowledge/skills in their jobs. It appears that there is no significant difference in the propensities with which "application of information technology and data processing" and "report writing and presentation skills" are perceived as valuable in different career types; this indicates that these two particular types of knowledge/skills acquired from doctoral education are less relevant in differentiating the PhD competences that may be useful in different career types.

A further comparison between technical positions in manufacturing (as reference category) and employment outside the conventional technical occupations using design-based logistic regressions (Table 7) shows that it is possible to distinguish between the two career types in terms of "general knowledge in PhD subject area", which is perceived as more valuable for technical positions in manufacturing but is less in employment outside the conventional technical occupations. Apart from the difference in the perceived usefulness of "general knowledge in PhD subject area", there is no significant difference in the perceived usefulness of all other PhD knowledge/skills between the two career types (Table A4). This implies that although PhD competence in technical positions in manufacturing also relies on knowledge that is directly tied to subject areas, compared to employment outside the conventional technical occupations, it is the general type of knowledge in the subject area, rather then the specific type of knowledge in the PhD topic, where the competence resides.

Thus, for the University of Manchester's 1998–2001 home S&E PhD graduates, PhD competences in academia/public research relatively lie in knowledge that is directly tied to subject areas. In

Table 7
Relative perceived usefulness of "general knowledge in PhD subject areas" between technical positions in manufacturing and employment outside the conventional technical occupations. Comparison uses technical positions in manufacturing as reference category. Data source and other explanations are the same as in Table 5.

	The linearised method		The jackknife method	
	Odds ratio	90% CI	Odds ratio	90% CI
General knowledge in PhD subject area				
Career type				
Employment outside the conventional technical occupations	0.317**	0.142–0.703	0.317**	0.134–0.746
Engineering	1.683	0.752–4.017	1.683	0.659–4.297

N observations: 185.
** Significance (two tailed): .05.

contrast, PhD competences in employment outside conventional technical occupations lie in the more general and transferable skills. PhD competences in technical positions in manufacturing lie in both knowledge that is directly tied to subject areas but in a more general form of knowledge in the PhD subject area (rather then specialist knowledge in PhD topic) and in a less intensive level of the general and transferable skills than it is used in employment outside the conventional technical occupations. In absolute terms, "general analytical skills" and "problem solving capability" acquired from doctoral education are valuable for jobs regardless of career types.

We also explored whether the perception of the usefulness of a specific type of knowledge/skills acquired from doctoral education in a specific career type is affected by respondents' previous employment in different career types. The results indicate that there is no significant difference.

6. Discussion and conclusions

This paper has examined the career patterns of the University of Manchester's 1998–2001 home S&E PhD graduates and which knowledge and skills developed through doctoral education are perceived as useful in the jobs they have held. We derive three broad results. First, in our case, academic/public research positions have become a secondary career type for the surveyed S&E PhDs in a long run. The academia/public research career type is characterised by a high level of employees with fixed term contracts, both in terms of first jobs, and in jobs after 7–10 years in the labour market. It shows that there is a large number of contract researchers struggling but determined to pursue this career type. From the very beginning, most of the PhDs who enter the private sector do not become industrial scientists in manufacturing. Even if they were industrial scientists initially, they transferred to dedicated managers gradually. The majority of the PhDs work in employment outside the conventional technical occupations, i.e. academic or public non-research or private sector outside the manufacturing technical jobs. This career type is not only successful at retaining its members, but is also the destination of the other career types.

Second, the study represents our first attempt to unpack the black box of S&E PhD jobs. We revealed the dynamics of S&E PhDs' employment in conventional and unconventional occupations that is otherwise invisible in traditional analyses based on employment dynamics inside and outside the academia/public sector. We have pointed out the increasing significance of S&E PhDs working in non-research academic/public research jobs and the dominance of jobs in managerial activities, business services or consultancy in industry.

Third, the way in which knowledge and skills acquired from doctoral education are perceived as useful by respondents in their jobs differs depending upon career types. Our study shows that doctoral education in science and engineering provides different competences that are relatively more valuable for different career types. These are knowledge directly tied to subject areas for academia/public research, both knowledge directly tied to subject areas but the more general type rather than in PhD topic and the more general and transferable skills for technical positions in manufacturing, and mainly the more general and transferable skills for employment outside the conventional technical occupations.

The career patterns that emerge from our survey show quite a different story from Martin and Irvine's (1981) UK case in radioastronomy. It confirms that over time, there has been a shift for S&E PhDs to work outside academia and academia has become a secondary employment sector or S&E PhDs while industry has become the major employment sector in the UK. This trend is in line with the American cases (Stephan, 1996; Stephan et al., 2004). Furthermore, our case corresponds to the PPARC survey (DTZ Pieda Consulting, 2003) that indicates the dominance of employment outside the industrial R&D laboratories. However, our case is different from Mangematin's (2000) French case, where in engineering science, a larger proportion of PhDs secured permanent academic positions (graduated between 1984 and 1996, in 1997, 44% secured permanent positions in academia) and most of the French PhDs working in the private sector were in research positions (37%), compared to less than 20% permanent positions in academia/public research 7–10 years after graduation in our UK case (based on Table 4) and 12% in technical positions in manufacturing. The similarity between the UK and the US cases and the difference in the French case indicate that although scholars in many countries are concerned with the decrease in academic jobs, international differences in career patterns of S&E PhDs remain and further research may look into the underlining institutional mechanisms that shape the differences.

The dominance of employment outside the conventional technical occupations for S&E PhDs present in the private sector and the increasing significance of this career type in the academic/public sector show the diversified career options for S&E PhDs and their wider roles in the economy; it suggests that S&E PhDs are contributing to knowledge production and absorption across many sectors in the economy. Although jobs outside the conventional technical occupations range from sales to school teaching, most of them are dedicated managerial positions, consultancy, programming or software developing positions in business services, and non-research positions in academia or public organisations. Hence, an in-depth examination to further untangle the heterogeneity of this career type, particularly the roles of S&E PhDs as dedicated managers and experts or consultants in business services, will further advance the notion of manpower training effect of public funded basic science through S&E doctoral education (Larédo, 2007; Martin and Irvine, 1981; Mowery and Sampat, 2005; Pavitt, 1991).

The study uses subjective measures to investigate the perceived usefulness of different knowledge/skills acquired from doctoral education in different career types. The diversity in the perception of the usefulness of different knowledge/skills acquired from doctoral education in our case may be interpreted as the effectiveness of the modern doctoral education in providing an adequate knowledge base for employment across different career types. This interpretation is not only in line with the manpower training effect of public funded basic science, but also reveals how and what types of knowledge produced in academia is transferred to different sectors through PhDs' career mobility. However, as most of our surveyed PhDs are working in employment outside the conventional technical occupations and as PhD competences in this career type mainly lie in more general and transferable skills, this may raise the question of the uniqueness of the PhD path to acquire such skills and how exactly a doctoral qualification may enhance one's employability if the person intends to enter employment outside the conventional technical occupations. These questions are open for debate and further research.

Appendix A.

See Tables A1–A4.

Table A1
Assessing non-response bias using the characteristic comparison method.

	Respondent	Non-respondent	Survey population at individual level
Gender			
Male	77 (75%)	385 (78%)	463 (78%)
Female	25 (25%)	109 (22%)	134 (22%)
Total	102 (100%)	494 (100%)	596 (100%)
$X^2 = 0.29$; df = 1; $p = 0.590$			
Discipline			
Engineering	26 (25%)	103 (21%)	129 (22%)
Science	76 (75%)	391 (79%)	467 (78%)
Total	102 (100%)	494 (100%)	596 (100%)
$X^2 = 1.073$; df = 1; $p = 0.300$			
Year of graduation			
1998	22 (22%)		128 (21%)
1999	22 (22%)		147 (25%)
2000	30 (30%)		182 (31%)
2001	26 (26%)		139 (23%)
Total	100 (100%)		596 (100%)
$X^2 = 0.528$; df = 3; $p = 0.913$			
Location			
UK	91 (89%)	421 (85%)	512 (86%)
Other EU	11 (11%)	73 (15%)	84 (14%)
Total	102 (100%)	494 (100%)	596 (100%)
$X^2 = 1.113$; df = 1; $p = 0.291$			

Table A2
Definition of a job.

Include any job (including self-employment), full-time or part-time, which you did for at least 6 months (or which you expect to last for at least 6 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.

Table A3
The construction of variable "career type".

Each respondent was asked to provide information about employment code of each job after PhD training among the following options	Each respondent was also asked to provide information about tasks in each job after PhD training among	Combination: employment code + job tasks	Career type
(1) University faculty position	(a) Managerial	(1)	Academic/public research
(2) University research position	(b) Research/development	(2)	
(3) Other university post	(c) Other, specify	(7)	
(4) Private sector company – service		(5) + (b)	Technical positions in manufacturing
(5) Private sector company – manufacturing		All other combinations	Employment outside the conventional technical occupations
(6) Private sector company – other			
(7) Research post in a government/public/voluntary organisation			
(8) Other position in a government/public/voluntary organisation			
(9) Running own company			
(10) Freelance worker			
(11) Other type of employment			

Table A4
Relative perceived usefulness of "general knowledge in PhD subject areas" between technical positions in manufacturing and employment outside the conventional technical occupations. Comparison uses technical positions in manufacturing as reference category. Data source and other explanations are the same as in Table 5.

	The linearised method		The jackknife method	
	Odds ratio	90% CI	Odds ratio	90% CI
Specialist knowledge in PhD topic				
Career type				
Employment outside the conventional technical occupations	0.543	0.199–1.477	0.543	0.182–1.621
Engineering	2.827*	1.034–7.728	2.827	0.936–8.537
General knowledge in PhD subject area				
Career type				
Employment outside the conventional technical occupations	0.317**	0.142–0.703	0.317**	0.134–0.746
Engineering	1.683	0.752–4.017	1.683	0.659–4.297
Application of information technology and data processing				
Career type				
Employment outside the conventional technical occupations	1.320	0.507–3.438	1.320	0.445–3.913
Engineering	0.481	0.165–1.401	0.481	0.143–1.611
General analytical skills				
Career type				
Employment outside the conventional technical occupations	1.567	0.711–3.456	1.567	0.679–3.619
Engineering	2.435*	1.019–5.817	2.435	0.944–6.278
Report writing and presentation skills				
Career type				
Employment outside the conventional technical occupations	0.910	0.429–1.929	0.910	0.412–2.009
Engineering	0.642	0.277–1.489	0.642	0.262–1.574
Project management skills				
Career type				
Employment outside the conventional technical occupations	1.479	0.649–3.371	1.479	0.600–3.648
Engineering	0.562	0.221–1.434	0.562	0.196–1.611
Problem solving capability				
Career type				
Employment outside the conventional technical occupations	1.243	0.549–2.817	1.243	0.510–3.028
Engineering	0.621	0.266–1.448	0.621	0.252–1.532

N observations: 185.
* Significance (two tailed): .1.
** Significance (two tailed): .05.

References

Abernathy, W.J., Rosenbloom, R.S., 1969. Parallel strategies in development projects. Management Science 15 (10), 486–505.
Almeida, P., Kogut, B., 1999. The localization of knowledge and the mobility of engineers in regional networks. Management Science 45 (7), 905–917.
Archer, K.J., Lemeshow, S., Hosmer, D.W., 2007. Goodness-of-fit tests for logistic regression models when data are collected using a complex sampling design. Computational Statistics & Data Analysis 51, 4450–4464.
Armstrong, J.S., Overton, T.S., 1977. Estimating nonresponse bias in mail surveys. Journal of Marketing Research 14 (3), 396–402.
Biddle, J., Roberts, K., 1994. Private sector scientists and engineers and the transition to management. The Journal of Human Resources 29 (1), 82–107.
Braddock, D.J., 1992. Scientific and technical employment, 1990–2005. Monthly Labor Review 115 (2), 28–41.
Burgess, R.G., 1997. The changing context of postgraduate education and training in the UK. In: Burgess, R.G. (Ed.), Beyond the First Degree: Graduate Education Lifelong Learning and Careers. SRHE/Open University Press, Buckingham.
Cervantes, M., 2001. Mobilising human resource for innovation. In: OECD Growth Background Papers No. 2. OECD, Paris.
Cochran, W.G., 1977. Sampling Techniques, 3rd ed. Wiley, New York.
Cohen, W.M., Levinthal, D.A., 1989. Innovation and learning: the two faces of R&D. The Economic Journal 99 (397), 569–596.
Committee of Vice-Chancellors and Principles, 1988. The British PhD. CVCP, London.
Craswell, G., 2007. Deconstructing the skills training debate in doctoral education. Higher Education Research & Development 26 (4), 377–391.
Creplet, F., Dupouet, O., Kern, F., Mehmanpazir, B., Munier, F., 2001. Consultants and experts in management consulting firms. Research Policy 30, 1517–1535.
Dany, F., Mangematin, V., 2004. Beyond the dualism between lifelong employment and job insecurity: some new career promises for young scientists. Higher Education Policy 17, 201–219.
David, P.A., Foray, D., 2002. An introduction to the economy of the knowledge society. International Social Science Journal 54 (171), 9–23.
DeFillippi, R.J., Arthur, M.B., 1994. The boundaryless career: a competency-based perspective. Journal of Organizational Behavior 15 (4), 307–324.
Delamont, S., Atkinson, P., 2001. Doctoral uncertainty: mastering craft knowledge. Social Studies of Science 31 (1), 87–107.
Department for Innovation, Universities & Skills, 2008. Innovation Nation. HMSO, London (accessed on 20.10.09) http://www.dius.gov.uk/innovation/ innovation_nation.
Department of Education and Science White Paper, 1987. Higher Education: Meeting the Challenge. HMSO, London.
Dosi, G., Freeman, C., Fabiani, S., 1994. The process of economic development: introducing some stylised facts and theories on technologies, firms and institutions. Industrial and Corporate Change 3 (1), 1–45.
DTZ Pieda Consulting, 2003. A Study of the Career Paths of PPARC PhD Students (accessed on 17.05.09) http://www.so.stfc.ac.uk/publications/pdf/ PiedaNew-Cohort.pdf.
Enders, J., 2002. Serving many masters: the PhD on the labour market, the everlasting need of inequality, and the premature death of Humboldt. Higher Education 44, 493–517.
Enders, J., 2005. Broader crossing: research training, knowledge dissemination and the transformation of academic work. Higher Education 49, 119–133.
Finn, M.G., Baker, J.G., 1993. Further jobs in natural science and engineering: shortage or surplus? Monthly Labor Review 116 (2), 54–61.
Foray, D., Lundvall, B., 1996. The knowledge-based economy: from the economics of knowledge to the learning economy. In: OECD Employment and Growth in the Knowledge-based Economy. OECD, Paris.
Fox, M.F., Stephan, P.E., 2001. Careers of young scientists: preferences, prospects and realities by gender and field. Social Studies of Science 31 (1), 109–122.
Freeman, C., 1992. Formal scientific and technical institutions in the national systems of innovation. In: Lundvall, B.Å. (Ed.), National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. Pinter, London.
Funtowicz, S.O., Ravetz, J.R., 1993. The emergence of post-normal science. In: van Schomberg, R. (Ed.), Science, Politics, and Mobility. Scientific Uncertainty and Decision-Making. Kluwer, Dordrecht.
Gibbons, M., Limoges, C., Nowotny, H., Schwartman, S., Scott, P., Trow, M., 1994. The Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. Sage, London.
Giret, J., Recotillet, I., 2004. The impact of CIFRE programme into early careers of PhD graduates in France. In: Paper Presented to the 16th Annual Conference of the European Association of Labour Economics, Lisbon.
Godin, B., 1996. Research and the practice of publication in industries. Research Policy 25, 587–606.
Hargadon, A., Sutton, R.I., 1997. Technology brokering and innovation in a product development firm. Administrative Science Quarterly 42 (4), 716–749.
Harris Report, 1996. Review of Postgraduate Education. HEFEC, CVCP and SCOP (accessed 08.03.09) http://www.hefce.ac.uk/pubs/hefce/1996/m14_96.htm.
Hosmer, D.W., Lemeshow, S., 1980. Goodness-of-fit tests for the multiple logistic regression model. Communications in Statistics A9 (10), 1043–1069.

Jones, O., 1992. Postgraduate scientists and R&D: the role of reputation in organisational choice. R&D Management 22 (4), 349–358.
Kogut, B., Zander, U., 1992. Knowledge of the firm, combination capability, and the replication of technology. Organization Science 3, 383–397.
Kogut, B., 2008. Knowledge, Options, and Institutions. Oxford University Press, New York.
Kornhauser, W., 1962. Scientists in Industry: Conflict and Accommodation. University of California Press, Berkeley and Los Angeles.
Lam, A., 2004. Societal institutions, learning organisations and innovation in the knowledge economy. Research on Technological Innovation and Management Policy 8, 43–67.
Lam, A., 2007. Knowledge networks and careers: academic scientists in industry–university links. Journal of Management Studies 44 (6), 993–1015.
Lambert, D.M., Harrington, T.C., 1990. Measuring nonresponse bias in costumer service mail surveys. Journal of Business Logistics 11 (2), 5–25.
Larédo, P., 2007. Revisiting the third mission of universities: toward a renewed categorization of university activities? Higher Education Policy 20, 441–456.
Lavoie, M., Finnie, R., 1998. The occupational dynamics of recent Canadian engineering graduates inside and outside the bounds of technology. Research Policy 27, 143–158.
Lavoie, M., Roy, R., Therrien, P., 2003. A growing trend toward knowledge work in Canada. Research Policy 32, 827–844.
Lawton, L., Parasuraman, A., 1980. The impact of the marketing concept on new product planning. The Journal of Marketing 44 (1), 19–25.
Lehtonen, R., Pahkinen, E.J., 2003. Practical Methods for Design and Analysis of Complex Surveys, 2nd ed. John Wiley & Sons, Chichester.
Leonard, D., 2000. Transforming doctoral studies: competencies and artistry. Higher Education in Europe XXV (2), 181–192.
Madsen, T., Mosakowski, E., Zaheer, S., 2003. Knowledge retention and personnel mobility: the nondistructive effects of inflows of experience. Organization Science 14 (2), 173–191.
Mangematin, V., 2000. PhD job market: professional trajectories and incentives during the PhD. Research Policy 29, 741–756.
Mangematin, V., 2001. Individual careers and collective research: is there a paradox? International Journal of Technology Management 22 (7/8), 670–675.
Martin, B., Irvine, J., 1981. Spin-off from basic science: the case of radioastronomy. Physics in Technology 12 (5), 204–212.
Martinelli, D., 1999. Labour market performance of French PhDs: a statistical analysis. In: OECD Mobilising Human Resources for Innovation. OECD, Paris.
McMillam, G.S., Deeds, D.L., 1998. The role of reputation in the recruitment of scientists. R&D Management 28 (4), 349–358.
Merton, R.K., 1973. The Sociology of Science. University of Chicago Press, Chicago.
Merton, R.K., 1988. The Matthew effect in science, II cumulative advantage and the symbolism of intellectual property. ISIS 79, 606–623.
Miozzo, M., Grimshaw, D. (Eds.), 2006. Knowledge Intensive Business Services: Organizational Forms and National Institutions. Edward Elgar, Cheltenham.
Mowery, D.C., Sampat, B.N., 2005. Universities in the national innovation systems. In: Fagerberg, J., Mowery, D.C., Nelson, R.R. (Eds.), The Oxford Handbook of Innovation. Oxford University Press, New York.
Murray, F., 2002. Innovation as co-evolution of scientific and technological networks: exploring tissue engineering. Research Policy 31, 1389–1403.
Murray, F., 2004. The role of academic inventors in entrepreneurial firms: sharing the laboratory life. Research Policy 33, 643–659.
Nowotny, H., Scott, P., Gibbons, M., 2001. Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty. Polity Press, Cambridge.
OECD, 1991. Science and Technology Policy: Review and Outlook. OECD, Paris.
OECD, 1992. Technology-Economy Programme. Technology and The Economy: The Key Relationship. OECD, Paris.
OECD, 2000. A New Economy? The Changing Role of Innovation and Information Technology in Growth. OECD, Paris.
Park, C., 2005. New variant PhD: the changing nature of the doctorate in the UK. Journal of Higher Education Policy and Management 27 (2), 189–207.
Pavitt, K., 1991. What makes basic research economically useful? Research Policy 20, 109–119.
Pelz, D.C., Andrews, F.M., 1966. Scientists in Organizations. John Wiley and Sons, New York.
Pole, C., 2000. Technicians and scholars in pursuit of the PhD: some reflections on doctoral study. Research Papers in Education 15 (1), 95–111.
Robin, S., Cahuzac, E., 2003. Knocking on academia's doors: an inquiry into the early careers of doctors in life science. Labour 17 (1), 1–23.
Rosenberg, N., 1990. Why do firms do basic research (with their own money)? Research Policy 19 (2), 165–174.
Rosenkopf, L., Almeida, P., 2003. Overcoming local search through alliances and mobility. Management Science 49 (6), 751–766.
Skinner, C.J., Holt, D., Smith, T.M.F., 1989. Analysis of Complex Surveys. Wiley, New York.
Slaughter, S., Leslie, L.L., 1997. Academic Capitalism. The Johns Hopkins University Press, Baltimore.
Stephan, P.A., 1996. The economics of science. Journal of Economic Literature 34, 1199–1235.
Stephan, P.E., Gurmu, S., Sumell, A.J., Black, G., 2007. Who's patenting in the university? Evidence from the survey of doctorate recipients. Economics of Innovation and New Technology 16, 71–99.
Stephan, P.E., Sumell, A.J., Black, G.C., Adams, J.D., 2004. Doctoral education and economic development: the flow of new Ph.D.s to industry. Economic Development Quarterly 18, 151–167.
The Dearing Report, 1997. Higher Education in the Learning Society: The National Committee of Inquiry into Higher Education. HMSO, London.
Wolter, K.M., 1985. Introduction to Variance Estimation. Springer, New York.
Ziman, J., 1996. Postacademic science: constructing knowledge with networks and norms. Science Studies 9 (1), 67–80.
Zucker, L.G., Darby, M.R., Armstrong, J.S., 2002a. Commercializing knowledge: university science, knowledge capture, and firm performance in biotechnology. Management Science 48 (10), 138–153.
Zucker, L.G., Darby, M.R., Torero, M., 2002b. Labor mobility from academe to commerce. Journal of Labor Economics 20 (3), 629–660.