The labour market of science and engineering PhDs

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Abstract

This paper examines the labour market of science and engineering PhDs. Drawing on a survey of science and engineering PhDs from a UK research-based university, this study employs job mobility histories to explore the labour market of science and engineering PhDs, including their knowledge and skill development. The results show that organisational careers are still an important feature of the labour market of science and engineering PhDs. Moreover, the paper derives distinctive features of the different segments of the labour market of science and engineering PhDs. We find that those employed in academic/public research experience internal labour markets but with a sharp contrast between core and periphery workers. Those employed outside the conventional technical occupations experience a highly hybrid labour market (strong occupational labour market features but promotions within organisations). Finally, those in technical positions in private sector manufacturing experience relatively more structured internal labour market features. Implications are drawn for the flow of knowledge and skills from science and engineering PhDs.

1 Introduction

Since the mid 1990s, the number of doctoral awards in the UK has almost doubled.[1] With the increase in the number of graduates with doctoral qualifications, however, scholars have raised concern about the lack of permanent job opportunities for science and engineering (S&E) PhDs in traditional occupations in academia and public laboratories (Dany and Mangematin, 2004; Giret and Recotillet, 2004; Huisman et al., 2002; Mangematin, 2000; Martinelli, 1999; Robin and Cahuzac, 2003, Lee et al., 2010). Moreover, the other main traditional employment opportunity for S&E PhDs, R&D positions in large manufacturing corporations, may be in decline due to structural changes and shifts in employment from manufacturing to services.[2] Despite these new challenges and opportunities for the employment of S&E PhDs, there has been little research on the labour market of S&E PhDs.

[1] The number of awards for doctorates in the UK increased from 4969 in 1994/95 to 9930 in 2008/09; Data include both full-time and part-time in all subjects; UK students only. Data source: The UK Higher Education Statistics Agency, http://www.hesa.ac.uk/index.php?option=com_datatables&Itemid=121&task=show_category&catdex=3, accessed online on 12 Oct. 2010.

[2] According to the UK National Statistics workforce jobs by industry, the share of employment in manufacturing fell from 29% in 1978 to 8% in 2010. On the other hand, the share of employment in services rose from 61% to

Labour market economists and sociologists of work have advanced our understanding of knowledge and skill development and job mobility by developing different models of labour markets, introducing the concepts of internal and occupational labour markets (Doeringer and Piore, 1971; Marsden 1986). These concepts have been recently challenged by the literature that argues that in the so-called new or knowledge economy, knowledge workers are free from organisational control and are more likely to experience 'network' or 'boundaryless' careers rather than organisational careers (Cappelli, 1999; DeFillippi and Arthur, 1998; DeFillippi, 2002; Hobday, 2000; Jones, 1996; Pink, 2001; Reed, 1996). This new research may have important implications for our understanding of many of the traditional occupations of S&E PhDs, such as those in university, public laboratories or industrial research, since they have been typically associated with organisational job security and stability (Stinchcombe, 1979). While there have been a few studies exploring the demand, recruitment or other particular aspects of the careers of S&E PhDs,[3] there have been no efforts to analyse comprehensively the labour market of S&E PhDs or to explore the careers of S&E PhDs in the knowledge economy.

The aim of the paper is to analyse the distinctive features of the labour market of S&Es PhDs. We address this research gap through a new analytical and methodological approach, by analysing job mobility histories to understand the labour market of S&E PhDs from a cross-organisational/labour market segment perspective. We draw on a survey designed to obtain retrospective data from graduates of a UK research-based university with 7-10 years job histories. Our survey is designed to gather information on the 'direction' of job mobility. This refers to whether the job move is upward or lateral, intra- or inter-organisational or within or across labour market segments. These indicators are vital signals pointing at different labour market types. The clustered sampling strategy and design-based non-parametric analysing methods used maximise the potential of analysis at different levels (individual, job and job transition). Both the data collection and the methods of analysis so far have been rarely applied in innovation studies. Our research shows striking results, many of which run counter to conventional perspectives. We show that organisational careers are still an important feature of the labour market of S&E PhDs. Moreover, we derive distinctive features of the different segments of the labour market of science and engineering PhDs. We find that those employed in academic/public research experience internal labour markets but with a sharp contrast between core

83%. Data source: The UK Office for National Statistics, http://www.statistics.gov.uk/STATBASE/tsdataset.asp?vlnk=495, accessed online on 12 Oct. 2010.

[3] For example, Mangematin (2000) explored the criteria for hiring PhD graduates in different sectors and incentives of PhD students. Gaughan and Robin (2004) investigated the entry into a permanent academic position for PhDs in France and the US. Stephan et al. (2007a) examined the demand for the highly skilled in nanotechnology in the US. Fox and Stephan (2001) revealed expectations and realities regarding employment among S&E PhDs in the US. Dany and Mangematin (2004) discussed employability of people with a doctoral degree in life science in France. Other studies explored the determinants of PhD career outcome (Giret and Recotillet, 2004; Robin and Cahuzac, 2003), the value of doctoral research training (Enders, 2002, 2005) and how S&E PhDs may contribute to research activities in industry (Stephan et al., 2004), particularly their role in the commercialisation of academic results (Lam, 2007; Murray, 2002, 2004; Stephan et al., 2007b; Zucker et al., 2002a, 2002b).

and periphery workers. Those employed outside the conventional technical occupations experience a highly hybrid labour market (strong occupational labour market features but promotions within organisations). Finally, those in technical positions in private sector manufacturing experience relatively more structured internal labour market features.

The paper is organised as follows. Section 2 reviews the literature on labour market segmentation and the gaps in our understanding of the labour market of S&E PhDs. Section 3 outlines the methodology. Section 4 presents the findings. Section 5 and Section 6 present the discussion and conclusion.

2 The labour market of science and engineering PhDs: labour market segmentation and gaps in the literature

This study builds on labour market research by economists and sociologists to explore the particular features of the labour market of science and engineering PhDs. In the 1970s, economists and sociologists started to observe segmentation within the labour markets. Doeringer and Piore (1971) introduced the distinction between the primary and the secondary labour markets, or the dual labour market segments. Piore (1971) stressed that the primary segment, which is normally situated in the Internal Labour Markets (ILMs), *"offers jobs which possess several of the following traits: high wages, good working conditions, employment stability and job security, equity and due process in the administration of work rules, and chances for advancement"* (pp. 92). The internal labour markets (ILMs) refer to the employment system where the career ladder is within an organisation, is characterised by promotions within the organisation, low turnover, long job tenure, organisation-specific skills and seniority based rewards (Doeringer and Piore, 1971; Kalleberg and Sørenson, 1979; Baron, et al., 1986). It was suggested that more highly skilled workers were more likely to be protected by job security offered by the ILMs (Mace, 1979; George and Shorey, 1985). On the other hand, the secondary segment often involves less attractive jobs that offer "*low wages, poor working conditions, considerable variability in employment, harsh and often arbitrary discipline, little opportunity to advance"*. (pp.92). Reich et al. (1973) also argued that labour market segments are *"distinguished by different labour market characteristics and behavioral rules"* (pp. 359). They pointed out that the differentiation between the primary and the secondary segments is mainly based on stability characteristics. They argued that primary jobs require and develop stable working habits and emphasise on-the-job training. Therefore, workers are offered high wages and upward job ladders. In contrast, for jobs in secondary segment, stable working habits are often not required or even discouraged. These jobs often feature low wages, high turnover and the lack of job ladders. Furthermore, secondary jobs are often filled by unskilled, minority, female or young workers.

Other contributions identify segmentation across occupations, industries and firms (Mace, 1979; George and Shorey, 1985; Osterman, 1988). Osterman (1975) proposed that jobs in the primary segment might be further divided based on degree of autonomy. Similarly, Reich et al. (1973) argued

that there could be segmentation in the primary segment between subordinate jobs and independent jobs. In their classification, subordinate jobs refer to jobs that are routinised and encourage workers to be disciplined, to follow rules and authority and to accept the goal of employers. Factory workers and many office administrative jobs fall into this category. By contrast, independent jobs encourage creativity, problem solving capabilities and self-initiating characteristics, often have professional standards for work and individual motivation and achievement are highly rewarded. Many professional jobs fall into this category.

Other classifications of different labour markets have been proposed. Osterman (1988) classifies employment subsystems into the industrial model (representing the organisation of blue-collar work), the salaried model (featuring most of the white-collar work such as managers and professionals), the craft subsystem (characterised by greater mobility and loyalty to the skills or profession than to the organisation - the employment system of programmers is a typical example) and the secondary subsystems (containing jobs that lack career prospects, within or via inter-organisational movement). Other boundaries used to divide labour market segments include a combination of qualifications required for jobs and firm size (Blossfeld and Mayer, 1988), firm employment systems (Köhler et al., 2006) and race or gender (Reich et al., 1973).

More significantly, although skilled workers are likely to have good jobs that are protected by job security offered by the ILMs, they are also associated with the employment system of the occupational labour markets (OLMs) (Althauser and Kalleberg, 1981; Marsden, 1986). The OLMs are characterised by a high level of inter-organisational mobility, a low level of inter-occupational mobility and progressive enhancement in skills and responsibility through external upward movement (Althauser and Kalleberg, 1981). However, job moves in the OLMs do not always involve promotions or pay rise, as sometimes employees move because of personal reasons (Marsden, 1986). The main characteristic of the OLMs is that the occupation-wide skills enable workers to move across organisations. Thus, the OLMs show features of highly standardised formal education/training requirements, the existence of strong occupational associations and strong occupational identification (Marsden, 1986; Tolbert, 1996).

The key determinant in distinguishing the two ideal types of labour markets particularly associated with skilled workers lies in the degree of specificity in knowledge and skill development (Becker, 1964; Eyraud et al., 1990; Williamson, 1981), i.e. the "portability" of knowledge and skills (Estevez-Abe et al., 2001). Williamson (1981) pointed out that the degree of specificity in knowledge and skill development, i.e. human asset specificity, can be identified in two ways: 1) the degree of skills that are specific to an organisation and 2) the availability of skills with which productivity can be merited. The more organisation-specific and rare the skills are, the more specific the knowledge and skills are. Hence, the ILMs feature a higher degree of specificity in knowledge and skill development that is

particular valuable or specific to the existing organisations but is not necessarily appreciated by others, while the OLMs feature knowledge/skill development that is not specific to existing employers and can be easily circulated and appreciated by other employers within the occupation. Therefore, the ILMs are associated with a higher level of intra-organisational upward mobility and in an ILM environment, one would expect a greater risk of job downgrading when changing the organisation (Eyraud et al., 1990). On the other hand, the OLMs are associated with a higher-level of inter-organisational mobility (but not necessarily upward) within occupations (hence low inter-occupational mobility).

In short, studies in this tradition indicate that skilled and educated workers are more likely to be protected by job stability and security and have better job prospects in upward progression, and the association between skilled/educated workers and their career outcomes as it appears through career trajectories is characterised either by intra-organisational mobility or by inter-organisational mobility within occupations. Employees in a pure ILM would be expected to have career mobility and progressions predominantly within the same organisations, while employees in a pure OLM would experience predominant inter-organisational mobility within occupations. However, in real life, often labour markets show intermediate job mobility, i.e. a mixture of intra- and inter-organisational job moves. Therefore, DiPrete and McManus (1993) argued that in reality many professional jobs are simultaneously situated within the ILMs and within the OLMs and they label labour markets that accommodate such jobs as "compound labour markets". They further pointed out that, as a result, "compound labour markets" simultaneously provide organisation-specific skills and occupational transferable skills. Based on this, it would be expected that when real job mobility of knowledge workers is examined, features of the "compound labour markets" are more likely to be observed. Furthermore, the way to describe labour markets of knowledge workers may also lie in how the features of the ILMs and the OLMs are combined and whether the features of the ILMs or the OLMs are more explicit.

Although studies generally suggested that the highly skilled are likely to be offered job security, it is also argued that due to social and economic changes such as market stagnation, job loss, market uncertainty and technological change in the modern industrial economies such as the UK and the US, the labour markets and employment relations of which are more deregulated, organisations are adopting the Flexible Firm strategies (Atkinson, 1984; Atkinson and Meager, 1986; Ledwith and Colgan, 1996; Kalleberg, 2001, 2003) to response to market pressures and to become more flexible. The Flexible Firm model stresses that organisations are using manpower strategies to look for two main types of organisational flexibility. First, functional or internal flexibility refers to the ability of employers to redeploy employees quickly and smoothly between activities and tasks or from one task to another (Atkinson, 1984; Kalleberg, 2003). The implication is that employees are expected to be multi-skilled. For instance, this might mean the deployment of workers between indirect and direct

production jobs (Atkinson, 1984). It is also suggested that the use of functional flexibility is often accomplished by the use of "High Performance Work Organisations" (HPWO) (Walton, 1994). Such work organisations empower workers to become involved in decision-making, to work in a multi-discipline project teams or act as entrepreneurs and enhance their commitment to the organisations by a series of quality control measures and by linking their compensation more directly with organisational performance (Kalleberg, 2003). The reasoning is that because individuals are increasingly involved in decision-making, individuals' human capital is the key to organisational success. Hence, organisational performance is determined by getting individual incentives right and the solution is seen as linking pay with performance (Lazear and Shaw, 2007). Second, numerical or external flexibility refers to the ability of organisations to adjust the size of their workforce in response to the fluctuation of demands by using workers who are not in their regular permanent full-time employment (Atkinson, 1984; Kalleberg, 2003). Atkinson (1984) further argued that in order to seek these two kinds of flexibility at the same time, there is an emerging organisational structure where workforce is polarised into the "core" and "peripheral" groups. Workers in the core group are most likely to be full-time permanent employees; they participate in organisations' key activities and are provided with favourable career prospects. However, increasingly, their employment security comes at the cost of accepting functional flexibility. That is, the core workers are expected to be multi-skilled, to be flexible in changing careers and retraining and to have their pay assessed by performance. However, in any case, the core workers are insulated from medium term market fluctuations and at most expect changes in tasks and responsibilities. On the other hand, the peripheral group comprises part-time, temporary and contract workers who are provided with little job security and progression. This group of workers is directly exposed to market fluctuations, as they can be easily dismissed if the employers no longer need them or unable to afford them. In this model, the highly skilled are not immune from becoming peripheral workers and typical examples are consultants and independent professionals (Kalleberg, 2003).

The indication that knowledge workers may work as free agents (Pink, 2001; Reed, 1996) because of the power of knowledge in the knowledge economy and how they are able to carry their knowledge with them across employers results in many studies that explore the derivation of careers of the highly skilled from the ILMs to the OLMs or even the boundaryless careers (DeFillippi and Authur, 1994). DeFillippi and Authur (1994) defined boundaryless careers as "*sequences of job opportunities that go beyond the boundaries of single employment settings*" (pp. 307). Furthermore, it is argued that the boundaryless careers are in opposition to the traditional bounded organisational careers, but do not characterise any single career form. There are hence several meanings attached to boundaryless careers: person-centred career mobility across separate employers, employability outside the present employer, external networks, the breaking down of the traditional hierarchical advancement principles, a person's rejection of existing career opportunities for personal or family reasons or any meaning of careers interpreted by individual career actors (Arthur and Rousseau, 1996).

However, critics pointed out that the construct of the boundaryless careers itself is somewhat boundaryless (Feldman and Ng, 2007), ranging from the objective and the subjective dimensions of career success to the physical and the psychological boundaries of career mobility. Even if we focus mainly on the objective and physical components of the boundaryless careers, the construct of the boundaryless careers is considerably unstructured and goes beyond the structured labour market concepts such as the ILMs and the OLMs, as both the ILMs and the OLMs highlight organised formal job ladders, either through seniority within an organisation or through occupational credentials/experiences within an occupation. Two aspects of the boundaryless careers indicate their unstructured nature. First, to a great extent, the boundaryless careers fit the concept of organisations' increasing interests in seeking functional flexibility through the adoption of the network/project-based organisation, a key HPWO characteristic which shows a new type of work organisation that deviates from the hierarchical single organisation-based setting towards a network/project-based organisational setting (Jones, 1996; DeFillippi and Arthur, 1998; DeFillippi, 2002; Hobday, 2000). The network/project-based organisational setting breaks the traditional functional department-based task allocations, where job descriptions are stable and predictable, and instead comprises dedicated members from all functional departments, as well as suppliers and clients, to work full time for a project on a "real time" coordination basis (DeFillippi, 2002). Although it is generally not suited to the mass production of commercial goods, it has been considered as a highly innovative, efficient and flexible form of organisation to deal with specific non-routine activities and complex tasks such as R&D and new product development (Hobday, 2000). Particularly in the service enhanced project-based organisations, project members work in an environment that is not confined to the functional departments' or employers' boundaries, physically and psychologically. Hence, one of the implications of boundaryless careers is that through the various types of networks, members in the project-based organisations or industries tend to be involved in job mobility across organisations in search of more interesting or significant projects, higher status, visibility or economic returns (Jones and DeFilippi, 1996). Indeed, many studies in job mobility in high-tech industries (Saxenian, 1996), film industry (Jones, 1996; DeFilippi and Arthur, 1998), design industry (Vinodrai, 2006), financial services and telecommunications sector (May et al., 2002) seem to show evidence of the shift towards the network/project-based work organisation that exhibit high rate of inter-organisational job mobility, and the encouragement of university-industry collaborations also provides such potential for academia and academic researchers (Lam, 2007).

Second, DeFillippi et al (2006) further suggested that, because of their capabilities to learn, knowledge workers are able to bring a combination of individual motivation, expertise and personal relationships into the workplace. They demonstrated cases of individuals establish their careers by changing not only employers but also occupational identities. For instance, in their cases, one actress applied her knowledge and skills in theatre to eventually become a director of customer service. Another

regulatory affairs director at a health care firm, after being made redundant, was able to use his expertise in regulations to help a start-up company in health care products and become the Chief Operating Officer at the firm. Therefore, the boundaryless careers further imply the possibility of job mobility across occupations. Hence the concept of the boundaryless careers is not only opposed to that of the organisational careers, but also goes beyond the concept of the occupational careers.

Finally, because the concept of boundaryless careers also highlights individuals' control and management of their own careers through learning and networking (DeFillippi and Arthur, 1996), this approach to careers actually focuses on individuals. It is fundamentally different from the institutional approach of the ILMs and the OLMs, which emphasising formal job ladders by focusing on groups, organisational structure and the political bargaining process among groups (Osterman, 2009).

Building on these issues, we suggest that there are a number of gaps in the literature. In particular, three features of labour markets need to be addressed in order to understand the labour market and careers of S&E PhDs. The first is the need to illuminate potential segmentation within the S&E PhD labour market. In order to compare with the less skilled or unskilled workers, the literature on labour markets tends to treat all highly skilled workers as a homogeneous group (Doeringer and Piore, 1971; Edwards et al., 1975; George and Shorey, 1985; Mace, 1979; Marsden, 1986; O'Connor, 1973; Osterman, 1988), apart from very few that argued that the highly skilled might also become peripheral workers (Kalleberg, 2003). One consequence of this is that different patterns of career behaviour that correspond to different labour market segments of knowledge workers often are invisible. Indeed, there is an absence of a classification scheme of labour market segments that can fully capture the characteristics of the knowledge economy. An insight into the nature of the segments within the S&E PhD labour market is provided by studies that demonstrate distinctive differences in incentives between academic scientists and industrial scientists (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). Nevertheless, these categories seem insufficient to capture the observed characteristics of the knowledge economy for a comprehensive analysis of careers and of the labour market of S&E PhDs. Many studies have shown the significant flow of undergraduate scientists and engineers to non-technical jobs (Lavoie and Finnie, 1998; Lavoie et al., 2003). Similarly the UK Particle Physics and Astronomy Research Council (DTZ Pieda Consulting, 2003) showed that out of those PhD students that had been sponsored by the council who worked in the private sector, most were employed outside the conventional technical occupations. Indeed, 29% were employed in software design/solutions/management, 24% in financial services and 24% in business services. Since individual knowledge and skill development is bound with organisational knowledge (Kogut and Zander 1992; Nelson and Winter, 1982), there are strong reasons to believe that knowledge and skill development outside these conventional S&E PhD occupations may be qualitatively different from knowledge and skill development within the conventional S&E PhD occupations. Our previous work

(Lee et al., 2010) derived three career types of the S&E PhDs. A first includes employment in academic/public research and a second includes industrial scientist and engineer positions in manufacturing. These two career types are considered as the conventional S&E PhD jobs. We classified all other jobs outside the conventional technical occupations as a third career type and was labelled as employment outside the conventional technical occupations. We also revealed how workers in different career types perceive differently the usefulness of different types of knowledge acquired from doctoral training in jobs. We have shown how knowledge and skill development differs among the three career types (Lee et al., 2010), therefore suggesting a potential segmentation of the S&E PhD labour markets based on the three career types.

The second feature that needs to be addressed concerns the knowledge and skill development of S&E PhDs. Efforts have been made to unpack the nature of human assets/ resources (Autor and Handel, 2009; Bozeman et al., 2001; Dietz and Bozeman, 2005; Nordhaug, 1993). Nevertheless, there is still very little research that explores the knowledge and skill development of S&E PhDs in different employment contexts. Exceptions include studies that show that industrial experience make a difference in academic scientists' network patterns (Dietz and Bozeman, 2005) and that doctoral training involving collaborations with industry helps careers in industry (Dany and Mangematin, 2004; Giret and Recotillet, 2004; Mangematin, 2000; Martinelli, 1999; Robin and Cahuzac, 2003). Even considering these efforts, research in this area remains underdeveloped. The traditional distinction between organisation-specific and general skills in labour markets (Becker, 1964; Eyraud et al., 1990) is far from adequate to grasp S&E PhDs' knowledge and skill development. The special nature of S&E doctoral training in labour markets is well documented (Pelz and Andrews 1966; Mangematin, 2001). The relationship between organisation-specific/general knowledge and job mobility is also theorised in labour market studies (Althauser and Kalleberg, 1981; Doeringer and Piore, 1971; Eyraud et al., 1990; Marsden, 1986; Williamson, 1981). By contrast, the role that sector-specific knowledge plays in labour markets however has rarely been discussed. Estevez-Abe et al (2001) defined sector-specific skills as skills that are specific to and raise productivity in a specific sector but not in others. This concept is much in line with the argument that sectors differ in knowledge base and innovation patterns (Malerba, 2002; Pavitt, 1984). That is, knowledge differs across sectors in terms of domains and the boundaries of sectoral systems are affected by the knowledge base and technologies of the sectors. For instance, Malerba and Orsenigo (2000) argued that knowledge in different sectors differs in the degree of accessibility, i.e. opportunities of gaining knowledge external or internal to a specific sector. For instance, source of knowledge of a sector may be mainly based on in-house R&D or may rely on external linkages of scientific breakthroughs in academia. Furthermore, knowledge is cumulative and the production of new knowledge builds on the existing knowledge (Dosi, 1982; Nelson and Winter, 1977). Because sector-specific knowledge is expected to be general and portable across organisations in a sector but it is specific when compared to other sectors, we argue that this type of knowledge should be studied separately in the labour markets. Therefore, we suggest that S&E

PhD knowledge and skills comprise not only knowledge and skills acquired through doctoral training, but also knowledge and skills that are specific and can only be valued within organisations, industries or occupations, as well as knowledge and skills that are general and can be used in a wide range of applications.

The third issue concerns the need to address careers from a comparative cross-sectoral perspective. Existing literature on career/job mobility of the highly skilled workers has focused on either a single industry or on general descriptive analysis, due to particular research designs and, to a large extent, the lack of longitudinal data. These methodological constraints affect our understanding of the dynamics of job mobility and how career mobility patterns of S&E PhDs might relate to knowledge and skill development in a cross-organisational, industrial or sectoral perspective. In particular, this offers limited insight into the extent to which knowledge workers' careers may be boundaryless or the extent to which organisational life may still be important. For instance, many studies have illustrated the potential dominance of the boundaryless careers in the microelectronics, film, design, financial services and telecommunications sector (DeFilippi and Arthur, 1998; Jones, 1996; May et al., 2002; Vinodrai, 2006; Saxenian, 1996). However, an integrated approach to the internal and the external labour markets might offer better insights into how organisations might adopt a variety of employment strategies that result in a continuous redrawing of the boundaries between the internal and the external employment structures (Grimshaw and Rubery, 1998). Hence, without a cross-organisational/industrial/sectoral analysis of careers of knowledge workers using real job histories, the ability to establish how 'boundaryless' or how 'organisational' knowledge workers' careers really are is limited. That is why Schein (2007) and Arthur (2008) called for studies that are based on individuals' job histories of real career mobility 'across' organisations/sectors/industries to examine the extent to which organisational or occupational boundaries are relevant to knowledge workers. Although some studies have focussed on early careers of S&E PhDs or on S&E PhDs in the public or the private sectors or research or non-research positions with cross-sectional data (Dany and Mangematin, 2004; Ender, 2002, 2005; Fox and Stephan, 2001; Giret and Recotillet, 2004; Mangematin, 2000; Martin and Irvine, 1981; Mason and Wagner, 1994; Stephan, 1996; Stephan et al., 2004; Robin and Cahuzac, 2003), we are not aware of any study featuring a dataset of longer job histories of S&E PhDs to examine labour market features of job mobility and knowledge and skill development from a cross-organisational and cross-occupational perspective. Our paper thus addresses the research questions of how labour market features differ by S&E PhD career types, and what knowledge is transferred through the job mobility of S&E doctoral personnel.

3 Methodology

3.1 Research setting

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 was 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. Furthermore, there are a number of benefits of studying S&E PhD graduates from the University of Manchester. Firstly, the University of Manchester is the largest single-site university in the UK and has renowned and well-developed engineering and physical science departments. This provides a reasonable size sample. 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 for graduate students either seeking an academic career or wanting to obtain a degree respected by industrial employers. We also adopt the strategy of selecting home (UK and other EU) PhD students graduated from specific years to minimise culture and cohort effects.

3.2 Data collection method

We adopt a complex survey design to collect data. The population sampled for this survey includes all the home PhD students that graduated between 1998 to 2001 from the science and engineering disciplines from the University and all jobs they have had since doctoral training. The sampling frame comprises 512 names with UK addresses and 84 names with other EU addresses at the individual level. 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 (Appendix 1) from individuals have the same selection probability, the sample is self-weighted. Such a sampling strategy allows jobs to be clustered into individuals. It is assumed that individuals are independent from each other, whereas jobs are correlated with the individuals to whom they belong.

The survey collects retrospective employment history (at the individual and job level). It covers 7-10 years employment history in order both to allow for changes in jobs and to minimise non responses caused by too long a period. A questionnaire intending to gather information to answer the research questions has been developed. The questionnaire comprises three main parts. The first part asks the respondent about personal demographic information such as gender, year of graduation, discipline and the nature of the PhD research project. The second part asks the respondent about the details of their current job. These details include whether the respondent is in employment (paid employment, self-employed, etc), when employment started in the current job, employment sector (a university, a government organisation, a private manufacturing or service firm, etc.), job title, job task (managerial mainly, research, development, etc.), whether the job is permanent, whether the job is full-time, whether the job is the result of a promotion from the previous job and whether the job involves a change of employer. The third part asks the respondent their job history since the PhD award. For each of the respondent's previous jobs, all questions in the second part are also asked in this part but in a

very concise format. Aiming at developing a questionnaire that not only maximises information obtained but also is user friendly, we designed a questionnaire that asks all the relevant questions with a layout of four A4 pages printed double sided on an A3 page.

3.3 The survey

The survey was conducted between April and July 2008 by post through the Alumni Office to preserve confidentiality. Our first wave of the survey resulted in 82 responses in four weeks. Where 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 could mainly come from non-responses. At the individual level, the distribution 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 across 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) (Appendix Table A2).

A total of 282 jobs are obtained. 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 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). The number of collected jobs for analysis is 268. There are very few cases of missing data due to missing information. Attrition due to such cases is assumed to be insignificant.

Two types of units of analysis are used. The first unit of analysis is the individual. The second type of analysing unit is the job transition. A job transition indicates a change from a previous job to the subsequent job. This unit of analysis is mainly used in the assessment of the UK S&E PhD labour market features based on labour market theories, particularly in assessing whether a job transition involves a change in employer or in occupation, whether the transition is associated with a promotion and the type of knowledge and skills that are perceived as the most useful in the transition.

We limited our study to respondents with UK addresses only to eliminate international differences in labour market features. We also used respondents previously or currently in professional jobs only. In this smaller sample, 90 responses and 161 job transitions are used for analysis (Table 1).

Table 1: Demographic characteristics of respondents,

Year of graduation		Gender		Whether currently in employment	
1998	21%	Male	72%	In paid employment	90%
1999	25%	Female	28%	Running own company/freelancing	3%
2000	29%			Unemployed/looking after family	7%
2001	25%				

Note: UK address only. N=90

3.4 Methods of analysis

The analysis is based on both the individual level and the job level (job transitions). When the individual is used as the analysing unit, analysis is based on un-weighted descriptive data analysis. When the job transition is used as the analysing unit, 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 is particularly suitable 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.

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 such as the design-based chi-square tests for independence. 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).

3.5 Measures

Three key indicators are explored in this paper and they are organisational mobility, occupational mobility and knowledge and skill development. The use of these indicators intends to differentiate the ILMs and the OLMs, two labour market models that are closely linked with the highly skilled (Table 2). While we discussed above organisational mobility in detail, here we discuss further the construct of

occupational mobility. Knowledge and skill development is measured by the perceived usefulness of different types of knowledge in jobs. Details of the operationalisation of these indicators are outlined below. This literature on labour market theories (Althauser and Kalleberg, 1981; Doeringer and Piore, 1971; Eyraud et al., 1990; Marsden, 1986) suggests that ILMs are associated with intra-organisational upward mobility and OLMs with both inter-organisational upward and non-promotion mobility. It also suggests that OLMs are associated with intra-occupational mobility. In ILM, there is high specificity of knowledge and skill development and in OLMs low specificity of knowledge and skill development.

Table 2: Indicators of the ILMs and the OLMs

	Organisational mobility				Occupational mobility		Degree of specificity in knowledge and skill development	
	Intra-organisational upward	Intra-organisational non-promotion	Inter-organisational upward	Intra-organisational non-promotion	Intra-occupational	Inter-occupational	Higher	Lower
ILMs	√				--	--	√	
OLMs			√	√	√			√

Note: The indicator of occupational mobility is only relevant to the OLMs

3.5.1 Types of organisational mobility

We asked respondents to indicate for each of their jobs, whether they were promoted from the previous job and whether the job mobility involved a change in employer. This resulted in four possible types of organisational mobility involved in a job transition: 1) intra-organisational upward mobility, 2) inter-organisational upward mobility, 3) intra-organisational non-promotion mobility and 4) inter-organisational non-promotion mobility.

Based on job transitions collected from our sample of respondents with UK addresses, design-based descriptive data analysis indicates that 38% of job transitions are classified as intra-organisational upward mobility, 22% are classified as inter-organisational upward mobility, 9% are classified as intra-organisational non-promotion mobility and 31% are classified as inter-organisational non-promotion mobility (Table 3).

Table 3: Distribution of the types of organisational mobility from job transition data, percentages

Type of organisational mobility	%
Intra-organisational upward mobility	38
Inter-organisational upward mobility	22
Intra-organisational non-promotion mobility	9
Inter-organisational non-promotion mobility	31
Total	100

Note: Design-based descriptive data analysis. Number of observations= 157. Analysing unit= the job transition.

3.5.2 Types of occupational mobility

Herr and Cramer (1984) argued that personal occupational identity is acquired through characteristics such as commitment, planning, and seeing what one does at the present time as well as in the future. This however means that occupational classification systems can be defined in various ways such as types of work (physical and non-physical) (Dawis et al., 1979), social-economic groups (such as blue-collar and whit collar) (Herr and Cramer, 1984), occupational interests (artistic, scientific, mechanical, etc.) (Droege and Padgett, 1979), or a further grouping of occupational titles (LFS User Guide Volume 5, 2009). So what would be potential occupations for S&E PhDs and how might they be classified? Occupational mobility refers to job mobility across one defined occupational group to another. We adopt Cheng and Kalleberg's (1996) definition according to which *"occupation refers to technical work activities that are transferred among employers and to skills that are transportable from firm to firm*" (pp.1238). This definition indicates that technical activities and skills are expected to be relatively homogeneous within one occupation but distinctly different from other occupations. That is to say, this definition uses knowledge and skills as boundary for occupations. Therefore, we might also define the proposed three S&E PhD labour market segments (i.e. academic/public research, technical positions in the private sector manufacturing and employment outside the conventional occupations) as three different occupational groups. This is in line with argument by Reich et al. (1973) that labour market segment may cut vertically across the occupational hierarchy. Hence, types of occupational mobility are constructed based on information given by respondents on the labour market segments. For each job transition, the type of occupational mobility can be defined by the labour market segment the previous job was in and by the labour market segment the subsequent job belongs to after the job mobility. Therefore, nine types of mobility are possible (see Table 4). However, the distribution of the types of job transitions within and across labour market segments shows that only five types of mobility are significant, as each of all the other types accounts for no more than 2% of the surveyed job transitions. Three involve mobility within labour market segments: 1) remaining a researcher in the academic/public after the job transition (19%), 2) remaining an industrial scientist or engineer in manufacturing after the job transition (11%) and 3) remaining employed outside the conventional technical occupations after the job transition (47%). And two involve mobility across segments: 4) from researcher in the academic/public research to employment outside the conventional technical occupations (8%) and 5) from industrial scientist or engineer in manufacturing to employment outside the conventional technical occupations (9%) (Table 4).

3.5.3 Types of knowledge/skills perceived to be valuable in a job transition

With regard to the types of knowledge and skills that are relatively more valuable for each job transition, we asked respondents to select one skill from the following four: 1) skills acquired from the PhD training, 2) organisation-specific skills acquired from the previous position, 3) sector-specific skills acquired from the previous position and 4) general skills. The assessment of what skills from a

previous job are useful in the subsequent job makes it possible to evaluate knowledge and skill development and their flow in the labour market.

Table 4: Distribution of the types of job mobility within/across segments/occupations.

Labour market segment of previous job	Labour market segment of job after job transition Data shown in percentages		
	A researcher in academic/public research	An industrial scientist or engineer in manufacturing	Employment outside the conventional technical occupations
A researcher in academic/public research	19	2	8
An industrial scientist or engineer in manufacturing	1	11	9
Employment outside the conventional technical occupations	1	2	47

Note: Design-based descriptive data analysis. Number of observations=157. Analysing unit: the job transition

From all job transitions collected in the smaller sample comprising only respondents in professional jobs with UK addresses, the design-based descriptive data analysis indicates that the percentage rating "skills acquired from PhD" as the most useful in the job transition is 27%. The figures are 18% for "organisation-specific skills acquired from previous position", 27% for "sector-specific skills acquired from previous position" and 28% for "general skills" (Table 5).

Table 5: Perceived usefulness of knowledge and skills in a job transition

Type of knowledge/skills	Perceived as the most useful in a job transition (%)
Skills acquired from PhD	27
Organisation-specific skills acquired from previous position	18
Sector-specific skills acquired from previous position	27
General skills	28
Total	100

Note: Design-based descriptive data analysis. Number of observations= 155. Analysing unit= the job transition.

4 Empirical findings

4.1 Organisational life is still important

We use the following definitions to describe job mobility within or across labour market segments. Stayers in academic/public research refer to respondents who have had job mobility always within academic/public research since graduation (indicating a sequence of job mobility always from and to academic/public sector researcher after each job transition). Similarly, stayers in technical positions in

the private sector manufacturing refer to respondents who have always been working as industrial scientists or engineers in manufacturing since graduation (indicating a sequence of job mobility always from and to industrial scientist or engineer after each job transition). Stayers in employment outside the conventional technical occupations refer to respondents who were in this labour market segment since PhD awards and have never moved out (indicating a sequence of job mobility always from and to employment outside the conventional technical occupations after each job transition). On the other hand, movers refer to respondents who have had job mobility across labour market segments. Our previous study (Lee et al., 2010) has shown that the direction of job mobility of movers is dominantly from the conventional technical occupations to employment outside the conventional technical occupations and then remaining in this labour market segment.

Descriptive data analysis based on individual respondents shows that, 7-10 years after graduation, the majority of stayers in the conventional technical occupations (in academic/public research and in technical occupations in the private sector manufacturing) have worked for only one employer since they graduated, and particularly for stayers in technical positions in the private sector manufacturing, 72% are still with their first employers (Table 6). T-tests indicate that on average stayers in the conventional technical occupations experience less employers than stayers in employment outside the conventional technical occupations or movers (Table 7).

Table 6: Number of employers

	Number of employer(s) Row percentage			
Type of mobility within/across labour market segment	1	2	3	>=4
Stayers in the conventional technical occupations (a)	64%	25%	11%	0%
Stayers in academic/public research (a1)	62%	29%	9%	0%
Stayers in technical positions in the private sector manufacturing (a2)	72%	14%	14%	0%
Stayers in employment outside the conventional technical occupations (b)	33%	33%	29%	5%
Movers (c)	24%	28%	28%	20%
Overall (d)	41%	28%	22%	9%

Note: Analysing unit= the individual. (a) N=28 (a1) N=21 (a2) N=7 (b) N=21 (c) N=31 (d) N=78

Table 7: Mean number of employers

Type of mobility within/across labour market segment	Mean	Standard error	95% confidence interval
Stayers in the conventional technical occupations (a)	1.46	0.13	1.20-1.73
Stayers in academic/public research (a1)	1.48	0.15	1.18-1.77
Stayers in technical positions in the private sector manufacturing (a2)	1.43	0.30	0.84-2.02
Stayers in employment outside the conventional technical occupations (b)	2.05	0.20	1.65-2.47
Movers (c)	2.48	0.21	2.06-2.91
Overall (d)	2.00	0.12	1.77-2.23

Note: Analysing unit= the individual. (a) N=28 (a1) N=21 (a2) N=7 (b) N=21 (c) N=31 (d) N=78

On average, around 69% of the survey respondents have worked for only one or two employers 7-10 years after graduation. Hence, organisational life is still important for the early to middle stage careers of the survey respondents.

This, however, gives little indication about the direction of job mobility. Based on analysis using the job transition as the analysing unit, a design-based cross-tabulation between stayers or movers in the labour market segments and types of organisational mobility reveals some details of the direction of job mobility (Table 8). The result shows three general features: 1) overall, on average, for any job transition, the probability of getting promoted is greater than that of not getting promoted (62% upward mobility), 2) on average, promotions are more likely to occur within organisations rather than externally (42% intra-organisational upward, compared to 20% inter-organisational upward) and 3) inter-organisational mobility is important, as every 1 in 2 job changes involves a change in employer (49% inter-organisational mobility). This shows that career progression in the S&E PhD labour market is upward in general and organisational career life remains important, but also points to the relevance of the boundaryless concept (Table 8).

Table 8: Types of job mobility within/across labour market segment and types of organisational mobility

	Type of organisational mobility Row percentage				
Type of mobility within/across labour market segment	Intra-organisational upward mobility	Inter-organisational upward mobility	Intra-organisational non-promotion mobility	Inter-organisational non-promotion mobility	Overall inter-organisational mobility
Stayers in the conventional technical occupations (e)	63%	11%	12%	14%	25%
Stayers in academic/public research (e1)	60%	10%	11%	19%	29%
Stayers in technical positions in the private sector manufacturing (e2)	67%	12%	15%	6%	18%
Stayers in employment outside the conventional technical occupations (f)	37%	29%	9%	25%	54%
Movers (g)	29%	20%	7%	44%	64%
Overall (h)	42%	20%	9%	29%	49%

Note: Design-based descriptive data analysis. Analysing unit = the job transition. Pearson uncorrected X^2 (6) = 18.872; Design-based F(5.42, 357.75)=2.148; P = 0.054. Number of observations (e) N=44 (e1) N=29 (e2) N=15 (f) N=42 (g) N=55 (h) N=141

4.2 The conventional technical occupations show strong ILM features

Job mobility of stayers within academic/public research shows dominant ILM features. 62% of those who have always been in this labour market segment have stayed with the same employers since

graduation (Table 6). For each job transition, if not moving out of the labour market segment, the propensity for getting promoted within the same organisation is 60% (Table 8) and the propensity to rate skills that are more specific and less portable as the more valuable types of knowledge for the job transition is 86% (skills acquired from PhD: 72%; organisation-specific skills from previous position: 14%) (Table 9). Similarly, for each job transition, stayers in technical positions in private sector manufacturing are more likely to experience more ILM-like mobility: 72% of those who have always been in this labour market segment have worked for the same employers since doctoral training (Table 6); for each job transition, the propensity of getting promoted within the same organisation (67%) is greater than other types of organisational mobility (Table 8). However, such technical ladder within an organisation does not seem to be strongly associated with skills acquired from doctoral training or organisation-specific skills, as the proportion of surveyed PhDs rating these skills as the most valuable types of knowledge for this type of job mobility is only 44% (skills acquired from PhD: 37%; organisation-specific skills from previous position: 7%) (Table 9). Hence, career behaviour of stayers in technical positions in private sector manufacturing is characterised by strong ILM-like mobility. However, as knowledge and skill development for stayers in this segment does not seem to emphasise strongly the more organisation-specific and less portable knowledge, their career behaviour is not as typical as would be expected in the ILMs, or as what is seen for stayers in academic/public research.

Table 9: Types of mobility within/across labour market segments and types of skills that are perceived to be the most valuable

	Type of knowledge and skills most useful for a job Row percentage (Column percentage)			
Type of mobility within/across labour market segment	Skills acquired from PhD	Organisation-specific skills acquired from previous position	Sector-specific skills acquired from previous position	General skills
Stayers in the conventional technical occupations (e)	60% (66%)	12% (28)	13% (15%)	15% (19%)
Stayers in academic/public research (e1)	72% (52%)	14% (14%)	11% (8%)	3% (3%)
Stayers in technical positions in the private sector manufacturing (e2)	37% (14%)	7% (4%)	19% (7%)	37% (16%)
Stayers in employment outside the conventional technical occupations (f)	10% (12%)	19% (29%)	40% (45%)	31% (39%)
Movers (g)	16% (22%)	27% (53%)	30% (40%)	27% (42%)
Overall (h)	28%	20%	28%	24%

Note: Design-based descriptive data analysis. Analysing unit = the job transition. Pearson uncorrected X^2 (6) = 35.187; Design-based F(5.72, 377.51)=3.541; P =0.002. Number of observations (e) N=44 (e1) N=29 (e2) N=15 (f) N=42 (g) N=55 (h) N=141

4.3 Employment outside the conventional technical occupations shows strong OLM features, but promotions are still more likely to occur within organisations

Once a S&E PhD is employed outside the conventional technical occupations, the propensity to switch back to the conventional technical occupations later on is very rare (Lee et al., 2010). Therefore, job mobility of workers employed outside the conventional technical occupations is highly restricted to this labour market segment/occupational group (see also Table 4). For stayers in this segment, for each job transition, the propensity to have inter-organisational mobility, the main organisational mobility feature of the OLMs, is 54% (Table 8). Moreover, knowledge and skills that are more general and more easily portable, i.e. sector-specific skills and general skills, are also perceived as having greater importance by stayers in this segment (sector-specific skills 40%, general skills 31%), compared to the perceived usefulness of these types of knowledge and skills by stayers in the conventional technical occupations (sector-specific skills 13%, general skills 15%) (Table 9). Finally, job tenure with an employer is relatively shorter for stayers in this segment (Table 6), compared to job tenure for stayers in the conventional technical occupations. Therefore, we are able to conclude that the career behaviour of stayers in this labour market segment shows stronger OLM features.

Indeed, a design-based chi-square test for independence indicates that types of organisational mobility are associated with different labour market trajectories, i.e. stayers in the conventional technical occupations, stayers in employment outside the conventional technical occupations and movers (p=0.054). Perceived usefulness of work-related competences are also associated with different labour market trajectories (p=0.002).

Finally, a point to note is that, although the labour market segment of stayers in employment outside the conventional technical occupations shows strong OLM features, workers are still more likely to have promotions internally within organisations (37%), rather than externally (29%) (Table 8); hence even in this OLM-type segment, organisational career life nonetheless remains important. A case-by-case investigation indicates that jobs in this segment are largely made up of dedicated managers (29%), consultants and many other professionals in services (49%). Furthermore, industrial scientist-turned-dedicated managers are equally likely to be prompted internally or externally to organisations. Dedicated managers in services are twice likely to be promoted externally than internally. However, job mobility for technical positions in the private sector services or consultants, which account for 49% of the jobs in this segment, is either intra-organisational upward or inter-organisational lateral (around 16:15). Therefore, the overall result is that the whole segment shows a high level of inter-organisational mobility, but promotions are still more likely to occur within organisations.

4.4 Job transitions of movers out of the conventional technical occupations is highly external to organisations

Many S&E PhDs change employers and move across labour market segments. Compared to stayers' job mobility, movers' job mobility is less likely to involve promotions (movers' average: 49%; overall average: 62%), particularly intra-organisational upward mobility (movers' average: 29%; overall average: 42%), and more likely to involve inter-organisational mobility (movers' average: 64%; overall average: 49%), particularly inter-organisational non-promotion mobility (movers' average: 44%; overall average: 29%) (Table 8). It also seems that on average, movers are more likely to perceive knowledge and skills that are more easily portable as more useful (Table 9). Hence the career behaviour of movers shows some strong OLM features.

Movers encounter many types of job mobility that involves segment-crossings. Tables 7-9 illustrate the average features of movers, but they do not reveal the dynamics of segment-crossing behaviour. Hence a breakdown of the details of the types of segment-crossing which movers might encounter for each job transition and perceived usefulness of work-related competences are discussed below.

There are two types of movers: movers who move out of academic/public research and movers who move out of technical positions in private sector manufacturing; both move into employment outside the conventional technical occupations. In contrast to stayers in academic/public research, where job mobility appears to be very stable (62% have stayed for the same employers since graduation and 60% have enjoyed promotions within the same organisations), movers moving out of this segment experience high propensity of non-promotion mobility. The specific transitions of movers out of academic/public research are the only type of mobility in the survey that shows a very low propensity of upward job mobility (32%); it is far more likely to have inter-organisational non-promotion mobility (55%), rather than to have intra-organisational upward mobility (16%). Furthermore, the propensity of not getting promoted at all in this type of job mobility is 68% (Table 10). This type of segment-crossing mobility is most likely to do with the high proportion of fixed-term post-doctoral researchers in academia. There is also evidence that stayers' perceived usefulness of knowledge in job transitions within academic/public research differs from movers' perception of useful knowledge in such segment-crossing transitions.

Movers' job transitions out of technical positions in private sector manufacturing show a different story than that experienced by movers out of academic/public research. Based on a case-by-case investigation, we can say that industrial scientists and engineers in manufacturing moving out of the occupation normally become dedicated managers in manufacturing (54%) or professionals in knowledge intensive business service firms (38%). 52% of job transitions in this type of mobility across segments have enjoyed promotions and particularly, if the participants stay within manufacturing, the propensity for promotions is as high as 71%; while if they move out of

manufacturing, the propensity for promotions drops to 33%. Job mobility of this type of movers differs from stayers in this segment, but there is no evidence indicating the perceived usefulness of knowledge is different in the two types of job transitions (Table 11).

Table 10: Difference in organisational mobility between stayers in academic/public research and movers moving out of academic/public research to employment outside the conventional technical occupations

	Type of organisational mobility Row percentage				
Type of mobility within/across labour market segment	Intra-organisational upward mobility	Inter-organisational upward mobility	Intra-organisational non-promotion mobility	Inter-organisational non-promotion mobility	Overall Inter-organisational mobility
Stayers in academic/public research (i)	60%	10%	11%	19%	29%
Movers:	16%	16%	13%	55%	71%
A researcher in academic/public research → Employment outside the conventional technical occupations (j)					

Note: Design-based descriptive data analysis. Analysing unit = the job transition. Pearson uncorrected X2 (3) = 26.665; Design-based F(2.93, 193.30)=2.247; P =0.086. Subpopulation number of observations (i) N=29 (j) N=12

Table 11: Difference in organisational mobility between stayers in technical positions in the private sector manufacturing and movers moving out of this segment to employment outside the conventional technical occupations

	Type of organisational mobility Row percentage				
Type of mobility within/across labour market segment	Intra-organisational upward mobility	Inter-organisational upward mobility	Intra-organisational non-promotion mobility	Inter-organisational non-promotion mobility	Overall Inter-organisational mobility
Stayers in the private sector manufacturing (k)	67%	12%	15%	6%	18%
Movers:	19%	36%	8%	37%	73%
An industrial scientist or engineer in manufacturing → A knowledge worker in employment outside the conventional technical occupations (l)					

Note: Design-based descriptive data analysis. Analysing unit = the job transition. Pearson uncorrected X^2 (3) =45.187; Design-based F(2.62, 173.22)=2.740; P =0.052. Subpopulation number of observations (k) N=15 (l) N=12

Table 12: Difference in organisational mobility between stayers in employment outside the conventional technical occupations and movers moving into this segment

	Type of organisational mobility Row percentage				
Type of mobility within/across labour market segment	Intra-organisational upward mobility	Inter-organisational upward mobility	Intra-organisational non-promotion mobility	Inter-organisational non-promotion mobility	Overall Inter-organisational mobility
Stayers in in employment outside the conventional technical occupations (m)	37%	29%	9%	25%	54%
Movers:	32%	22%	5%	41%	63%
Employment outside the conventional technical occupations → Employment outside the conventional technical occupations (n)					

Note: Design-based descriptive data analysis. Analysing unit = the job transition. Pearson uncorrected X^2 (3) = 4.141, Design-based F(2.87, 187.17)=0.457; P =0.702. Subpopulation number of observations (m) N=42 (n) N=22

Because both types of movers move into employment outside the conventional technical occupations, an interesting question is whether these movers' job mobility within employment outside the conventional technical occupations and stayers' job mobility in this segment share a similar pattern of job mobility. Our investigation suggests that segment-crossing transitions (i.e. transitions from academic/public research or technical positions in the private sector manufacturing to employment outside the conventional technical occupations) show different characteristics from within-segment transitions in the conventional technical occupations. However, once the surveyed PhD scientists or engineers move into employment outside the conventional technical occupations, there is no difference in the pattern of organisational mobility between movers' move within this segment and that of stayers who have always been in this segment (Table 12), nor is there a difference in the perceived usefulness of knowledge.

4.5 Patterns of individual knowledge flow are non-random

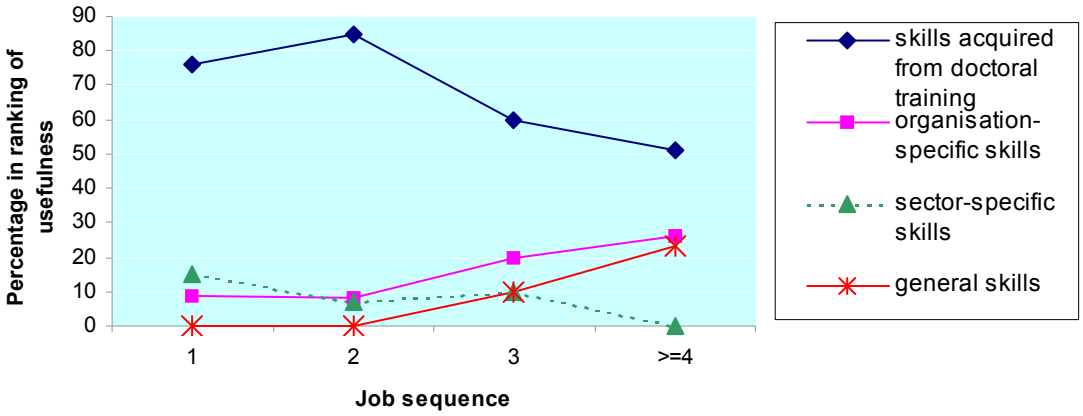
4.5.1 The perceived usefulness of knowledge and skills varies by career stage

It is recognised that knowledge and skills acquired from S&E doctoral training are special assets and resources for S&E PhDs. Little is known about the perceived usefulness of this type of knowledge and skills compared to other types of knowledge and skills developed in the labour markets and how such perceived difference vary in segments and in S&E PhDs' career stages. Therefore, in this section, we use jobs as analysing units and design-based estimations to explore how the perceived usefulness of different types of knowledge and skills differs by job sequence (the first, the second, the third and the fourth or more jobs) and by different segments. Results are shown in Figure 1 to Figure 5. Although jobs are used as analysing units, because each individual can have only one first job, one second job, and so on, in this way, we are able to separate segment effect and career stage effect in the analysis. For instance, Figure 1 illustrates the perceived usefulness of different types of knowledge by job

sequence for stayers in academic/public research. For all the stayers' first jobs in this segment, nearly 80% of them ranked knowledge and skills from doctoral training as the most useful type of knowledge in the jobs. As an individual can have only one first job, this can also be interpreted in an alternative way. That is, nearly 80% of stayers in academic/public research regarded knowledge and skills from doctoral training as the most useful type of knowledge in their first jobs. This explains how we separate segment effect and career stage effect in the analysis of the perceived usefulness of knowledge. Figure 1 shows that knowledge and skills from doctoral training is considered as the most useful type of knowledge in their jobs for researchers in academic/public research throughout the survey period, although the perceived usefulness is declining with the increase of the number of job changes. Furthermore, compared to knowledge acquired from doctoral training, all other types of knowledge and skills seem to be marginal in terms of the perceived usefulness in jobs, although the usefulness of organisation-specific skills and general skills seem to increase over job changes.

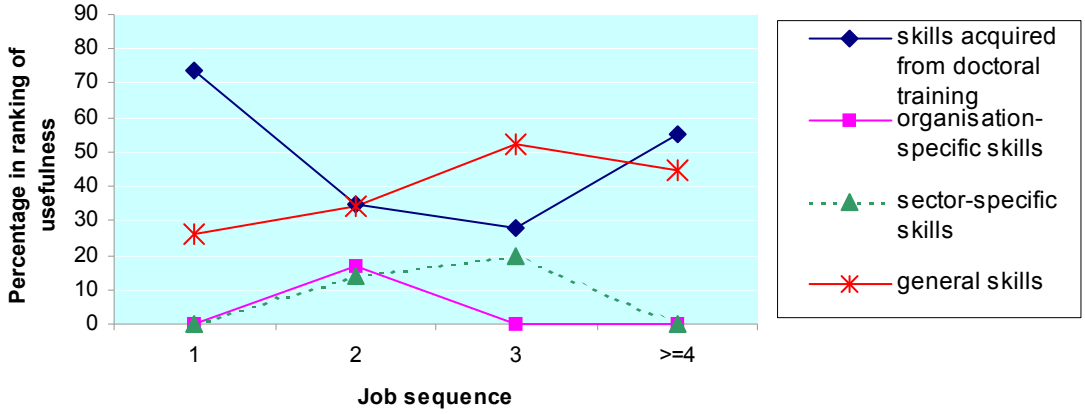
For stayers in technical positions in private sector manufacturing, because the limit of cases, we treat the findings with cautions. Nonetheless, we found that knowledge and skills acquired from doctoral training and general skills seem to be considered as more useful for their jobs throughout the survey period (Figure 2). This is consistent with findings in Section 4.2 that although career behaviour in this segment is characterised by strong ILM-like mobility, knowledge and skill development for stayers in this segment does not seem to be always associated with the more specific and less portable knowledge. For instance, in this segment, organisation-specific skills do not appear to be important.

Figure 1: Perceived usefulness of knowledge by job sequence for stayers in academic/public research



Notes: Data based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation and design-based descriptive data analysis. Analysing unit: the job. N observations=47.

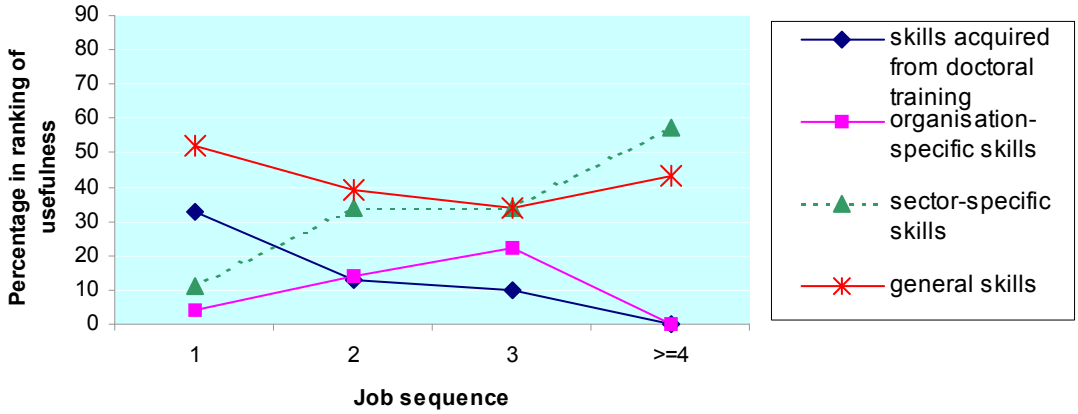
Figure 2: Perceived usefulness of knowledge by job sequence for stayers in technical positions in private sector manufacturing



Notes: Data based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation and design-based descriptive data analysis. Analysing unit: the job. N observations=20.

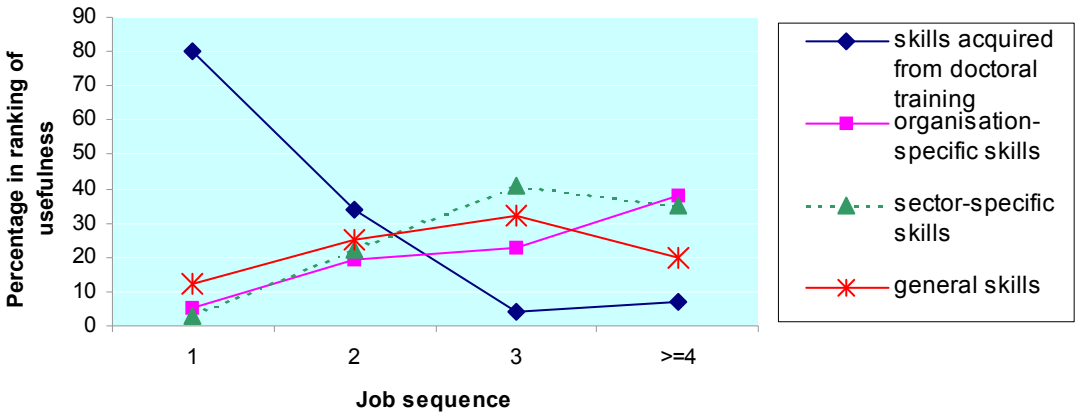
For stayers in employment outside the conventional technical occupations, we saw a consistent importance of general skills in jobs throughout the survey period, a sharp increase in the importance of sector-specific skills as the number of job held increases and a slight increase in perceived usefulness of organisation-specific skills. On the other hand, the perceived usefulness of knowledge and skills acquired from doctoral training decreases over time (Figure 3). These results are in line with findings in Section 4.3 that shows that stayers in this segment are more likely to perceive knowledge and skills that are more general and more easily portable, i.e. sector-specific skills and general skills, as having greater importance.

Figure 3: Perceived usefulness of knowledge by job sequence for stayers in technical positions in employment outside the conventional technical occupations



Notes: Data based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation and design-based descriptive data analysis. Analysing unit: the job. N observations=72.

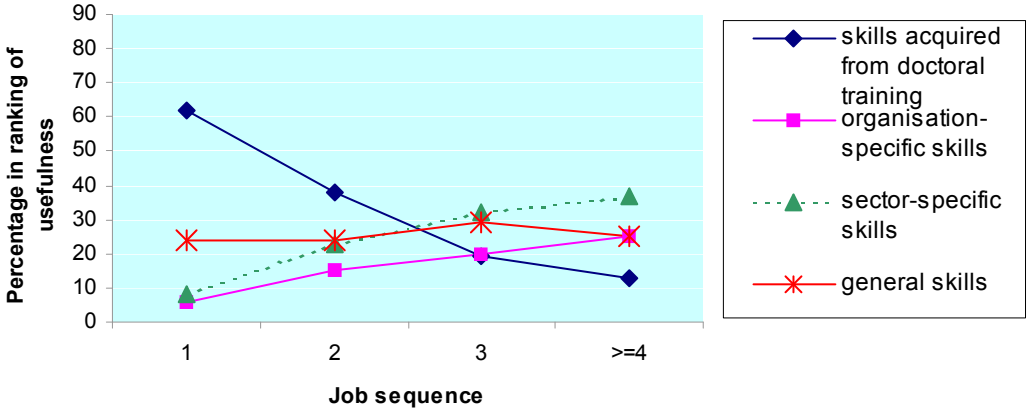
Figure 4: Perceived usefulness of knowledge by job sequence for movers



Notes: Data based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation and design-based descriptive data analysis. Analysing unit: the job. N observations=85.

In short, for researchers in academic/public research, knowledge acquired from doctoral training remains the most useful type of knowledge in jobs throughout their career stages in the survey period. For workers outside academic/public research, general skills appear to be very important. For those in technical positions in private sector manufacturing, knowledge and skills from doctoral training are also perceived to be very useful. While for those in employment outside the conventional technical occupations, the perceived usefulness of sector-specific skills increases dramatically as the number of job changes increases. These findings are consistent with job mobility patterns in these segments.

Figure 5: Perceived usefulness of knowledge by job sequence for all respondents



Notes: Data based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation and design-based descriptive data analysis. Analysing unit: the job. N

Interestingly, the pattern of the perceived usefulness of the various types of knowledge and skills by job sequence for movers is rather similar to the pattern perceived by all respondents (Figure 4 and

Figure 5). Similarities between the two patterns are not surprising, as the direction of mobility for movers is from the conventional technical occupations to employment outside the conventional technical occupations and the direction of job mobility of all respondents is the same. Because the conventional technical occupations highlight knowledge and skills from doctoral training and employment outside the conventional technical occupations shows sharp increase in the perceived usefulness of sector-specific skills and low percentage of perceived usefulness of knowledge and skills from doctoral training in jobs, the general features for movers and for all respondents show a sharp decrease of the perceived usefulness of knowledge and skills from doctoral training when the number of jobs held increases, and the general increased importance of sector-specific skills. For movers specifically, organisation-specific skills seem to become very important as the number of job changes increases[4]. However, the combined perceived usefulness of general skills and sector-specific skills still accounts for the majority in this category. Indeed, a further detailed investigation shows that for movers, although in their later career stage, organisation-specific skills seem to become very important and the propensity for intra-organisation upward job mobility may increase, inter-organisation job mobility remains more prominent.

4.5.2 Knowledge from doctoral training and organisation-specific skills are rewarded and largely kept within organisations while the more general and transferable knowledge flows more easily across organisations

Section 4.5.1 discussed how the perceived usefulness of the various types of knowledge and skills differs by segment and career stage. The following sections focus on how the various types of knowledge and skills might be involved in different types of job mobility and transitions. As predicted in labour market theories, knowledge that is more specific and less portable is highly associated with intra-organisational upward mobility. 50% of surveyed job transitions that rank skills from PhD training as the most useful type of knowledge in the subsequent jobs are classified as intra-organisational upward mobility. Similarly, 71% of surveyed job transitions that rank organisation-specific skills acquired from the previous jobs as the most useful type of knowledge in the subsequent jobs are classified as intra-organisational upward mobility (Table 13). This indicates that these types of knowledge and skills indeed are less portable and more difficult to transfer from one organisation to another by an individual's job mobility. The extent to which they are considered the most useful in transitions when job mobility involves a change in employer is only around 30-40%.

[4] Based on a case-by-case investigation, this is due to the following reasons. First, only 13 out of 27 movers have more then four jobs. Among them, four have 5 jobs and only one has 6 jobs. Among those who have more than 4 jobs, high flyers (a sequence of promotions for 5-6 jobs in the survey period) happen to be one industrial scientist-turned-dedicated manager who have 5 jobs with promotions within the same organisation and one scientist-turned-dedicated manager who initially was an academic fixed-term researcher and then has 5 jobs with promotions within a public research organisation. Both ranked organisation-specific skills as the most useful knowledge for their jobs in the managerial track. As these two individuals' job transitions from the technical track to the managerial track happen within their first three jobs, their later jobs along would make up nearly 30% of jobs that rank organisation-specific skills as the most useful knowledge in the category of movers' fourth or further jobs.

By contrast, knowledge that is more general and more easily portable is associated with inter-organisational mobility. Around 57% of surveyed job transitions that rank sector-specific skills acquired from the previous jobs as the most useful type of knowledge in the subsequent jobs are classified as inter-organisational mobility (18% upward mobility; 39% non-promotion mobility). Similarly, as high as 71% of surveyed job transitions that rank general skills as the most useful type of knowledge in the subsequent jobs belong to inter-organisational mobility (33% upward mobility; 38% non-promotion mobility) (Table 13).

Table 13: Types of organisational mobility and type of knowledge that is perceived to be the most valuable

Type of knowledge most useful for a job	Type of organisational mobility Row percentage			
	Intra-organisational upward mobility	Inter-organisational upward mobility	Intra-organisational non-promotion mobility	Inter-organisational non-promotion mobility
Skills acquired from PhD (o)	50%	18%	10%	22%
Organisation-specific skills acquired from previous position (p)	71%	10%	4%	15%
Sector-specific skills acquired from previous position (q)	25%	18%	18%	39%
General skills (r)	27%	33%	2%	38%
Overall (s)	42%	20%	9%	29%

Note: Design-based descriptive data analysis. Analysing unit = the job transition. Pearson uncorrected X^2 (9) = 25.5462; Design-based F(8.02, 529.05)=2.337; P = 0.018. Number of observations (o) N=39 (p) N=28 (q) N=39 (r) N=35 (s) N=141

5 Discussion

In this paper, we studied histories of job mobility of individuals to explore the labour market of S&E PhDs from a cross-organisational and cross-labour market segment perspective. In doing so we also studied the relationship between career patterns and knowledge and skill development. We found that job mobility and knowledge and skill development differ in the three career types analysed and therefore argue that the S&E PhD labour market is segmented. We also found that organisational life is still a prominent feature of the labour market of S&E PhDs. On average, our survey respondents' promotion opportunities are still more likely to occur within organisations rather than externally, whether the S&E PhDs are working within or outside the conventional technical occupations. However, we also found that, as a whole, the concept of boundaryless careers is also relevant to the S&E PhD labour markets, as inter-organisational job mobility accounts for around half of the surveyed job transitions and many also involve segment-crossing. Furthermore, the pattern of knowledge flow is non-random and to a greater or lesser extent, knowledge is localised within organisations or labour market segments.

5.1 Segmented S&E PhD labour market

As some segments display more ILM-like features while some others show relatively more OLM-like or external labour market features, the results resonate with DiPrete and McManus' (1993) concept of

'compound' labour markets, which highlights that some labour markets may simultaneously be situated in both the ILMs and the OLMs. For instance, the dominant features of the conventional technical occupations are consistent with the ILM model, while the dominant features of employment outside the conventional technical occupations are more consistent with the OLM model. Movers' career behaviour is highly external; they might initially experience some turbulence in transitions, but after that, there is no difference in the direction of job mobility and skill development between movers into employment outside the conventional technical occupations and stayers who have always been in this labour market segment.

There is heterogeneity with some job mobility revealing relative better chances to obtain upward progression. For our survey respondents, we found that job mobility within each of the three main labour market segments, i.e. academic/public research, technical positions in private sector manufacturing and employment outside the conventional technical occupations, is more likely to be upward. When job mobility involves segment-crossing, it is less likely to be upward than the average. For example, when academic researchers move out of academic/public research, most of them do not experience promotions (Table 8). When industrial scientists or engineers in manufacturing move out of the occupations, they have around half the chance of experiencing promotion (Table 9). These types of job mobility have relatively lower upward job mobility than the average for the sample (62% of the total surveyed job transitions involve promotion).

The concept of 'compound' labour markets can also apply to individual labour market segments. We found that each of the segments of the labour markets of S&E PhDs shows a distinctive mixture of ILM and OLM features. We therefore label the academic/public research as the 'dualist' segment, employment outside the conventional technical occupation as the 'hybrid' segment and technical positions in manufacturing as the 'structured' segment of the S&Es PhDs labour market. We discuss below the characteristics of each of these labour market segments.

5.1.1 The dualist segment

Working as researchers in academic/public research appears to be at the same time the most stable (as stayers in the segment experience strong ILM-like labour market features) and the least stable type of occupation. More than two third of those who initially took positions in this segment were offered jobs on a fixed-term basis, while the number of fixed-term positions offered in other segments is almost negligible (Lee et al, 2010). This reflects the high use of temporary contracts in all public sector organisations as compared to the private sector. Moreover, among all types of job mobility, moving out of academic/public research is the only type of job mobility that involves a significant proportion of non-promotion moves. The strong contrast between the permanent and the fixed-term members may indicate that many universities and public research organisations may be organising their employment strategies according to employment systems that segment their labour force into 'core' and 'periphery'

groups in order to adjust to changing market conditions (Atkinson, 1984; Atkinson and Meager, 1986; Ledwith and Colgan, 1996). Core workers, such as faculty members, may be organised according to typical ILM arrangements, while periphery workers, such as fixed-term researchers, may be organised according to more competitive and less secure employment features (Camuffo, 2002; Osterman, 1988). This S&E PhD labour market segment (academic/public sector research) therefore can be labelled as a 'dualist' labour market segment, to highlight the sharp contrast between the 'core' and the 'periphery' workers.

It thus has been argued that academic and public research organisations may face challenges in recruitment and career development in competition with the private sector (EI-Khawas, 1994; Gilliot et al., 2002; Michaels et al., 2001; Reponen, 1994), in a new environment where managing talent by companies is through disproportionate rewards. This is compounded by the fact that the hazard of reaching the bottom of the academic career ladder seems enormous and transitions from fixed-term researchers to the private sector often mean a completely new start in industry (hence feature lateral move), while career trajectories in all other types of employment for S&E PhDs seem to be comparatively smoother. Nevertheless, it is apparent that many S&E PhDs are willing to try to have their careers in academic/public research, in spite of being aware of the difficulties. Indeed, 39% of the survey respondents had academic/public research positions for their first jobs. This implies that it would be over-simplistic to approach careers research by considering only objective measures such as promotions. Some career theorists stress that the concept of careers cannot be reduced only to the prospects of upward progression or material rewards. The concept of the 'protean' career (Hall, 1976, 1996, 2002) seems relevant. This implies a primary focus on an individual's subjective interpretation of career success. According to Briscoe and Hall (2006), a person with protean career potential is highly value-driven, in the sense that the individual's internal value acts as guidance and measure for the success of his/her career and also self-directed, in the sense that the individual has the ability to self-manage his/her career and to be adaptive to learning demands. Such a person is likely to experience several career cycles of exploration-trial-establishment-mastery process in that they often cross firm/occupational boundary for job moves. Often, the moves are lateral rather than upward and might involve salary loss (Mirvis and Hall, 1996). The concept of the protean careers can be useful in explaining why so many doctoral graduates are willing to stay in fixed-termed positions in academic/public research due to personal interest in research and the academic environment, regardless of the relatively less secure employment and the potential lack of upward progression prospects.

5.1.2 The hybrid segment

Although employment outside the conventional technical occupations shows stronger OLM features, on average promotions are still more likely to occur internally. Apart from dedicated managers in services who are more likely to be promoted external to organisations, industrial scientist-turned-

dedicated managers are equally likely to be promoted internally or externally, and in particular, members in the largest group in this S&E PhD segment, consultants and many other professionals in services, which make up of 49% of the segment, are likely to get promotion within organisations or to move out of the organisations without promotion. Hence, the finding is particularly significant, because these occupations are often considered to be associated with 'boundaryless' careers (Barley et al., 2004; DeFilippi and Arthur, 1998; Jones, 1996; May et al., 2002; Saxenian, 1996; Vinodrai, 2006). Our findings, however, revealed that although careers of stayers in this segment may be free from organisational control to a certain extent, they are often still organised according to the ILM model. This echoes Grimshaw and Rubery's (1998) argument stressing that the changing boundary of the externalised features of the labour market is embedded in the ILMs. Therefore, it would not be sufficient to discuss boundaryless careers or the OLMs without reference to the ILMs. We can, therefore, describe this segment of the S&E PhD labour market (employment outside the conventional technical occupations) as an 'ILM-embedded OLM'.

This highlights the point that employment in the emerging knowledge-intensive industries is probably more organisation-bound than what is suggested by the boundaryless careers concept. That is, more efforts may be and are necessary by employers in the project-based network organisations to retain employees and their knowledge than is suggested in the conventional literature on the knowledge economy. Indeed, this finding is consistent with recent studies that stress the continuous importance of the ILMs in the knowledge economy (Bagdadli et al., 2003; Baldry et al., 2007; Cox et al., 2008; Donnelly, 2009; Hamori and Kakarika, 2009; McGovern et al., 2007; Rutherford, 2006). Furthermore, this also fits the studies on the hybrid organisational forms (Camuffo, 2002; Foss, 2002), which highlight that network organisations may be seen as the infusion of the market and the hierarchy, either in the form of internal hybrids (Foss, 2003; Zenger, 2002) (such as the team-based organisations), where the market control is infused with the hierarchy, or in the form of external hybrids (Williamson, 1996) (such as alliances), where the hierarchy control is infused with the market.

One factor that contributes to the segment's high inter-organisational mobility is likely to do with the suggestion that, in the hybrid organisations, with team-based flat structures, promotions are no longer seen as an adequate 'prize' for effort, and reflecting the lack of internal career ladders in project-based organisations, many firms have introduced new incentive instrument such as performance pay (Foss, 2003; May et al., 2002; Zenger, 2002). Similarly, Marsden (2010) pointed out the growing use of entry tournaments to regulate labour markets in project-based organisations. One reason is associated with the quality problem. Since the organisation of a project is a temporary formation, often when problems associated with the project appear, the project generally has been long completed, and the team-members are long gone. Therefore, recruiting team-members with high reputation or 'stars' becomes the key human resource measure. Hence, as obtaining a project job is highly competitive, therefore the compensation (pay) is high. At the same time, this means that many would fail in the competition,

slide into lower status and move around organisations without upward job progression. This segment's emphasis on sector-specific skills and general skills is likely to be another factor that contributes to the high inter-organisational mobility, as there are lower barriers for members to move across employers. However, as Camuffo (2002) pointed out, performance relies on competences and knowledge, and because competences and knowledge are contextual, the formation of competences and knowledge that good performance relies on always require time. Hence, both employers and knowledge workers will continue to have incentives to capitalise on reciprocal knowledge investments. Similarly, it has been argued that because work always requires coordination, performance improves with team and time continuity (Pfeffer and Sutton, 2006) and with good systems (Beechler and Woodward, 2009). Therefore, individual competences will always be sticky to organisation to a greater or lesser extent. This could explain why organisational career life remains important in the segment. Overall, this S&E PhD labour market segment (employment outside the conventional technical occupations) can be labelled as the 'hybrid' segment, indicating that the boundary between the internal and the external labour market features within the segment can not be clearly defined.

The 'hybrid' segment of employment outside the conventional technical occupations reflects a new scenario that challenges the picture of knowledge workers as free agents having expert power to move freely around employers working without coordination within the organisation (Pink, 2001; Reed, 1996). Theories on organisational knowledge demonstrate the link between individual skills and organisational knowledge (Kogut and Zander 1992; Nelson and Winter 1982). These very same theories can also be applied to the level of the boundary of a firm, a university or a laboratory. Experts and knowledge workers will always need time to develop shared norms and rules with colleagues in order to have better coordination to get greater performance. Hence, again, the implications for human resource management for consultants, experts, dedicated managers and other professionals in business services point out that human resources practices targeting these personnel should not just focus on pay incentives to key staff but also on good systems that enhance knowledge coordination (Beechler and Woodward, 2009; Pfeffer and Sutton, 2006; Teece 2003).

5.1.3 The structured segment

Finally, technical positions in private sector manufacturing seem to have labour market features the explanation of which is relatively straightforward, as industrial scientists or engineers in manufacturing largely experience promotions internal to their organisations until they get promotions to become dedicated managers or decide (voluntarily or involuntarily) to switch career track to other sectors such as services. At the same time, many industrial scientists and engineers in manufacturing might actually enjoy staying in the technical track (Allen and Katz, 1986, 1992; Gunz, 1980). Therefore, industrial scientists and engineers in manufacturing seem to be still situated in a very structured labour market segment (Marsden, 2010), and have certain personal flexibility in terms of

their career progression. Hence, we label this labour market segment of technical positions in private sector manufacturing as the 'structured' segment.

5.2 The need of further research on how to overcome the barrier of knowledge flow from academia to employment outside the conventional technical occupations

By rendering the labour market segment of employment outside the conventional technical occupations explicit, we have been able to unpack the interrelationships among the S&E PhD labour market segments, job mobility and knowledge and skill development. We focus here on the implications for knowledge flow. The question is the extent to which knowledge produced in academia may transfer to industry or to which spillovers in industry could occur by individual S&E PhDs' job mobility. This is connected to the particular implications of manpower training effect of publicly funded basic science (Larédo, 2007; Mangematin, 2001; Martin and Irvine, 1981; Mowery and Sampat, 2005; Pavitt, 1991).

There have been explicit UK policies designed to enhance the flow of academic knowledge to industry. One of the most relevant is the EPSRC (Engineering and Physical Sciences Research Council) EngD (Engineering Doctorate) Scheme. This has been launched to recruit research engineers in the fields of complexity sciences, systems biology and life science interface since 1992. The scheme requires students to spend 75% of the time directly working in industry under the supervision of their industrial supervisors and 25% of the time at university attending taught technical specialist and management courses.[5] This is designed to encourage direct knowledge flow from academia to industry. Other measures involve policies that foster university-industry collaborations (Howells et al., 1998).

Our findings indicated that knowledge and skills acquired from S&E doctoral training largely stay and are circulated within organisations and within the conventional technical occupations. If the conventional technical occupations in industry (i.e. technical positions in private sector manufacturing) had been the major private sector employment destination for S&E PhDs, we would have been able to conclude without doubt that a large amount of knowledge acquired from S&E doctoral training, even subject-specific knowledge, is transferred from academia to industry through individuals' job mobility. However, this is not the case, because technical positions in manufacturing represent only a minority of S&E PhD's employment (Lee et al., 2010). That is, academic knowledge flows naturally to private sector manufacturing through technical tasks conducted by S&E PhDs.

However, there is a barrier for the flow of academic knowledge to industry through doctorates' mobility between academia and employment outside the conventional technical occupations.

[5] Details in EPSRC website: http://www.epsrc.ac.uk/SiteCollectionDocuments/other/IDCGoodPracticeGuidelines.pdf (accessed on 07 April 2011)

Moreover, this segment is gaining dominance as careers progress. The EngD Scheme or policies encoraging university-industry collaborations do not seem to address this issue. Therefore, efforts to overcome this barrier might need to pay special attention to exploring possible ways of how to forge closer ties between universities and activities conducted by consultants, professionals in services and managers as a potential means of knowledge transfer.

6 Conclusions

This paper has explored the labour market of S&E. The results indicated that the proposed three segments of the S&E PhD labour market show different labour market features, but overall, ILM-type features can be seen in all segments. The paper also derived implications for human resource management of the S&E PhD knowledge workers. Because knowledge and skill development are more or less organisation-bound, human resource practices may need to focus on creating good systems to enhance coordination among knowledge workers rather than simply on targeting star performers.

Furthermore, knowledge and skills acquired from S&E doctoral training and organisation-specific skills largely stay and are circulated within organisations and within the conventional technical occupations. There is a barrier for the flow of academic knowledge to industry through doctorates' mobility between academia and employment outside the conventional technical occupations. Further research may explore how to reduce the barrier.

We acknowledge some limitations of this study. We focus on S&E PhDs form the University of Manchester with 7-10 years of employment history in the labour market. The inferences do not go beyond the survey population. Hence, the career and labour market patterns described in this paper can not be generalised to all S&E PhDs, particularly to PhDs at a late stage of their careers. Also, promotion opportunities are measured only if job transitions occurred. This means that those who have not experience any job transition are unfortunately lost when job transitions are used as analysing units. However, overall, we believe that our research sheds light on the understanding of career behaviour of S&E PhD knowledge workers, provide useful insights into the flow of knowledge and bridge current debates regarding knowledge workers and organisational careers from a cross-organisational/labour market segment prospective.

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Appendix 1: Definition of a job

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

Appendix Table 2: 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			