Career patterns and competences of PhDs in science and engineering

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Abstract

Based on a retrospective survey of science and engineering (S&E) PhDs from a UK research-based university with 7-10 years job histories and the design-based non-parametric analysing methods, this thesis drew on theories on careers, organisational knowledge and learning and labour markets to explore the interrelationship between knowledge flow and careers of science and engineering PhDs.

The results showed that employment outside the conventional technical occupations is the main destination for the survey respondents. This labour market segment is not only successful at retaining its members, but is also the destination of the other career types. Furthermore, S&E PhDs in the conventional technical occupations draw quite a lot of knowledge from S&E doctoral training in their jobs, even from the subject-specific dimension of it. By contrast, members in employment outside the conventional technical occupations are less likely to perceive knowledge and skills from doctoral training to be useful in their jobs, and when they do, the emphasis is more on general analytical skills and problem solving capabilities.

The results also revealed the distinctive labour market features of different S&E PhD labour market segments: the sharp contrast of the core and peripheral workers in academic/public research, the highly hybrid labour market form in employment outside the conventional technical occupations and the relatively more structured labour market features in technical positions in private sector manufacturing. Regardless of the differences, nonetheless, as a whole, organisational life is still a prominent feature of the S&E PhD labour markets.

Furthermore, the extent to which fluid job mobility contributes to S&E PhDs' individual knowledge flow depends on the types of knowledge under discussion. The emerging occupations associated with the knowledge economy are characterised by high inter-organisational mobility and by an emphasis of sector-specific and general knowledge. However, even for sector-specific and general knowledge, we have demonstrated that to a certain extent, these types of knowledge and skills are sticky to organisations. Hence, S&E PhD experts and knowledge workers' careers and individual knowledge flow are not really boundaryless but moderately localised within organisations.

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Copyright Statement

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1 Introduction

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

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

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

More than a decade later, policymakers are still concerned about the shortage of scientists and engineers due to the continued lack of interest in science and engineering among students, but this time the concern is not just about how to keep science and engineering graduates in their conventional occupations. The contemporary argument is that, in the knowledge economy, there is an intensified pace of scientific and technological knowledge production and knowledge production is becoming more widespread and widely distributed across a host of new places and actors in many cases outside conventional technical occupations, particularly due to the development of ICTs that accelerate the speed of knowledge dissemination and accumulation. It is argued that the most striking difference in knowledge production is that innovation capability today relies more on new ways of combination or exploitation of existing knowledge, rather than on the ability to discover new scientific laws or principles (David and Foray, 2002; Soete, 2002). It is thus suggested that in the knowledge economy, knowledge workers, who are highly educated and excel in absorbing knowledge, will emerge as the dominant occupation (Lindley, 2002). That is, many professionally trained PhD scientists and engineers may be increasingly employed in occupations outside the conventional technical occupations. This calls for an examination of the wider roles of science and engineering PhDs in the knowledge economy, beyond their conventional occupations. Therefore, in contrast to the attitudes in the late 1980s and the early 1990s, policymakers have begun to recognise that one of the reasons for supporting the production of larger numbers of science and engineering graduates is that, in the new economy, with more and more sectors adopting new technologies, the demand for scientists and engineers is increasing outside the conventional boundaries of science and engineering occupations in order to adopt, produce and diffuse knowledge efficiently (The Dearing Report, 1997; Foray and Lundvall, 1996; OECD, 2000). Moreover, with structural change in the economy, including the decline of manufacturing and the increasing importance of services, the amount of highly skilled personnel, such as scientists and engineers, in the service sector is becoming increasingly significant (Cervantes, 2001; Lavoie and Finnie, 1998; Lavoie et al., 2003), as many jobs and functions are displaced or outsourced from traditional manufacturing sectors (Miozzo and Grimshaw, 2006). Indeed, the 2002 Roberts' review of supply of science and engineering skills in the UK, entitled "SET for Success", clearly stated that many scientists and engineers make contributions to the economy through employment in many sectors, not only through working in industrial R&D (The Robert Report, 2002).

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

The change in the rationale for the demand of scientists and engineers itself demands further research. In the context of S&E PhDs, scholars in science, technology and innovation policy studies, argue that what makes the employment pattern of science and engineering (S&E) PhDs significant is that human resource training for industry and government through S&E doctoral education is considered one of the main social economic benefits of publicly funded basic science (Larédo, 2007; Mangematin, 2001; Martin and Irvine, 1981; Mowery and Sampat, 2005; Pavitt, 1991). Although this effect is well recognised, exactly what type of knowledge flows from academia to industry through S&E PhDs' employment in the private sector is little known. To further explore the dynamics of knowledge flow associated with career mobility of S&E PhDs, rather than a one-off examination of the transition from doctoral training to the labour markets, a full examination in S&E PhD labour markets in a longitudinal perspective would provide richer insights. The literature on work organisation has argued that one implication of the knowledge economy is that the power of knowledge networks has replaced conventional bureaucratic controls (Pink, 2001; Reed, 1996). Hence knowledge workers are said to be free from organisational control and they are likely to experience boundaryless (DeFillippi and Arthur, 1994) or network/project based careers rather than organisational careers (Barley et al., 2004; Cappelli, 1999; DeFillippi and Arthur, 1998; DeFillippi, 2002; Hobday, 2000; Jones, 1996; Lam, 2007). This implies a boundaryless potential for knowledge that can be transferred through individuals' mobility. In the context of S&E PhDs, however, this potential might face constrain as S&E PhDs' occupations, whether as academics, public laboratory or industrial researchers, are traditionally associated with organisational job security and stability (Stinchcombe, 1979). This means that the impact of the knowledge economy on science and engineering PhDs will be manifest not only on their types of occupations they have but also on their job mobility. The two effects then point out the significant implications in knowledge flow.

The thesis is organised as follows. Chapter 2 reviews literature and derives the research questions. Chapter 3 outlines the methodology. Chapter 4, 5 demonstrate results that answer research questions. Discussion is presented in Chapter 6 and conclusions are summarised in Chapter 7.

2 Literature Review

This section explores how careers of S&E PhD knowledge workers and their individual knowledge flow are inextricably linked. Although labour market theorists have established the interrelationship between careers and knowledge and skill development in general, labour market theories have not been applied to examine heterogeneity within labour markets of knowledge workers, particularly the highest formally trained knowledge workers in science and engineering disciplines, the S&E PhDs. Regarding this, we argue that three areas require further exploration. The first is the need of a suitable classification of the segments within the highly skilled S&E PhD labour markets to inform us better of the dynamics of knowledge and skill development within the segments in the knowledge economy. The second is the need to unpack the substance of S&E PhDs' individual knowledge and skill development, and how it may shape and be shaped by the labour market segments - because of the lack of studies on knowledge dynamics in the S&E labour markets, after Becker (1964) and Williamson's (1981) distinction of the firm-specific and general knowledge. The third is the need to approach careers of S&E PhD knowledge workers in a longitudinal perspective, as studies in the existing literature rarely use real job histories and therefore it is little known how knowledge workers move across organisations and occupations. Hence, although great attention has been paid to the emerging boundaryless (DeFillippi and Arthur, 1994) or project-based network organisations and to the demise of organisational life, questions regarding the extent to which careers are boundaryless and how labour market features of one segment of S&E PhD knowledge workers compares to those of another segment remain unanswered. The following review outlines how these gaps in the literature may be identified.

2.1 Research on careers of scientists and engineers/the highly skilled

There are two approaches to research on careers: one focuses on "organisations" while the other is primarily interested in "occupations" (Arthur, 2008). The organisational careers scholars are interested in the relationship between the individuals and the organisations, i.e. how individuals and organisations interact over time. It is argued that career/job mobility is bounded with social contexts (Barley, 1989; Mayrhofer et al.,

2007) or social structure (DiPrete et al, 1997; Fujiwara-Greve and Greve, 2000; Haveman and Cohen, 1994). On the other hand, the occupational careers scholars try to explore the "vocational guidance" that helps a person to find entry to an occupation that match his/her interests and abilities; they are usually concerned with the psychology of careers (Schein, 1975; Super, 1957). In reviewing literature on career patterns of S&E PhD scientists and engineers, we find that it is helpful to start our discussion while bearing this distinction in mind. We propose a potential synergy by combining these two traditions of research on careers. That is, although offering a thorough analytical framework in institutions, individuals' careers and knowledge/skill development, the literature of organisational focus on careers has not paid specific attention to the heterogeneity within the S&E PhD labour markets. On the other hand, by emphasising psychological aspect of careers, the literature with an occupational focus on careers has explored the attributes and the determinants of careers of S&E PhDs in different occupational contexts. Hence, the differences in careers of S&E PhDs in different occupational contexts provide foundations for us to explore the heterogeneity within the S&E PhD labour markets.

2.1.1 Organisational focus

The organisational careers scholars are interested in the structure of employment and work organisation. Earlier literature was largely based on sociologists' concerns on social mobility and focused on the determinants of the shift of jobs among occupations. A career is defined as "*the evolving sequence of a person's work experiences over time*" (Arthur et al., 1989, pp. 8). It is argued that the studies of careers provide access to the empirical relation between social action and social structure (Barley, 1989), as Becker and Strauss (1956) claimed that a sociological theory of career should be "*a fairly comprehensive statement about careers as related to both institutions and to persons*" (pp. 253). This points out that although a primary focus of human resource management studies has been placed on individual psychology that emphasises choices and motivations (Schein, 1975), individual careers are nonetheless structured within organisational and social settings.

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. Such employment system 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. Such jobs also often have professional standards for work and reward individual motivation and achievement. Many professional jobs fall into this category.

Other classifications of different labour markets have been proposed. Osterman (1988) classified 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 rises, 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.

A 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 the skills are, the more specific the knowledge and skills are. Similarly, the rarer the skills on which productivity relies, the more specific the knowledge and skills are. Hence, the ILMs feature a higher degree of specificity in knowledge and skill development that is particularly 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. Furthermore, 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 human resource 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 who 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 emphasise formal job ladders by focusing on groups, organisational structure and the political bargaining process among groups (Osterman, 2009).

In short, in this section, we have introduced several types of labour market models. The ILMs and the OLMs are highly associated with the highly skilled. They are structured and their mobility patterns could be identified through knowledge and skill development. In general, the careers prospects of workers in these labour markets are good. We have also discussed the compound labour markets, which is a way to describe how in a real world, the labour markets of the highly skilled often are the co-existence of the ILMs and the OLMs. The Flexible Firm model stresses how workforce is polarised into the "core" and "peripheral" groups. The two groups are distinguished by job security, i.e. permanent or fixed-term jobs in terms of employment contract. Finally, the boundaryless careers are unstructured and often emphasise individuals' control of their careers by networking.

2.1.2 Occupational focus

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. For instance, they have been defined based on type of work (such as physical and non-physical) (Dawis et al., 1979), on social-economic groups (such as blue-collar and white collar) (Herr and Cramer, 1984) or on occupational interests (artistic, scientific, mechanical, etc.) (Droege and Padgett, 1979). The current UK Labour Force Survey (LFS) uses further grouping of occupational titles as main occupational groups. These are: 1) managers and senior officials, 2) professional occupations, 3) associate professional and technical occupations, 4) administrative and secretarial occupations, 5) skilled trades occupations, 6) personal service occupations, 7) sales and customer service occupations, 8) process, plant and machine operatives and 9) elementary occupations (LFS User Guide Volume 5, 2009). So what would be the potential occupations for S&E PhDs and how might they be classified? The following section reviews how existing literature discusses different types of jobs that are relevant to scientists and engineers or S&E PhDs and the determinants of having careers in these types of jobs.

The discussion of careers of academic scientists is rooted in the sociology of science. Scholars discussing the epistemology of science, i.e. the production of scientific knowledge, observe the career behaviour of academic scientists to explain their scientific productivity and hence how knowledge is produced. The majority of the work investigates the determinants of scientific productivity of academic scientists (hence linked to promotion). These determinants could be the effects of personal or institutional prestige (Allison et al., 1982; Allison and Long, 1990; Allison and Stewart, 1974; Merton, 1968), invisible college (Crane, 1969; Price, 1963), mentoring (Long and McGinnis, 1985) or demographic factors such as gender and age (Cole, 1979; Long et al, 1993). These determinants may also be assessed through a life cycle perspective (Levin and Stephan, 1989, 1991; Stephan and Levin, 1992).

The literature on the careers of scientific personnel in the management of innovation, on the other hand, mostly focuses on industrial scientists and engineers, mainly on the discussion of career development of scientific and technical personnel in large corporate firms with R&D labs. The key concerns have been shown to be the potential conflict between creativity and profit utilisation (Kornhauser, 1962), hence the creation of the dual career ladder system to provide suitable matches for scientists and scientist-turned-dedicated managers (Allen and Katz, 1986, 1992; Gunz, 1980), and consequently the effects of personal motivations and incentives of industrial scientists and engineers on their intentions in pursuing different career tracks or the effects on mobility (Biddle and Roberts, 1994; Debackere et al., 1997; Johnson and Sargeant, 1998; Rynes, 1987).

Scientists and engineers may also be defined through their formal training. Studies covering the distribution of scientists and engineers working in both the public and the private sectors are mostly based on surveys of S&E doctorates, as they are the main population that could potentially have careers across both academia and the private sector. The interest in investigating the S&E PhD labour market is broadly due to two reasons. First, the extent to which science and engineering doctorates are working in the private sector as knowledge flow from academia to industry (Larédo, 2007; Mangematin, 2001; Martin and Irvine, 1981; Mowery and Sampat, 2005; Pavitt, 1991). Second, as the massification of higher education (including awards in doctorates in the past few decades) has made it very difficult for many doctorates to secure faculty positions, many studies empirically investigated determinants of employment opportunities for S&E doctorates in the public and the private sectors (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).

The literature in this approach points out that the extent to which S&E PhDs are employed in industry shifts over time and seems to become increasingly significant. Martin and Irvine (1981) surveyed PhDs trained in two UK radioastronomy observatories (Jodrell Bank and Cambridge) between 1945 and 1978. Their data revealed that, at the time of survey, the first jobs for respondents were 55% in academia, 22% in government and 17% in industry, and the most recent jobs were 46% in academia, 29% in government and 20% in industry. This indicates that throughout the period, career patterns for radioastronomy PhDs in the UK were rather stable. Stephan (1996) showed that in the US, up to 1991, academia remained the largest employment sector for doctoral scientists although the proportion was decreasing. Industry was the second largest employment sector for doctoral scientists and the proportion was increasing. Stephan et al. (2004), based on data from the US Survey of Doctorate Recipients from 1973 to 1999, further pointed out that for those who have left graduate schools for more than 5 years, in all science and engineering fields, employment in industry grew so rapidly that by 1989, industry surpassed the tenure-track academic sector as the most common employment sector for S&E PhDs and, by the mid-1990s, it surpassed all types of academic employment. Similarly, a report by Mason and Wanger (1994) that used survey data of first destinations of UK PhDs who graduated in 1991 in science and engineering from the Universities Statistical Record (USR) showed that, for those who were in employment in the UK, the proportion of those who were in education or public sector was estimated to be 40%, while jobs in industry accounted for around 60%. A UK survey targeting PPARC (Particle Physics and Astronomy Research Council) sponsored PhD students (DTZ Pieda Consulting, 2003) also estimated that 6-8 years after awards ended, in 2003, 15% of the sponsored students were either in permanent university research positions or in government/public sector research positions and 54% were in the private sector. Ender’s (2002) German case, based on a survey of three cohorts of German doctorates (1979/1980, 1984/1985, 1980/1990) in 1999, reported that, in the long run (15 to 20 years after graduation), only 40% of mathematics graduates and 20% of electrical engineering graduates were in higher education. These studies imply that, in many countries, industry is establishing its dominance as the major S&E PhD employment sector.

Because these observations may indicate an employment pattern that diverges from the traditional expectation that PhDs are trained to become academics, this has led scholars to discuss a number of issues. These include: the incentives for doing a PhD (Mangematin, 2000), expectations and realities regarding employment (Fox and Stephan, 2001; Mangematin, 2000), value of the doctoral research training (Enders, 2002, 2005), employability of people with a doctoral degree (Dany and Mangematin, 2004), determinants of S&E PhD career outcome (Giret and Recotillet, 2004;

Mangematin, 2000; Robin and Cahuzac, 2003), and how S&E PhDs may contribute to research activities in industry (Mangematin, 2000; Stephan et al., 2004).

As innovations are increasingly science-based in some industries, such as biotechnology, there are increased interests in discovering mechanisms that foster greater social and economic benefits of academic science (Etzkowitz, 1983; Gibbons et al., 1994). A better understanding of the mechanisms that shape scientists' and engineers' career behaviour in boundary-crossing between academia and industry has become vital for policy makers, universities and individual scientists. Research on academic entrepreneurship has thus pointed out the roles of star scientists (Zucker et al., 2002a, 2002b), of networks of inventors or scientists (Lam, 2005, 2007; Murray, 2002, 2004; Stephan et al., 2007), of academic scientists as active agents that shape the relationships between the scientific and the commercial worlds (Lam, 2010) and of the effects of industrial working experience on productivity of academic scientists (Dietz and Bozeman, 2005).

In reality, trained scientists and engineers do change jobs, firms, organisations and occupations in their careers. One of the aspects of career behaviour of trained scientists and engineers is knowledge flows that highly skilled associated with. The following section discusses how knowledge flow might be inextricably linked with career patterns.

2.2 Careers and knowledge flow

Obviously, there could be many channels for knowledge flow and spillovers (such as research collaboration/alliances and trade in goods). Many studies have indicated that career/job mobility of highly skilled personnel is one of the most important channels for knowledge circulation, technology transfers and innovation spillovers (Almeida and Kogut, 1999; Madsen et al., 2003; Rosenkopf and Almeida, 2003; Saxenian, 1990; Smith, 2000). One obvious example illustrating how knowledge flow is inextricably linked with career/job mobility is personnel mobility in the semiconductor industry; most of the firms in Silicon Valley can be traced back to Fairchild, and Fairchild was actually established by assistants of William Shockley, who left the pioneer of semiconductor industry, Bell Labs, to establish his own company Shockley Semiconductors (Almeida and Kogut, 1999).

However, studies exercising this idea often are descriptive (Saxenian, 1990; Smith, 2000) or have taken for granted personnel mobility as the proxy for knowledge flow (Madsen et al., 2003; Smith, 2000). Although Almeida and associates, based on patent citation data, proved how heavily inventors' existing firms cite the inventors' previous ideas that were produced when they were working for other firms (Almeida and Kogut, 1999; Rosenkopf and Almeida, 2003), as most skilled workers are far from being inventors, a more general idea of how exactly knowledge spillovers occur, or what types of knowledge are transferred through career mobility of highly skilled personnel, is yet to be established. We argue that the answers may reside in the types of knowledge and skills that an individual could accumulate when he or she serves within an organisation, an industry or a sector and in the incentives and the ways to acquire them. This corresponds to the notion of how careers might be interpreted as process of knowledge (Arthur, 2008; Bird, 1996); that is, careers can be seen as *"accumulations of information and knowledge embodied in skills, expertises, and relationship networks that are acquired through an evolving sequence of work experiences over time" (Bird, 1996, pp. 150).* This interpretation of careers obviously highlights the importance of individual learning throughout one's career. The following sections hence discuss individual learning, how it is bounded with social structures, and its interrelationship with job mobility.

However, before we proceed to the next section, it would be helpful to clarify some concepts. Firstly, the concept of career, job and occupational mobility can be constructed as follows. Career mobility includes everything from changing jobs to changing organisations to changing occupations (Feldman and Ng, 2007). Job mobility involves any changes in work responsibilities, ranks or titles within or outside organisations (Appendix 1). Job transition refers to the change from a previous job to the subsequent job. Occupational mobility refers to job mobility across one defined occupational group to another. We adopt Cheng and Kalleberg's (1996) definition where "*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 among occupations. That is to say, this definition uses knowledge and skills as boundary for occupations.

Moreover, regarding the concept of spillovers and knowledge flow, Griliches (1992) argued that true research and development spillovers are ideas borrowed by one research team from research results of another team. Rogers (1995) pointed out that the diffusion of a specific innovation needs communication channels from *"an individual or other unit of adoption that has knowledge of the innovation or experience with using it"* to *"another individual or other unit that does not yet have experience with the innovation"* through *"a communication channel connecting the two units" (pp. 18).* Hence, the Griliches (1992) and Rogers' (1995) definitions of knowledge flow and spillovers clearly pointed out that, for them to occur through the channel of an individual's job mobility, some ideas used in the individual's current job need to be drawn from the person's previous job.

2.2.1 Individual knowledge

The incentive for individuals to learn may be linked to how investment in human assets/resources in people will influence their future real income (Becker, 1962, 1964; Mincer, 1958; Schultz, 1961). Such human assets/resources include formal education, on-the-job training, immigration and health. With special reference to education, Becker (1964) argued that on-the-job training and schooling raise earning and productivity by providing knowledge, skills and effective ways of analysing problems. Schultz (1961) also pointed out that investing expenditures in skills, knowledge and other similar attributes that affect human capabilities to do productive work lead to the increase in the productivity of human effort and hence will yield a positive rate of return. Mincer (1958) confirmed that inter-occupational differentials in income are a function of differences in training. However, critics have pointed out that since Becker, Mincer and Schultz, the concept of human assets/resources has not advanced much as the "substance" of human assets/resources virtually remains a black box (Autor and Handel, 2009; Bozeman et al., 2001; Dietz and Bozeman, 2005; Nordhaug, 1993).

Efforts thus have been made to unpack the substance of human assets/resources. Autor and Handel (2009) proposed a framework by taking occupational assignment and job tasks into account. In order to assess economic effects of human assets/resources on organisations, Nordhaug (1993) argued that it is necessary to identify work-related competences. Building on Becker (1964) and Williamson's (1981) contributions by distinguishing organisation-specific and general knowledge and how they are related to employment relationship, Nordhaug (1993) further distinguished employees' various types of competences in organisations by looking into two dimensions: the degree of task specificity and the degree of organisational or industry specificity. He argued that it makes more sense to talk about the substance (types) of human assets/resources rather than the amount, and that the varied types of employee competences in organisations are better suited to the understanding of how the human assets/resources might be configurated and circulated within the organisations.

Bozeman et al. (2001) and Dietz and Bozeman (2005) added another dimension to the understanding of human assets/resources by developing the concept of science and technology (S&T) human capital. They defined S&T human capital as "*a walking set of knowledge, skills, technical know-how, and, just as important, a set of substantive network communications…*" (Dietz and Bozeman, 2005, pp. 353). They further argued that S&T human capital must recognise variation in educational background, as no two physics degrees are the same; furthermore, the S&T human capital of a doctorate who has gained gaining all degrees in biochemistry is qualitatively different from that of another doctorate who has gained first degree in art, master degree in biology and a PhD in biochemistry (Bozeman et al., 2001). Scientists' on-the-job research training in industry must also be qualitatively different from research training in academia (Dietz and Bozeman, 2005).

2.2.2 Individual learning and social/organisational knowledge

Section 2.2.1 has discussed the potential value of different types of individual knowledge and how they may contribute to individual career success. However, the discussion has not explained "how" individuals learn. In this section, we adopt the concept that individual learning is contextual and bounded with social structures such as organisations to illustrate the mechanism that shapes individual learning.

Philosopher Ryle's (1949) distinction between "knowing that" and "knowing how", and psychologist and economist Simon's (1978) distinction between "substantive" (knowing what should be the right action to take) and "procedural" (knowing how the action is taken and executed) rationality pointed out two different types of knowledge. At individual level, the philosophical reasoning has been empirically confirmed through developments in neurosciences about human memory regarding "declarative" and "procedural" knowledge (Squire, 1987; Squire and Kandel, 1999).

On the one hand, declarative knowledge is related to factual knowledge such as knowledge of facts, events, data, concepts, rules, laws and theories. Such type of memory normally needs to be consciously retrieved. Moreover, such memory is designed to represent objects in the external world and the association between them. Furthermore, it is knowledge that can potentially be declared or stored as a mental image. On the other hand, procedural knowledge deals with learned skills or modifiable cognitive operations and it can be recollected unconsciously. Such skills/operations are often improved through repeated practice and are expressed through performance. For instance, the skill of riding a bicycle or swimming can be acquired gradually through several trials. Once acquired, such capability can be applied automatically and unconsciously. Indeed, one can learn such skills without knowing or being able to declare what exactly is being learned (Squire and Kandel, 1999). The distinction between the two types of knowledge is best explained by the example of learning by amnesia patients. Psychologists discovered that amnesia patients could learn (with demonstration of how to do it) and retain the capability of mirror-drawing (related to learned skills, modifiable cognitive operations) despite their inability to remember any previous practice (related to facts, events) (Squire and Kandel, 1999). The modularity of human memory corresponds to the tacit and the explicit dimension of individual learning.

It is obvious that individuals learn. The less straightforward question to answer is, however, what the relationship between individual knowledge and social knowledge is.

For instance, within the organisational context, do organisations learn, know or remember something? Can individual knowledge in an organisation translate into organisational knowledge? How? Similarly, can organisational knowledge in an organisation, if organisations can learn, translate into individual knowledge of the members and, if yes, how? In exploring answers to these questions, scholars working on organisational studies have looked into the incentives of individuals and the relationship between individual knowledge and social knowledge.

Nelson and Winter (1982) proposed that "routines" serve as organisational memory, and that organisations remember by doing; organisations keep the memory as long as all staff "know their jobs". Kogut and Zander (1996) argued that although individuals form the micro-foundation of organisations, individuals in an organisation can only have "partial knowledge" of the organisation and the knowledge of the organisation is more than the sum of all individuals' partial knowledge. This indicates that an organisation itself knows something (Kogut, 2008).

Hutchins (1996) studied how divisions of skills of individuals manage to control a large ship navigating in the wild and demonstrated that an organisation or a team can learn through coordination among its members. Cohen and Bacdayan (1994) demonstrated empirically that individuals are able to store organisational routines in their procedural memory, illustrating the way that organisational knowledge is able to translate into individual knowledge. The latter case also corresponds to Simon's (1957) concept of "bounded rationality", which stresses that individual decision-making is often guided by some rules and experiences, rather than purely by the full information given and the maximisation of benefits. Hence, Nelson and Nelson (2002) concluded that much of human action is "collective" in nature and thus "culturally specified rules" and individual knowledge are interactive. Kogut and Zander (1992) concluded that social knowledge is embedded in individual relationships and individual relationships are structured by organising principles, i.e. a "shared template" (Kogut, 2008). As individual knowledge is able to translate into organisational knowledge and organisational knowledge is able to translate into individual knowledge, this is in line with the reasoning stressing that actors' actions and institutions are recursively related;

although actors' actions are guided by bounded rationality, actors are knowledgeable and their choice can modify institutions (Barley and Tolbert, 1997).

It has therefore been proposed that the types of knowledge in organisations are embrained knowledge, embodied knowledge, encoded knowledge and embedded knowledge (Blackler, 1995; Collins, 1993; Lam, 2004). Nonaka (1994) argued that knowledge in organisations could be classified alongside two dimensions: one regarding explicit and tacit and the other regarding individual and collective. Lam (2004) summed up that the two dimensions of knowledge creation results in the four types of knowledge in organisations. According to Lam (2004), embrained knowledge is explicit and individual. It is related to an individual's conceptual skills and cognitive abilities, is formal, abstract and theoretical and typically learned from formal education or reading books. Embodied knowledge is tacit and individual. It depends on an individual's know how and is learned through experience and apprenticeship training. Encoded knowledge is explicit and collective. It is shared in organisations with written rules and principles. Embedded knowledge is tacit and collective. It is organised through mutually shared routines, norms, identities, habits or cultures in the organisations in an interactive form. This typology of knowledge in organisations clearly points out that individual knowledge forms only part of organisational knowledge.

Therefore, although recognising individual incentives and motivations, we believe that individual learning is however guided by bounded rationality (Simon, 1957). That is, not only can individual learning not be detached from institutional settings, norms, rules, routines, experiences, etc., but also it shapes and is shaped by them. The theoretical background of this thesis hence is in line with the essence of the evolutionary theory of economics (Nelson and Winter, 1982). Furthermore, although individuals make up a team, an organisation or a community, etc., knowledge of the team, the organisation or the community is more than the sum of knowledge of individuals that make up the team/organisation/community (Kogut, 2008). The discussion of the knowledge that may be portable through individuals' career mobility hence features mainly the individual dimension of knowledge in organisations. This should not be mistaken with the idea that the whole of organisational or social knowledge is possible to be transferred through individuals' career mobility.

2.2.3 The interrelationships among work-related competences, employment contexts and career/job mobility

Section 2.2.2 has discussed how individual learning is contextual (bounded with task, organisation, occupation, industry, sector, etc). Therefore, although individuals are able to manage and enhance their human assets and resources through knowledge and skill development in order to maximise their employability in the labour markets, the ways to acquire specific types of knowledge and skills are not solely determined by individuals, but also shaped by organisational or institutional norms and routines. One's knowledge and skills base can be acquired from formal education or on-the-job training. However, specific types of employment value certain specific types of knowledge and skills. Those specific types of knowledge and skills are referred to as work-related competences (Nordhaug, 1993). Therefore, the configuration from one's individual knowledge and skill base to work-related competences is rooted in employment contexts. That is, an individual's work-related competences are defined through matched employment settings that recognise their potential contribution (DeFillippi and Arthur, 1994). In other words, they are determined by employees' knowledge base (formal education, on-the-job training, etc.) that is then filtered through organisational, occupational or sectoral standards, routines, norms and experiences (i.e. institutional settings embedded in a specific task, organisation, occupation, industry and sector). Nordhaug (1993) referred to this process as the competence configuration process. The difference between one's knowledge and skill base and work-related competences corresponds to the distinction between "knowing", i.e. putting current knowledge to work, and "learning", i.e. the process of acquiring or creating new knowledge (DeFillippi et al., 2006).

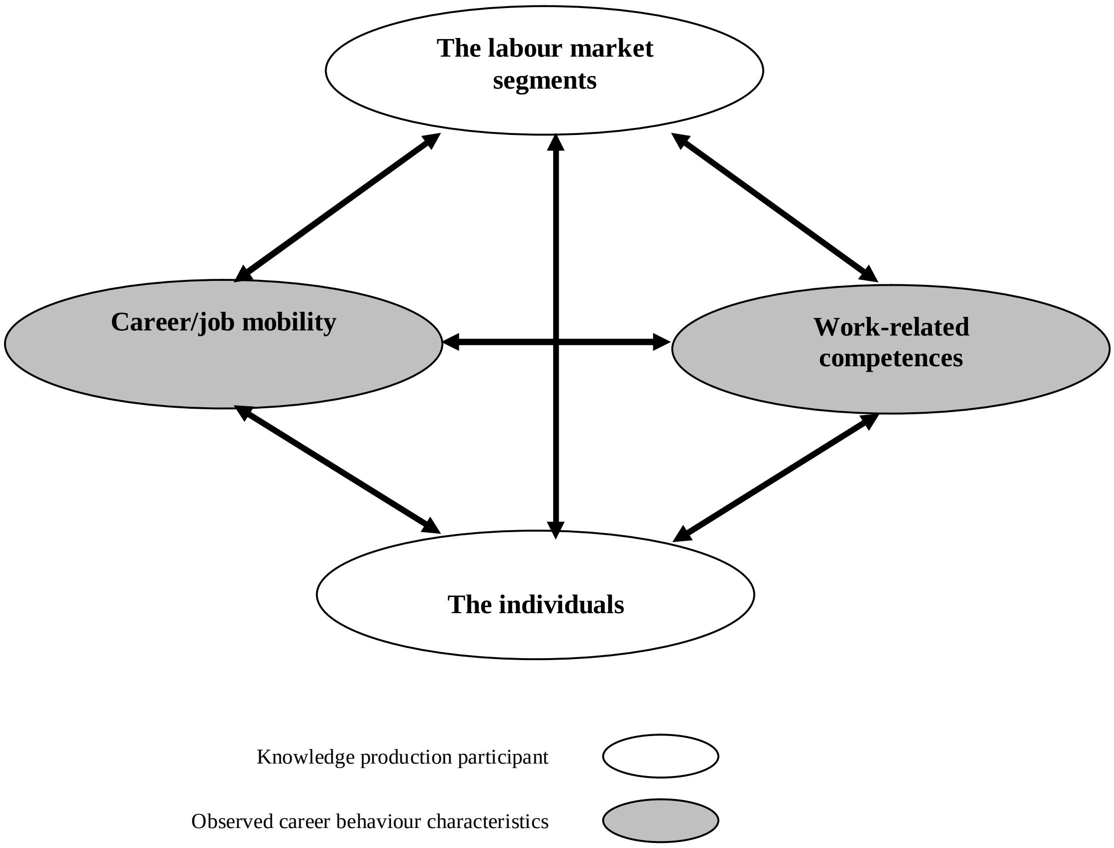
Since one's work-related competences indicate one's knowledge and skills that are appreciated by potential employers and therefore the person's employability, they are able to point out the direction of one's potential career/job mobility. This indicates that there is an underlying structure that regulates employment contexts (task, organisation, occupation, industry and sector), work-related competences and career/job mobility.

The structure of the relationships among heterogeneity in employment contexts, work-related competences and career/job mobility has been long established by the labour market theorists from an organisational tradition. As defined by Reich et al. (1973), labour market segments are *"distinguished by different labour market characteristics and behavioral rules"* (pp. 359). Therefore, we propose that, as long as a classification scheme which comprises different categories of employment contexts based on tasks, organisations, occupations, industries or sectors could lead to more or less homogeneous features of job mobility and of the corresponding work-related competences within a category, but such features distinctively differ among categories in the classification scheme, we may call these categories labour market segments. That is, with a proper classification of employment contexts, labour market segments could be identified. This thesis follows this logic to explore the interrelationship between career/job mobility and work-related competences in different labour market segments. Furthermore, this thesis uses individuals' account to explore the interrelationship. That is, individuals are seen as capable of having career/job mobility across tasks, organisations, occupations, industries and sectors, given by the condition that the individuals have recognised work-related competences, whose definition depends on the corresponding labour market segments. Traditional institutional labour market literature suggests that once individual workers are structured into specific labour market segments, their behaviours are determined. In this respect, however, while we recognise the importance of institutional settings, this thesis also adopts the view that individuals' actions and institutions are recursively related. That is, although actors' actions are guided by bounded rationality, actors are knowledgeable and their choice can modify institutions (Barley and Tolbert, 1997) (details of the theoretical reasoning of the interrelationship between individual and social knowledge has been demonstrated in Section 2.2.2.) Hence, although it may be measured by means of individuals' accounts, the two observed phenomena, i.e. individuals' career/job mobility and perceived work-related competences, are jointly constructed by the two types of knowledge production participants, i.e. the individuals and the labour market segments. We refer individuals and labour market segments as knowledge production participants because both individuals and organisations can learn, and their leaning is shaped by each other. This means that these two observed career behaviour characteristics are neither purely individual features nor purely social features.

The relationships among individuals' work-related competences, the labour market segments they are in, and their career/job mobility could be interpreted as follows. The flow of individuals' work-related competences through career/job mobility could be seen as individual knowledge flow. However, the patterns of such knowledge flow are not random. Individual knowledge flow through skilled workers' job mobility could be internal or external to organisations, occupations, industries, sectors, etc. These patterns are likely to be associated with specific types of workers' knowledge and skills that are appreciated by the potential employers. This process configures the workers' knowledge and skill base into work-related competences for career/job mobility. Through job mobility that might further bring new tasks or specific organisational, occupational, industrial or sectoral settings, skilled workers' existing competences evolve to a new knowledge and skill base that might be appreciated by different types of future employers. This leads to new patterns of career/job mobility. Hence the knowledge production participants, i.e. the individuals and the labour market segments (task, organisation, occupation, industry and sector) and observed career behaviour characteristics, i.e. work-related competences and job mobility, are interrelated; they influence and are influenced by each other and the relationships are on-going continuous two-way relationships. The illustration of the relationship among the labour market segments, the individuals and the observed qualities of career/job mobility and work-related competences is shown in Figure 2.1.

Individual knowledge flow may be interpreted as the non-random job mobility patterns of skilled workers. The concept of spillovers through individuals' job mobility may be further developed through knowledge flow, but it requires more qualifications than knowledge flow. Spillovers through an individual's job mobility occurs when the individual moves from job *i* to job *j*, internally or externally, and in job *j*, the individual draws knowledge and skills that are acquired from or used in job *i* to excel work requirements in job *j*. Ideally spillovers should measure the types or the extent of knowledge and skills that are acquired from or used in job *i*, and then are applied in job *j*.

Figure 2.1: The interrelationships among knowledge production participants and the observed career behaviour characteristics



2.3 Gaps in the existing literature about the S&E PhD labour markets

The structure of the relationships among labour market segments, work-related competences and career/job mobility, which was discussed in Section 2.2.3, explains how knowledge flow is inextricably linked with career patterns. To apply this framework to S&E PhD knowledge workers to explain the dynamics of knowledge flow in different S&E PhD employment contexts, however, some further considerations need to be taken into account. First, a fundamental problem is that the existing literature is inadequate in recognising the heterogeneity within the labour markets of S&E PhD knowledge workers. Knowledge workers have been treated more or less in the same labour markets (Doeringer and Piore, 1971; Edwards et al., 1975; George and Shorey, 1985; Mace, 1979; Marsden, 1986; O’Connor, 1973; Osterman, 1988). To highlight the heterogeneity, based on lessons of the literature on occupational differences, i.e. what S&E PhD knowledge workers do and prefer to do, we argue that occupational differences are fundamentally one of the main factors that cause the heterogeneity. Therefore a suitable classification of occupational or sectoral differences should be incorporated into analysis. Second, critics have pointed out that, since Becker (1964) and Williamson (1981), the concept of human assets/resources has not advanced much and the "substance" of human assets/resources virtually remains a black box (Autor and Handel, 2009; Bozeman et al., 2001; Dietz and Bozeman, 2005; Nordhaug, 1993). Although some efforts have been done (Autor and Handel, 2009; Bozeman et al., 2001; Dietz and Bozeman, 2005; Nordhaug, 1993), work-related competences that are specific to S&E PhDs remain unexplored. Third, there are few studies approaching careers of knowledge workers in a longitudinal perspective and our understanding of career mobility and career behaviour across organisations, occupations or labour market segments remains limited (Arthur, 2008; Schein, 2007). Details of these inadequacies in the literature are discussed below and this thesis intends to fill these gaps.

2.3.1 Existing literature is inadequate in recognising S&E PhD labour market segments

A fundamental problem in the existing organisational literature is that labour market segments within highly skilled knowledge workers have rarely been taken into account. In order to compare them with the less skilled or unskilled, literature on the organisational tradition in career/job mobility of the highly skilled/knowledge workers treats the highly skilled 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 studies that argued that the highly skilled might also become peripheral workers (Kalleberg, 2003). The consequence is that different patterns of career behaviour that correspond to different labour market segments within knowledge workers are invisible. For instance, Malhotra and Morris (2009) found that, even within the sector of knowledge intensive business services, it is highly heterogeneous in how knowledge is organised. Furthermore, Sammarra and Biggiero (2008) also identified the heterogeneity in types of knowledge that have been transferred within a network of firms in the aerospace industry. These examples of heterogeneity in how knowledge is organised within knowledge intensive business services or within a network implies that differences in career patterns within them may not be ignored, according to labour market theories.

Similarly, regarding analyses about career patterns of S&E PhDs by applying the labour market theories, there is a lack of a classification scheme of segments that can fully capture the characteristics of the knowledge economy. In this aspect, literature on the occupational tradition has clearly pointed out the distinctive differences in incentives between academic scientists and industrial scientists and many studies on careers of doctorates are based on their positions in either the public or the private sectors. They provide a potential classification of segments within the S&E PhD labour markets. However, we argue that this classification is not sufficient to capture the observed characteristics of the knowledge economy into career analysis.

While academia and government may be traditionally regarded as the main sectors for employment for S&E graduates, many universities and government organisations might be employing more S&E PhDs for non-research tasks such as for developing strategies or policies. These are some examples of unconventional S&E PhD jobs within the conventional S&E PhD sector. Similarly, it is often taken for granted that many S&E PhDs will occupy research positions in industry, and these positions have traditionally been associated with R&D laboratories in large firms, in industries such as chemicals, pharmaceuticals, aerospace, semiconductors, etc. It is unclear whether modern S&E doctorates are more likely to be employed in such conventional research positions or in banks or consultancy firms. Indeed, the UK PPARC case (DTZ Pieda Consulting, 2003) showed that for those PPARC sponsored PhDs who worked in the private sector, 29% were in software design/solutions/management, 24% were in financial services and 24% were in business services. Many studies have also shown the significant outflow of trained scientists and engineers to non-technological jobs at undergraduate level (Lavoie and Finnie, 1998; Lavoie et al., 2003). Therefore, to address these changes, apart from bearing in mind the academia/non-academia and the research/non-research distinctions, in this thesis we pay special attention to S&E PhD jobs within and outside the "conventional S&E PhD occupations", i.e. academic or public research positions and technical positions in private sector manufacturing. That is, the existing literature is inadequate in recognising that more and more S&E PhDs may work in occupations outside academia, public research organisations or industrial R&D laboratories. Indeed, since knowledge and skill development is bounded with social/organisational routines (Kogut, 2008; Nelson and Winter, 1982), there is a strong reason to believe that knowledge and skill development in work outside these conventional S&E PhD occupations is qualitatively different from knowledge and skill development in work within the conventional S&E PhD occupations. Hence, apart from potential segments of academic/public research and technical positions in private sector manufacturing, an extra segment, i.e. employment outside the conventional technical occupations, needs to be incorporated into the analysis of the S&E PhD labour markets.

2.3.2 Existing literature is inadequate in unpacking S&E PhD work-related competences

There have been criticisms regarding the lack of studies on how "substance" of individuals' human assets/resources/learning, i.e. work-related competences, may differ in and correspond to different labour market segments, further to Becker (1964) and Williamson's (1981) discussion of human asset specificity (details discussed in Section 2.2.1). Although some efforts are made to unpack the substance of work-related competences (Bozeman et al., 2001; Dietz and Bozeman, 2005; Autor and Handel, 2009; Nordhaug, 1993), very little has been done regarding work-related competences of S&E PhDs in different employment contexts. Some exceptions include studies that have shown that industrial experience makes a difference in academic scientists' network patterns (Dietz and Bozeman, 2005) and 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). However, further details on exactly how the different dimensions of doctoral training are perceived as useful in different employment contexts or on how knowledge and skills acquired from doctoral training are perceived as useful in the labour markets when compared to other types of knowledge and skills developed through working experience virtually remain underdeveloped.

Based on discussion about the relationship between individual knowledge and social or organisational knowledge, we argue that the configuration of individuals' work-related competences from individual knowledge and skill base cannot escape from employment contexts (task, organisation, occupation, industry and sector). Hence perceived work-related competences are expected to vary by labour market segments.

A potential classification of S&E PhD labour market segments discussed in Section 2.3.1 would be the first step to offer better insights into the mechanism of how S&E PhDs knowledge and skills are configurated into work-related competences. The second step would be to consider what might be regarded as the S&E PhDs' knowledge and skill base, which would then be able to be configurated into work-related competences. We propose two approaches to examine S&E PhDs' knowledge and skill base. The first approach is to see S&E PhDs as a special type of personnel because of their research training in science and engineering. Scholars in innovation studies have pointed out the contributions of S&E PhD personnel to the economy. Pelz and Andrews (1966) stressed that PhD and non-PhD personnel differ significantly in their motivations and the quantity and quality of their output. Mangematin (2001) also pointed out the special nature of doctoral workforce because its members, on the one hand, are trained in universities and contribute to the production of new knowledge and, on the other hand, serve as an important channel for knowledge transfer from academia to industry if they enter industry after doctoral education.

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

These two purposes or dimensions of modern doctoral education, scholarship and professional training, which are regarded by some as competing (Burgess, 1997;

Leonard, 2000; Pole, 2000), reflect the dual nature of the PhD as a “product” and as a “process” (Park 2005). The scholarship dimension is rooted in the general perception and requirement that a PhD thesis has to be original and advance disciplinary knowledge. This implies that the purpose of scholarship in doctoral education is assessed by a final “product”, a thesis; a thesis has to demonstrate that some original knowledge has been produced. On the other hand, the dimension of professional training places emphasis on the “process”, the development of the procedure and the capability to conduct research independently.

Pole (2001) argued that, apart from substantive knowledge, which is acquired from the specific disciplinary focus of the doctorate and makes a PhD student an expert or a specialist in a specific field, technical skills, craft knowledge and personal/social skills are also acquired from doctoral training. Technical skills refer to skills developed as a result of implementing research, particular through the methodology employed in the research. Such skills comprise capabilities of identifying and using proper instruments, designing, constructing and using sophisticated equipment or writing and effective use of software. They may also refer to the ability to design and analyse a survey, to use database and statistical packages and to conduct interviews or observations. Craft knowledge, although closely linked to technical knowledge, refers to the ability to manage a research project in its various aspects. Hence it goes beyond the notion of individual technical competences. This type of knowledge incorporates the whole process of research including research design, experimentation, fieldwork, analysis, writing, publishing, research exploitation and even the management of staff and finance. Indeed, Delamont and Atkinson (2001) stress the importance of craft knowledge by studying the transition of students from undergraduates to doctoral researchers in several natural science departments where experimentation and fieldwork are particularly important. They found that the transition is accompanied by a sense of reality-shock, as students realise that their excellence in substantive knowledge does not always make experimentation or fieldwork work. Rather, problem solving capabilities through tacit skills that are acquired through trial and error and through mentoring of senior staff are often the key to successful research. Finally, personal or social skills are more relevant to social sciences doctorates. Because social scientists’ research often requires effective communication with a wide range of people, they are also likely to develop skills related to communication, teamwork or the development of self-confidence.

Pole (2001) further pointed out that many doctorates see gaining substantive knowledge as an automatic product from doctoral training. They also often emphasise their gain in technical skills and craft knowledge. Naturally, as PhD projects are open-ended scientific investigations, without the in-depth understanding of knowledge in the discipline needed to make an elegant argument and the ability to frame proper research questions and subsequently to execute the research, an original contribution to knowledge in the discipline is implausible. Hence, it is reasonable to assume that if a PhD award is granted, it is a guarantee that the receiver is equipped with in-depth knowledge in a specific discipline and has the capabilities to design and implement an independent piece of research. This implies that the process of a PhD study is a journey of individual learning, both to acquire knowledge in the discipline and procedures to construct knowledge, and that successful postgraduates should leave university with knowledge and skills, some of which are subject-specific and others that are more general and transferable.

The second approach is to consider that individual knowledge and skill base of S&E PhDs comprises 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, and knowledge and skills that are general and can be used in a wide range of applications, although these types of knowledge and skills are not entirely exclusive from each other.

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, the source of knowledge of a sector may be mainly based on in-house R&D or may rely on external linkages with scientific breakthroughs in academia. Furthermore, knowledge is cumulative and the production of new knowledge builds on the existing knowledge. The path-dependency feature of knowledge is also referred to as technological trajectory (Dosi, 1982; Nelson and Winter, 1977). Indeed, Pavitt (1984) has demonstrated the diversity across sectors in accessibility and cumulativeness of knowledge. Because sector-specific knowledge is expected to be general and portable across organisations in a sector but is specific when compared to other sectors, we argue that this type of knowledge should be studied separately in the labour markets.

By unpacking the types of knowledge and skill base of S&E PhDs, the corresponding work-related competence in different labour market segments can then be further explored.

2.3.3 Existing literature is inadequate in addressing careers in a cross-level perspective

Methodologically, existing literature on the organisational tradition in career/job mobility of the highly skilled/knowledge workers has its primary interests either in a single industry or in an organisation or in descriptive analysis - this is due to particular research designs and to a great extent, the lack of longitudinal data. This methodological constraint affects our understanding of the dynamics of mobility patterns and how career mobility patterns might relate to knowledge and skill development in a cross-organisational, industrial or sectoral perspective. In particular it offers limited views in explaining the extent to which knowledge workers' careers are boundaryless or the extent to which organisational life is still important.

For instance, many studies have illustrated the potential dominance of the boundaryless careers in high-tech industries (Saxenian, 1996), in the film industry (Jones, 1996; DeFilippi and Arthur, 1998), in the design industry (Vinodrai, 2006) and in financial services and the telecommunications sector (May et al., 2002).

On the other hand, Jacoby (1999) argued that the labour markets are in flux, but it would be a mistake to say that organisational life has melted into thin air; the change is in degree but not in kind, and long-term employment is still the norm of the labour market. Hence, research in employment in organisations calls for reconceptualisation of internal labour markets (ILMs) and the impact of the emerging network organisations (Piore, 2002; Camuffo, 2002). Efforts have been made to show that organisational life is still important for workers. Baldry et al. (2007) found that many software developers still rank an organisational career as of great importance. McGovern et al. (2007) indicated that the majority of British workers still see themselves in the formal organisational career ladder and that figure is not much different from the figure in 1984. Donnelly (2009) reported that the majority of the US and the UK IT and management consultants in a survey consider internal job transitions as their most likely next career move. Rutherford (2006) surveyed two employers in two Canadian regions of Kitchener and Sault Ste. Marie and found that in responding to skill shortages, most employers are willing to retrain existing employees or hire unskilled workers to train them internally, rather than to hire skilled employees externally. Furthermore, in responding to increasing demand, 67% of employers in Kitchener prefer to hire full time employees or to make existing employees work overtime, rather than to hire part time or temporary employees. Rutherford (2006) thus concluded that ILMs remain important. Hamori and Kakarika (2009) also reported that for CEOs from the 500 largest organisations in the US and the 500 largest in Europe, those who have stayed longer in the organisations are promoted quicker to the CEO positions. Even for low-skilled workers, Cox et al. (2008) showed that there is a sign of a rebirth of internalised features in the UK National Health Services (NHS).

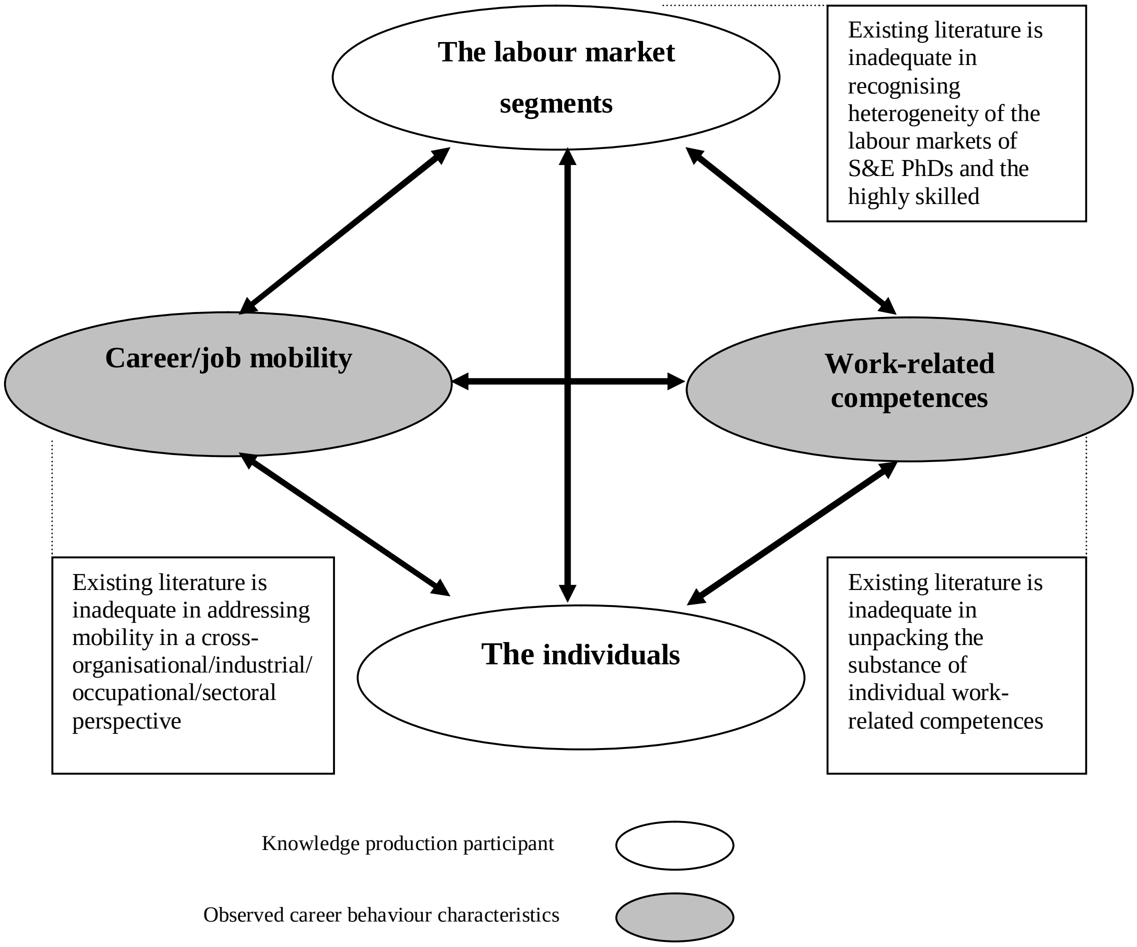
Grimshaw and Rubery (1998) argued that the changing boundary of the externalised features of the labour market is embedded in the ILMs; an integrated approach to the internalised and the externalised labour markets might contribute better to the understanding of the fact that organisations might adopt a variety of employment strategies that result in a continuous redrawing of the boundaries between the internalised and the externalised employment structures. Therefore, to a greater or lesser extent, knowledge workers are all bounded by the organisational or occupational boundaries. This corresponds to DiPrete and McManus' (1993) concept of "compound labour markets", which stresses the relative composition of the ILM and the OLM labour market features.

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 careers are relevant to knowledge workers 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 applied to knowledge workers.

Although there are some studies focused on early careers of S&E PhDs or on S&E PhDs in the public or the private sectors or the 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; Stephan, 1996; Stephan et al., 2004; Robin and Cahuzac, 2003), as far as we know, there is no study featuring a dataset of longer job histories of S&E PhDs to examine labour market features in job mobility and in knowledge and skill development by taking the emerging segment in the knowledge economy into account with a cross-organisational and cross-occupational perspective.

The relationship among the labour market segments, the individuals and the observed qualities of career/job mobility and work-related competences has been discussed in Section 2.2.3 and illustrated in Figure 2.1. In this section we have discussed the inadequacies of the literature on labour market segments, on career/job mobility and on work-related competences. How these inadequacies relate to the existing literature is illustrated in Figure 2.2.

Figure 2.2: Illustration of literature gaps



To sum up, although labour market theories have established the relationship among labour market segments, work-related competences and career mobility, the inadequacies of existing literature identified above are yet to be overcome in order to apply the theories to capture career dynamics of S&E PhD workers in the knowledge economy in a satisfactory manner. This thesis aims at filling these gaps. Hence, the novelty of this thesis lies in identifying the heterogeneous labour market segments for S&E PhDs in the knowledge economy, in unpacking the substance of work-related competences that correspond to the various S&E PhD labour market segments and in overcoming the methodological problems by exploring the S&E PhD labour markets in a cross-organisational/industrial/occupational/sectoral perspective using longitudinal data. The ultimate objective is to explore, by applying labour market theories, the dynamics of how knowledge flow is inextricably linked with career behaviour. Hence, the thesis employs the framework developed in the previous sections and asks two sets of general research questions.

First, we focus on developing a plausible classification of labour market segments that can enhance our understanding of S&E PhD careers in the knowledge economy. The boundary of the segments is verified by their distinctive differences in the perceived usefulness of the various types of knowledge/skills acquired from doctoral training by the survey respondents. Hence the first set of research questions are:

1) What are the S&E PhD labour market segments?
2) To what extent are different types of competences acquired from doctoral training relevant to different labour market segments?

These research questions are answered in Chapter 4 entitled "S&E PhD labour market segments and S&E PhD competences".

Second, we consider knowledge and skills acquired from doctoral training as one type of skills among the various types of skills that are useful in the labour markets and apply labour market theories to explore dynamics of job mobility and knowledge and skill development within and across the S&E PhD labour market segments. This way we are able to explore the S&E PhD labour market dynamics. Hence the second set of research questions are:

3) To what extent do existing labour market models apply to S&E PhDs?
    3.1) What types of job mobility do S&E PhDs have? Does job mobility vary by labour market segment?
    3.2) What types of knowledge and skills are perceived to be useful and are rewarded in the S&E PhD labour market/labour market segments?

These research questions are answered in Chapter 5 entitled "The S&E PhD labour markets".

3 Methodology

3.1 Data

3.1.1 Research setting

We explore the research questions through a complex survey of PhD graduates from a UK research-based university, the University of Manchester. For exploratory purposes, our strategy was to adopt a single university setting to avoid the effects and complexities caused by different universities and regions. There are other benefits of studying S&E PhD graduates from the University of Manchester. Firstly, it is the largest single-site university in the UK and has renowned and well-developed engineering and physical science departments. Practically this provides a reasonable sample size from engineering and physical science disciplines. Second, it is a member of the UK Russell Group, which represents the top 20 leading universities in the UK (the University of Manchester was ranked in the third place in the 2008 UK research assessment in terms of the number of full-time equivalent staffs that are judged to be "world leading" or "internationally excellent"). Its leading position in research means that it should offer attractive doctoral training and thus it is an academic environment where students, regardless of whether they aim at academic careers or simply want to have degrees that are respected by industrial employers, would like to obtain their doctoral degrees from. We also adopt the strategy of selecting home (UK and other EU) PhD students graduated from specific years to minimise culture and cohort effects.

3.1.2 Data collection method

3.1.2.1 The survey design

We adopt a complex survey design as the data collection method. Complex survey design is widely adopted in large national government surveys such as the UK Labour Force Survey and the British General Household Survey as the survey design is cost-effective. The characteristics of the survey design are the incorporation of stratifications or clusters in the sampling procedure. The collected data are not from a simple random sampling procedure. Hence in data analysis, such design procedure has to be taken into account.

As the research setting is PhD holders and their jobs from the University of Manchester, the population sampled for this survey includes all the home PhD students that graduated between 1998 to 2001 in science and engineering disciplines from the University and all jobs they have had since the doctoral awards. 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). All names in the sampling frame and all their jobs since PhD awards are sampled. Therefore, all names in the sampling frame have the same selection probability and all jobs from individuals have the same selection probability. Hence, the sample is self-weighted. Such sampling strategy allows jobs to be clustered into individuals. It is assumed that individuals are independent from each other, while jobs are correlated with individuals to whom they belong.

The survey was intended to collect retrospective employment history (covering 7-10 years employment history to address the change in the distribution of labour market segments but not too long to minimize non response) at individual level and job level. The reasons to design a retrospective survey to collect longitudinal data, rather than other types of longitudinal surveys such as a panel survey or repeated cross-section surveys, are as follows. First, a panel survey would need 7-10 years to collect the same intended range of job histories. This is impossible to do in a four-years PhD project. Repeated cross-section surveys, even though there may be no need to track respondents, would need the same time frame as in a panel survey to achieve the intended range of job histories. Hence, this approach is not feasible either. Second, because we are interested in particular in exploring the transitions of states, i.e. whether a change of job involves a change of employer, a change of occupation, a change of labour market segment, a change of status (promotion) or a change in the perceived usefulness of a type of knowledge and skills in the job, only real job histories with event history formation that documents the timing of changes are able to explore these dynamics. This means that repeated cross-section surveys are not suitable to the research purpose.

Although panel data are also suitable to explore dynamics, because a panel survey often asks respondents about their current status instead of the date of transitions, some information about transitions might be lost. For instance, if a person was in job A in the previous survey, and changed to job B after the survey, but then changed back to job A in the time of the subsequent survey, the change of job between the two surveys would virtually become invisible. Hence, a retrospective survey seems to be the most suitable way for this study to collect longitudinal data.

In a retrospective survey, respondents are surveyed only once and they are asked about their past histories. There are several further advantages of using the retrospective survey design to obtain longitudinal data. It is the simplest and the cheapest way to obtain longitudinal data because respondents are surveyed only once. Furthermore, it provides longitudinal data immediately without the hassle of tracking down the respondents and the researchers do not have to wait for a long time to observe changes in respondents. There are also drawbacks of using such survey design. The quality of the longitudinal data that are collected through such survey design is dependent largely on respondents' recall of the events. As respondents may not remember everything about the surveyed events precisely, accuracy of the data might be a potential problem. Buck et al. (1996) pointed out that when using the retrospective survey design, researchers should avoid to survey events that are too frequent or insignificant in life; normally less frequent and more significant events such as dates of getting married or divorced, having a child or changing one's job are likely to be remembered with accuracy. The inaccuracy problem of recall errors associated with the retrospective survey design can also be limited by a trade-off between the length of study and the number of life events being collected.

Examples of using the retrospective design to obtain longitudinal data can be seen in social surveys such as the UK national Women and Employment Survey (WES) (Martin and Roberts, 1984), which aimed at assessing how factors such as getting married or divorced, having a child or whether husbands are employed affect women's employment, and the UK national Barriers to Leaving Income Support Survey (BLIS) (Shaw et al., 1995), which intends to collection information to assess factors that affect the spell of receiving Income Support (IS).

Our final assessment is that, given the financial and time constraints, a retrospective survey design is appropriate for our research to obtain longitudinal data in the most efficient way. We also believe that the problem of recall errors is limited in our research design because it is recognised that the timing of changing jobs are significant events in life. Furthermore, we have carefully chosen the research design to obtain job histories of 7-10 years to make sure that the change in the distribution of labour market segments can be sufficiently addressed but the survey period is not too long to cause significant recall errors.

The survey is designed to obtain retrospective job histories of 7-10 years after PhD awards, types of knowledge acquired from doctoral education and from the labour markets and how they are perceived as valuable in different jobs. We believe that by adopting this survey design we bring a novel way of assessing knowledge dynamics into innovation studies.

The survey mode adopted is the mail survey. The main consideration for adopting this survey mode is the difficulty for the project researcher to access respondents. Due to the 1998 UK Data Protection Act, even though we are able to obtain a list of names who are qualified for the survey (PhD graduates from the University of Manchester between 1998 and 2001 in science and engineering disciplines with UK or other EU addresses) from the Alumni Office, the researcher however is not able to access these potential respondents directly through their telephone numbers or addresses. Hence, face-to-face interviews and telephone interviews were ruled out from the beginning of the research design because this would have been too costly to outsource to the Alumni Office. However, the Alumni Office was happy to assist with sending out questionnaires.

A mail survey hence appeared to be the most feasible way of conducting our survey, because this approach could be done by preparing our questionnaire and sent it out by the Alumni Office. Apart from the cost-effective advantage, there are other strengths of using a mail survey. For instance, mail questionnaires have less limitations regarding geographical distance, avoid problems associated with interviewers, provide plenty of time for respondents to answer the questions (hence no pressure to give immediate answers), minimise respondents' embarrassment in answering personal or sensitive questions (hence more honest answers) and save the researcher's time in case of respondents' absence when the interviewer calls (Moser and Kalton, 1971).

However, there are also drawbacks associated with a mail survey. A major disadvantage is the low response rate, particularly when a mail survey is compared with a face-to-face interview (de Vaus, 2002; Moser and Kalton, 1971). As a low response rate may result in biased estimates, several measures have been proposed to boost the response rate in a mail survey. For instance, it is suggested that the surveyor avoids a lengthy questionnaire and makes sure that survey questions are very clear and straightforward. This can be done by pilot work that tests the questionnaire (wording, length, clarity, etc.). It is also recommended that a cover letter should be sent out together with the questionnaire and it should clearly state the sponsorship of the survey and contact details of the surveyor. Furthermore, studies also pointed out that providing a stamped addressed returning envelope with the questionnaire helps to enhance the response rate. Moreover, it is vital to use follow-ups such as reminders or more waves of surveys (American Statistical Association, 1997; Moser and Kalton, 1971). These measures are all taken in our survey and the details will be discussed in the following sections.

There are some other limitations associated with mail surveys and they should be acknowledged. First, mail surveys may not be suitable for research aiming at obtaining information from complicated questions. Second, answers given by respondents have to be accepted as final, unless further follow-up investigations can be afforded. Third, mail surveys are inappropriate if the purpose of the surveys is to obtain spontaneous answers. Fourth, because the respondents can see all survey questions before answering any one of them, the questions may not be regarded as independent. Fifth, in mail surveys, the surveyor cannot be sure that it is the right person who answers the questionnaire. Sixth, in a mail survey, there is no opportunity for the surveyor to assess any respondent's answer by observational data such as the person's manner or attitude towards the survey questions (Moser and Kalton, 1971). Among the above limitations, the one that is more relevant to our survey is probably the first one, because some of our survey questions are complicated. However, we believe that our respondents are highly intelligent and should have no problems in answering the questions. We have also minimised this problem by pilot testing the questionnaire by three S&E PhDs.

3.1.2.2 The questionnaire

A questionnaire intending to gather information to answer the research questions has been developed (Appendix 2). The main objective of the questionnaire of course is to address the research questions. However, practically, a well-designed questionnaire should be user friendly and if not enhance the response rate, should at least avoid potential negative effects on response rate. Aiming at developing a questionnaire that not only maximise information obtained but also is user friendly, we have managed to develop a questionnaire that asks all the relevant questions with a layout of four A4 papers printed double sides in a A3 paper. This design enhances convenience in filling out the questionnaire by the respondents without the worry of missing any page. The length of the questionnaire is also designed deliberately to make sure that sufficient information will be gathered but not too long to put any potential respondent off.

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 such as the number of publications resulted from PhD project, how the project interacts with industry, etc. This part of information leads to an article presented at the 2009 DRUID summer conference (Appendix 3).

The second part asks the respondent about the details of the respondent's current job. These details include:

- Whether the respondent is in employment (paid employment, self-employed, etc)
- Timing of the current job started
- Employment sector (a university, a government organisation, a private manufacturing or service firm, etc.)
- 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

- Whether the job involves a change of employer
- The most valuable types of knowledge and skills acquired from doctoral training in the job and the most valuable types of knowledge and skills in the job (by selecting from skills acquired from PhD, organisation-specific skills from the previous job, sector-specific skills from the previous job or general skills).

The third part asks the respondent their job history since the PhD award. In each of the respondent's previous jobs, all questions in the second part are also asked repeatedly in this part but in a very concise format.

The questionnaire is developed based on two previous versions of surveys of postgraduates. One is the 1997 UK survey of the 1987/88 and the 1988/89 postgraduates funded by the Research Councils (available from the UK Economic and Social Data Service ESDS: http://www. Esds.ac.uk). The purposes of the survey were to address: 1) job mobility between the first and the most recent jobs, 2) quality, motivation and course outcomes of the funded students, 3) knowledge acquired from the study considered useful in the first and the most recent jobs and 4) the effectiveness of the course in helping the students for employment. From this questionnaire, we adopt the basic definition of a job but with modification. In particular we define a change in task, responsibility or title in the same organisation as a job change, while the 1997 UK survey of the postgraduates funded by the Research Councils regarded that all such changes are counted as no job change. The other one is the 2003 UK survey targeting the PPARC (Particle Physics and Astronomy Research Council) sponsored PhD students' career outcomes 6-8 years after awards ended (DTZ Pieda Consulting, 2003). We are particularly inspired by how the questionnaire was designed to trace employment history. Unfortunately, the information of job histories gathered in this survey only told us the employment sector and the task of each job; no other labour market features were captured.

Hence, although derived from the two previous questionnaire designs, because our questionnaire aims at addressing specific research questions proposed in Chapter 2, the questionnaire comprises extra questions specifically developed for this questionnaire. Therefore, apart form some questions that we could derive from literature directly, we also interviewed several PhD scientists and engineers prior to the development of the questionnaire. The participants in the interviews are as follows:

- One professor from an engineering school at a UK leading research-based university
- One industrial scientist from a laboratory at a large multinational pharmaceutical (manufacturing) company
- One consultant (team leader) from a large multinational engineering consultancy
- One post-doctoral researcher from an engineering school at a UK leading research-based university
- One writing-up PhD from an engineering school at a UK leading research-based university

Hence, the questionnaire developed in this thesis is unique in the following aspects. First, apart from the conventional technical occupations, we have rendered employment outside the conventional technical occupations visible. This is done by differentiating manufacturing and services in the private sector and by distinguishing managerial, technical (research/development/design/production) and other tasks in a job. In this way, we are able to identify the unconventional jobs in the conventional S&E PhD sector (such as administrations in academia) or the unconventional jobs that involve the conventional technical tasks (such as IT consultants in services). The details of how we construct the concept of the various S&E PhD labour market segments are further discussed in Section 3.3.1 (measures of labour market segments).

The second is that our questionnaire is able to address the dynamics of transitions between employment conditions and knowledge states. Hence, the questionnaire in particular asked respondents to rank the usefulness of the various types of knowledge and skills acquired from doctoral training as well as the usefulness of the various types of knowledge and skills developed in the labour markets for each job or each job transition. The categories of knowledge and skills used in the questionnaires are largely based on what has been mentioned in literature with some further development by the researcher in this study. Moreover, a special feature in our questionnaire is that, apart from unpacking the various types of knowledge and skills acquired from doctoral training, we also position knowledge and skills acquired from doctoral training alongside with other types of knowledge and skills in the labour markets to assess the S&E PhD labour market features. The details of how the variables are developed and constructed are further discussed in Section 3.3.2 and Section 3.3.3.

The third is that our questionnaire is able to inform us about the “direction” of job mobility. The “direction” of job mobility refers to whether the job move is upward or lateral, is intra-organisational or inter-organisational or is intra-occupational or inter-occupational. These features are vital signals indicating labour market types. Hence the questionnaire is designed to gather information that measures changes in employment between jobs. This is utilised by posting questions such as whether a job transition is involved with a change in employer, a change in job task, a change in occupation or a change in status (promotion). These questions help to determine the direction of job mobility. The details of how the variables of the various types of job mobility are constructed are further discussed in Section 3.3.4 and Section 3.3.5.

The information gathered from the questionnaire also features the timing of each job move. Hence, the data are able to further conduct an event-history analysis (i.e. survival analysis or duration analysis) (an example is shown in the paper presented at the DRUID 2009 summer conference; Appendix 3). However, in this thesis, we mainly explore the changes involved between jobs.

3.1.2.3 The survey

The survey was conducted between April and July 2008 by post through the Alumni Office to preserve confidentiality, in order to comply with the UK 1998 Data Protection Act. Each questionnaire was sent out together with a Manchester Business School headed cover letter stating the purpose of the survey, the sponsorship (in this case, the project is supported by an ESRC studentship) and the contacts of the survey researcher. Our first wave of survey resulted in 82 responses in four weeks just before the response deadline. If e-mails were available, e-mail reminders were sent to encourage responses. After the deadline, 20 more respondents returned the survey questionnaires. A total of 91 UK and 11 other EU responses were obtained. There were 38 UK and 7 other EU undelivered returned questionnaires. The overall response rate is 18.51% at individual level (19.20% for UK addresses and 15.3% for other EU addresses).

As the sample is self-weighted, bias mainly comes from non-responses. In this thesis, three types of analysing units are used. The first type of analysing unit is the individual. At the individual level, the distributions of survey population according to gender, discipline, year of graduation and location (UK or other EU) are known. A characteristic comparison between respondents and non-respondents in these dimensions using chi-square tests for independence (Armstrong and Overton, 1977; Lawton and Parasuraman, 1980; Lambert and Harrington, 1990) indicates that there is no evidence showing that respondents and non-respondents at individual level are different in gender (X^2=0.29; df=1; *p*=0.590), discipline (X^2=1.073; df=1; *p*=0.300), year of graduation (X^2=0.528; df=3; *p*=0.913) and location (X^2=1.113; df=1; *p*=0.291) (Table 3.1).

The second type of analysing unit is the job. A total of 282 jobs are obtained (Appendix 1 provided the definition of a job). As there is no information about the number of total jobs held by the surveyed PhDs, a comparison of the mean number of jobs held by each individual between the concurrent waves (Armstrong and Overton, 1977; Lambert and Harrington, 1990) indicates that there is no significant difference (t(97)=1.134; two-tailed *p*=0.260) between the number of jobs held by respondents from the first wave (mean=2.92; SE =0.130; N=79) and the number of jobs held by respondents from the second wave (mean=2.60; SE =0.245; N=20).

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

Table 3.1: 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			

The third type of analysing unit is the job transition. A job transition indicates a change from a previous job to the subsequent job. This type of analysing unit is mainly used in the assessment of the UK S&E PhD labour market features based on labour market theories in Chapter 5, 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 is perceived as the most valuable in the transition. Hence, when this type of analysing unit is used, we limited cases to respondents who are in paid professional jobs with UK addresses to eliminate international differences in labour market features. In this smaller sample, 90 responses, 253 jobs and 161 job transitions are used for analysis.

3.2 Design-based analysing methods

The analysis in this thesis is based on both individual level analysis and job level analysis (including jobs and job transitions). When the individual is used as the analysing unit, analysis is based on un-weighted descriptive data analysis. When the job or 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), as they are collected through a complex survey. The design-based survey data analysing approach takes the complexity of sampling design and the existence of intra-cluster correlation into account and uses non-parametric variance estimators. Such non-parametric variance estimators are generally unbiased and consistent but result in higher variances and inefficiency (Skinner et al., 1989). The design-based approach estimates marginal effects of explanatory variables and serves for research aiming at exploratory purpose. This approach is different from the model-based approach, which is derived from theories, seeks to establish precise models, estimates independent effects of predictors and aims at having predictive power. The design-based analysing approach is widely applied in research for policy purpose, particularly in social policy (Deaton, 1997) and in public health research (Lemeshow et al., 1998; Moonesinghe et al., 2010). This analysing approach however is rarely seen in innovation studies.

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 (means, cross-tabulations, etc.) and design-based logistic regressions (in Chapter 4). The analysing tool is STATA Release 10.1. For survey data analysis, by default, the STATA svy command uses the linearisation method based on a first-order Taylor series linear approximation for covariance matrix estimation (Wolter, 1985) and the pseudolikelihood estimation to fit the model (Lehtonen and Pahkinen, 2003). For design-based logistic regression models, the weighted version of the Hosmer-

Lemeshow tests (Hosmer and Lemeshow, 1980) run through the STATA svylogitgof command developed by Archer et al. (2007) is applied to assess the goodness-of-fit for the models. The jackknife method based on sample reuse techniques for covariance matrix estimation is also available under the STATA svy commend. Hence, logistic regression results using the linearisation method for covariance matrix estimation are compared with results using the jackknife method (in Chapter 4).

3.3 Measures

Several constructs are vital in this thesis. The first is the potential segmentation within the S&E PhD labour Markets. A more detailed discussion about the way we operationalise this construct through our survey is outlined in Section 3.3.1. Furthermore, three key indicators are explored: knowledge and skill development, organisational mobility and occupational mobility. These indicators are intended to differentiate the ILMs and the OLMs, the two labour market models that are closely associated with the highly skilled (Table 3.2). Based on these indicators, we are able to explore the extent to which each of the two labour market models are relevant to the S&E PhD labour markets. Knowledge and skill development is measured by the perceived usefulness of different types of knowledge in jobs. We have proposed two ways to discuss S&E PhDs' knowledge and skill development in jobs. One is to focus on how different dimensions of S&E doctoral training are perceived to be useful in jobs. Details of how we operationalise this construct through the survey is shown in Section 3.3.2. The second way to discuss knowledge and skill development of S&E PhDs is to discuss all relevant types of knowledge and skills in the labour markets and how they might be used in jobs. The way we operationalise this construct is outlined in Section 3.3.3. Furthermore, details of how we operationalise the construct of organisational mobility and occupational mobility are illustrated in Sections 3.3.4 and 3.3.5. Moreover, information about another relevant indicator, i.e. whether the employment contract is permanent or fixed-term in a job to identify 'core' and 'periphery' workers, is obtained through survey questions directly (Appendix 2). Therefore this measure is not further discussed. Finally, if job mobility is cross-organisational and cross-occupational, we may conclude that our respondents experience boundaryless careers.

Table 3.2: Indicators of the ILMs and the OLMs

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

3.3.1 Labour market segments

The study intends to explore what the impact of the knowledge economy might be on employment and on knowledge dynamics of S&E PhDs. This leads to our question regarding the adequacy of the traditional classification of S&E PhDs' employment (i.e. researchers in academia or public research organisations and industrial scientists in large laboratories in manufacturing) to approach knowledge dynamics of S&E PhDs in the knowledge economy. We therefore hypothesise that there must be an emerging type of S&E PhD employment that is "different" from the conventional ones. With regards to this emerging type of employment, about which we know extremely little, we defined it as employment outside the conventional technical occupations.

In order to explore how the emerging type of employment might differ from the conventional ones, we adopt the concept that, because learning (and knowledge) is contextual (Kogut, 2008; Nelson and Winter, 1982), individuals' work-related competences therefore depend on the employment contexts (DeFillippi and Arthur, 1994; Nordhaug, 1993). This leads to the notion that PhDs in different types of employment might share different knowledge bases. Besides, according to labour market theorists, different knowledge and skill development leads to different patterns of job mobility (Althauser and Kalleberg, 1981; Baron, et al., 1986; Doeringer and Piore, 1971; Kalleberg and Sørenson, 1979; Marsden, 1986). Moreover, Reich et al. (1973) stressed that labour market segments are "*distinguished by different labour market characteristics and behavioral rules*" (pp. 359). Hence, if different types of

S&E PhD employment show distinctive knowledge bases and job mobility patterns, we may refer to them as different labour market segments.

It is well documented that the reward systems in academic/public research and in large laboratories in private sector manufacturing are quite different. Merton's (1973) universalism argument clearly pointed out that in academia, professional recognition and rewards should be given to those who are the most productive or able to demonstrate the most significant contribution to their fields. Therefore, in order to be recognised at early stage of their career, young academics have to devote themselves to more publications in renowned journals. Consequently, academic scientists normally cannot afford to switch subject areas/disciplines suddenly away from their PhD work, especially if their research is experimental and they highly depend on their existing equipment. This naturally results in the significant importance of knowledge in specific subject areas for academic scientists.

On the other hand, it is argued that industrial scientists often face tensions between professional science, which concerns the contributions to knowledge, and industrial organisation, which favours profits, cost savings and normally short-term results. (Kornhauser, 1962). However, firms also do basic research for many reasons (Cohen and Levinthal, 1989; Rosenberg, 1990). Therefore, in some industries such as chemicals and pharmaceuticals, there is a strong culture of publishing (Godin, 1996; Stephan, 1996). This shows that substantive knowledge in related subject areas is likely to be important for industrial scientists to be seen as competent. Nonetheless, for industrial scientists, figuring out what works for product development is probably more important than a full understanding of why the solution works, as they often work in product-oriented projects and race with time to launch new products, Therefore, substantive knowledge used by industrial scientists is more likely to be general in certain subject areas rather than specific (as are PhD topics).

Therefore, regarding the conventional technical occupations for S&E PhDs, it is more straightforward to hypothesise that knowledge and skill development in academic/public research and in technical positions in private sector manufacturing are different. Consequently, patterns of job mobility are likely to be different too, according to labour market theories (Althauser and Kalleberg, 1981; Baron, et al., 1986; Doeringer and Piore, 1971; Kalleberg and Sørenson, 1979; Marsden, 1986). If they indeed demonstrate distinctive features in the use of knowledge and in patterns of job mobility, we could be confident to suggest that S&E PhDs in academic/public research and in technical positions in private sector manufacturing are in different labour market segments. We may also refer to these two segments as the conventional technical segments.

The remaining question is how we might describe labour market features of the residual groups, i.e. employment outside the conventional technical occupations. This emerging employment type is likely to be associated with some key characteristics of knowledge economy, i.e. the rise of employment in services, the increasingly important role of knowledge and the growing number of knowledge professionals and managers (David and Foray, 2002; Lindley, 2002; McGovern et al., 2007; Miles and Boden, 2000; Soete, 2002). For jobs in the emerging S&E PhD employment, although we know extremely little about them, nonetheless we suspect that many would probably be consultants, occupiers of technical positions in services and managers. These jobs are qualitatively diversified. For instance, in terms of motivations, consultants may search for interesting projects (Jones and DeFilippi, 1996) while managers are looking for status (Allen and Katz, 1986; Allen and Katz, 1992). What we might attempt to focus, however, is to explore whether there are some "peculiarities" in labour market features among these residual groups and whether their "peculiarities" are distinguishable from the two conventional technical segments. If such "peculiarities" in labour market features exist, they might be seen as a group and share a base for an emerging labour market segment.

There are some "peculiarities" in labour market features among professional jobs in services and managers that could be traced. For instance, occupiers of professional jobs in services are often found to encounter lack of internal job ladders within organisations (May et al., 2002) or to exhibit lack of royalty to the existing employers (Alvesson, 2000). Therefore, turnover problems are recognised by both management and employees. This indicates a higher level of inter-organisational job mobility. Furthermore, a great emphasis of interpersonal and transferable knowledge in jobs is also found in professional services (Miles, 2003). Similarly, for managers, even in an internal labour market environment, they are likely to possess transferable competences and easily move around organisations (Doeringer and Piore, 1971).

Thus these residual groups seem to share a similar knowledge base that puts a great emphasis on transferable knowledge, rather than knowledge in PhD subject areas, which remains highly valuable for academics or industrial scientists in laboratories in manufacturing. They also seem to share similarity in having greater opportunity for inter-organisational job mobility. This provides potential for an emerging labour market segment. However, because the segment is emerging, in spite of the traced common characteristics, i.e. the highlight of transferable knowledge and the higher potential for inter-organisational mobility, for any attempt to generalise behaviour rules of the segment, it is always possible to find some exceptions. Literature on emerging technologies might be useful in explaining the unstable nature of an emerging labour market. Scholars stressed that if a technology is emerging, very little could be observed about the process of the rapid technological change, because it would involve a constant (and rapid) negotiation and re-negotiation among groups that shape the technology (Garud and Rappa, 1994). As technology may be defined as knowledge (Laudan, 1984; Layton, 1984; Rosenberg, 1982) and knowledge may be seen as boundary of labour market segments (Althauser and Kalleberg, 1981; Baron, et al., 1986; Doeringer and Piore, 1971; Kalleberg and Sørenson, 1979; Marsden, 1986), we might suggest that an emerging labour market segment would encounter a very similar process before it is fully established.

Due to the unstable nature of the segment of unconventional jobs, we may refer to it as a quasi-labour market segment; it is yet to be seen as an established or a stable segment and further qualifications are required. That is to say, referring to the whole of the unconventional jobs as a labour market segment remains problematic and debatable. Therefore, we shall emphasise that although we label the whole group of unconventional jobs as a labour market segment in many places in the thesis, it is a quasi-segment in nature. The intention of the thesis is to try to concentrate on the peculiarities of labour market features among subgroups in the residual category and on how such peculiarities might be distinctively different from the other two segments in the conventional S&E PhD jobs. Most importantly, we wish to explore what we might learn from any observed distinction.

We define a variable "labour market segment" comprising the three different employment settings, i.e. "academic/public research", "technical positions in private sector manufacturing" and "employment outside the conventional technical occupations". We are not aware of any existing literature or survey that attempts to identify the conventional and unconventional technical occupations by using the same measure as the one developed in this thesis.

Each respondent was asked to provide information about the type of each job held after PhD training. Each respondent was also asked to provide information about tasks in each job held after PhD training. The variable "labour market segments" is then constructed based on information given by respondents' job type and job tasks (Box 3.1). The academic/public research labour market segment is restricted to PhDs conducting research tasks in academia or government/public/non-profit organisations (employment code 01, 02, 07). The technical positions in private sector manufacturing labour market segment is restricted to PhDs conducting industrial research, development, design or production in manufacturing (employment code 05 + tasks in research, development, design or production); PhDs who have become dedicated managers in manufacturing are not considered as being engaged in this labour market segment. The academic/public research and technical positions in private sector manufacturing segments are regarded as the conventional technical occupations. All other jobs are defined as employment outside the conventional technical occupations. This classification intends to explore the difference in the use of knowledge and skills between the conventional technical occupations and the increasingly significant employment outside the conventional technical occupations. According to this measure, for the whole sample, the distribution of our respondents' first jobs was 42% in academia/public research, 21% in technical positions in private sector manufacturing and 37% in employment outside the conventional technical occupations. The distribution of the respondents' most recent jobs is 30% in academia/public research, 12% in technical positions in private sector manufacturing and 58% in employment outside the conventional technical occupations (Table 3.3).

Box 3.1: Questions in the questionnaire that construct the variable "labour market segment". In the questionnaire, the respondent was provided with employment code and asked to fill in his or her job history.

Employment Code

01	University faculty position (professor, reader, senior lecturer, lecturer)	**04**	Private sector company - service	**07**	Research position in a government/public/voluntary organisation	**09**	Running own company
02	University research position (research assistant, research fellow)	**05**	Private sector company - manufacturing	**08**	Other position in a government/public/voluntary organisation	**10**	Freelance worker
03	Other university post	**06**	Private sector company - Other			**11**	Other type of employment

Job History (Please provide information about ***all your previous jobs*** you have done since you obtained your PhD ***in chronological order***.)

Time (e.g. From May 1999 to Dec 2001)	Employment code	*Main* responsibility in this job Please √ one box only.	(Continued…)
From --------------------------- To ---------------------------	☐☐	❑ Managerial ❑ Research/ Development ❑ Other. Specify -- --	
From --------------------------- To ---------------------------	☐☐	❑ Managerial ❑ Research/ Development ❑ Other. Specify -- --	
(Continued…)			

Table 3.3: Distribution of labour market segments of S&E PhDs

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

Note: (a) The analysing unit is the individual.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates, 7-10 years after graduation.

3.3.2 Types of knowledge/skills acquired from doctoral education

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

When we refer to transferable skills, however, it is argued that the notion of transferability remains ambiguous because it is highly bounded with the context of application (Craswell, 2007). Pole (2000) argued that apart from substantive knowledge, doctoral students also gain more transferable skills such as technical skills and craft knowledge during their study. Technical skills are techniques that are required to conduct research effectively. They could be programming skills, the effective use of software and the ability to design a research and analyse the results. We classify them as application of information technology and data processing skills and general analytical skills. Craft knowledge, although closely linked to technical skills, emphasises the capability to make a research project work. This will involve project management skills, report writing and presentation skills and experimentation and fieldwork. Delamont and Atkinson (2001) reported shocks and uncertainties encountered by PhD students in biochemistry, earth science and physical geography when they realised that to make an experiment work is far more than the capability of being able to apply theories and techniques needed for the experiment. We therefore refer to this particular dimension of craft knowledge in making things work as problem solving capability. We are not aware of any existing survey questionnaire that assesses knowledge and skills acquired from doctoral training based on these categories used in our survey. For instance, the 1997 UK survey of the 1987/88 and the 1988/89 postgraduates funded by the Research Councils asked respondents to provide at most three types of knowledge and skills that they regard as the most useful ones. Because the options were open, respondents could provide any type of knowledge and skills for answers. While the 2003 UK PPARC survey provided 20 options for respondents to select (at most) five types of skills and knowledge acquired from doctoral training to be useful in their jobs (without ranking). The differences between the PPARC survey questionnaire and our questionnaire in assessing the use of knowledge and skills acquired from doctoral training are as follows. First, we split the option of "knowledge of specific subject area" in the PPARC survey into options of "specialist knowledge in PhD topic" and "general knowledge in PhD subject area". The reason for such an arrangement is that we believe that "specialist knowledge in PhD topic" is particular relevant to academic knowledge produced by S&E PhDs during their doctoral training and is different from "general knowledge in PhD subject area", which is more associated with knowledge in textbooks and is often widely known by students in the subject area. This distinction enables us to assess how far a doctorate could carry the academic knowledge he/she produced during his/her doctoral training outside academia. Second, we grouped the PPARC survey's options of "project management skills", "organisation and planning", "time management (working systematically, planning and prioritising work)" and "budget/financial management skills" into a single option of "project management skills". Similarly, we grouped the PPARC survey's options of "writing software" and "familiarity with a range of IT systems" into one option of "application of information technology and data processing". We also grouped the PPARC survey's options of "report writing skills" and “oral presentation skills” into a single option of “report writing and presentation skills”. Third, we used the term “general analytical skills”, rather than the PPARC survey’s “quantitative data analysis and interpretation”, to represent the highly sought after reasoning skills, because we believe that such reasoning skills comprise both qualitative and quantitative data analysis and are thus more than “quantitative data analysis and interpretation”. Fourth, we used the term “problem solving capability” to refer to the ability to make an experiment or fieldwork work, while the PPARC survey questionnaire in this specific dimension comprises “designing and building scientific equipment” and “designing and implementing practical ways to solve problems”. Finally, the PPARC survey also assessed the usefulness of undergraduate teaching and several types of personal skills, while we did not. The PPARC survey also provided an empty space for respondents to give any type of knowledge and skills they regard to be useful but not listed, while our survey did not have this feature either. In spite of the lack of these features, we are confident that the options assessed in our survey more or less comply with the studies of types of knowledge and skills gained from doctoral training by Pole (2000) and Delamont and Atkinson (2001). The comparison between the PPARC survey and ours in the use of knowledge from doctoral training is shown in Table 3.4.

In the questionnaire, we asked respondents to rank the three most valuable types of knowledge/skills that they gained from their PhD and used in each of their jobs. That is, we were interested in measuring the perceived usefulness of a specific type of PhD knowledge/skills in a job. The most valuable knowledge/skills is given 3 scores; the second most important one is given 2 scores and the third is given 1 score. The knowledge/skills gained from doctoral education to be ranked are: 1) specialist knowledge in PhD topic; 2) general knowledge in PhD subject area; 3) application of information technology and data processing; 4) general analytical skills; 5) report writing and presentation skills; 6) project management skills; and 7) problem solving capability (Box 3.2). Based on the same measure, for each job, each type of knowledge/skills acquired from doctoral education can be distinguished further by whether it has been selected as one of the three most valuable PhD skills in the job or not. To highlight the differences, a variable “important competence”, which indicates whether a specific knowledge/skill has been selected as one of the three most variable

PhD knowledge/skills in a job (coded as “yes” if it has been selected and “no” if not been selected), was created. Based on design-based descriptive data analysis, at the level of jobs, it appears that “general analytical skills” and “problem solving capability” are perceived as one of the three most valuable PhD competences in more than half of the survey jobs in all the three labour market segments. “Specialist knowledge in PhD topic” and “general knowledge in PhD subject area” are perceived as at least somewhat important in more than half of the survey jobs in academic/public research. In general, perceived usefulness in “specialist knowledge in PhD topic”, “general knowledge in PhD subject area” and “project management skills” appears to have greater variation by labour market segments (Table 3.5).

Table 3.4: Comparison of the 2003 UK PPARC survey questionnaire and the questionnaire developed in this thesis in the use of knowledge in jobs

The 2003 UK PPARC survey questionnaire	The questionnaire developed in this thesis
▪ Project management skills ▪ Organisation and planning ▪ Time management (working systematically, planning and prioritising work) ▪ Budget/financial management skills	▪ Project management skills
▪ Knowledge of specific subject area	▪ Specialist knowledge in PhD topic ▪ General knowledge in PhD subject area
▪ Writing software ▪ Familiarity with a range of IT systems	▪ Application of information technology and data processing
▪ Report writing skills ▪ Oral presentation skills	▪ Report writing and presentation skills
▪ Quantitative data analysis and interpretation	▪ General analytical skills
▪ Designing and building scientific equipment ▪ Designing and implementing practical ways to solve problems	▪ Problem solving capability
▪ Taking individual initiative ▪ Team working/interpersonal/communication skills ▪ Creativity and innovation ▪ Self motivation ▪ Assertiveness ▪ Leadership skills ▪ Entrepreneurial skills	
▪ Undergraduate teaching	
▪ Other (please write in the space below)	

Box 3.2: Questions in the questionnaire that distinguish the most valuable types of knowledge and skills acquired from doctoral training in each job. In the questionnaire, the respondent was asked to fill in his or her job history and in each job, to rank the three most valuable types of skills gained from doctoral training for the job.

Job History (Please provide information about *all your previous jobs* you have done since you obtained your PhD *in chronological order*.)

Time (e.g. From May 1999 to Dec 2001)	(Continued…)	What are the most valuable skills you gained from your PhD for this job? *Please Rank the 3 most valuable.*	(Continued…)
From --------------------------- To ---------------------------		( ) Specialist knowledge in PhD topic ( ) General knowledge in PhD subject area ( ) Application of information technology and data processing ( ) General analytical skills ( ) Report writing and presentation skills ( ) Project management skills ( ) Problem solving capability	
From --------------------------- To ---------------------------		( ) Specialist knowledge in PhD topic ( ) General knowledge in PhD subject area ( ) Application of information technology and data processing ( ) General analytical skills ( ) Report writing and presentation skills ( ) Project management skills ( ) Problem solving capability	
(Continued…)		(Continued…)	

Table 3.5: Perceived usefulness of PhD competences by labour market segments

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

Note: (a) Analysis is based on the design-based descriptive data analysis. The number of observations is 268 and the analysing unit is the job.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates, 7-10 years after graduation.

3.3.3 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 in the labour markets, for each job, we asked respondents to identify the type of skills that is the most valuable in the job among four types of skills: 1) skills acquired from PhD, 2) organisation-specific skills acquired from previous position, 3) sector-specific skills acquired from previous position and 4) general skills (Box 3.3). The assessment of the usefulness of skills from a previous job to the subsequent job (a job transition) makes it possible to evaluate knowledge and skill development and flow in the labour markets. We are not aware of any existing survey assessing knowledge and skill development in the labour markets using the same measure, in particular for S&E PhDs.

Skills acquired from PhD are considered as a special type of human assets/resource as Mangematin (2001) pointed out the special nature of doctoral human resources in the contribution of new knowledge production during doctoral training. The perceived usefulness of skills and knowledge acquired from doctoral training in the labour markets by doctorates may hence reflect the extent of knowledge that has been transferred from academia to the labour markets. The assessment of skill development about organisation-specific skills and general skills in the labour markets is adopted directly from Becker (1964) and Williamson's (1981) distinction. Built on their contribution, Estevez-Abe et al (2001) distinguished the development of sector-specific skills in the labour markets. They draw a parallel with organisation-specific skills and say that sector-specific skills can be seen as the type of skill that is specific to, and enhances productivity in, a specific sector, but not specific to, or enhances productivity in, other sectors. This concept corresponds to the argument stressing that sectors differ in knowledge base and innovation patterns (Malerba, 2002). We incorporate this extra dimension into the analysis of skill development in the S&E PhD labour markets to unpack the substance of knowledge and skill development in different employment contexts.

Relatively, the first two types of skills may be considered as knowledge that is more specific, i.e. less portable, because they are or confined within certain specific modes of knowledge production or organisations. On the other hand, the latter two types may be considered as knowledge that is more general, i.e. more easily portable, because they are able to apply to a wider range of the varieties of organisations.

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 same 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 3.6).

Box 3.3: Questions in the questionnaire that distinguish the most valuable type of knowledge and skills in each job transition. In the questionnaire, the respondent was asked to fill in his or her job history and in each job, to select the most valuable type of skills for the job.

Job History (Please provide information about *__all your previous jobs__* you have done since you obtained your PhD *__in chronological order__*.)

Time (e.g. From May 1999 to Dec 2001)	(Continued…)	Which skills are the most useful for this job? *__Please √one box only.__*	(Continued…)
From -------------------------- To --------------------------		❑ Skills acquired from PhD ❑ ***__Organisation-__***specific skills acquired from previous position ❑ ***__Sector-__***specific skills acquired from previous position ❑ General skills	
From -------------------------- To --------------------------		❑ Skills acquired from PhD ❑ ***__Organisation-__***specific skills acquired from previous position ❑ ***__Sector-__***specific skills acquired from previous position ❑ General skills	
(Continued…)		(Continued…)	

Table 3.6: Perceived usefulness of knowledge and skills in a job transition

Type of knowledge/skills	Perceived as the most useful in a job transition (%)(a)
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: (a) Analysis is based on the design-based descriptive data analysis. The number of observations is 155 and the analysing unit is the job transition.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates, 7-10 years after graduation.

3.3.4 Types of organisational mobility

We asked respondents for each of their jobs, whether they got promoted from the previous job and whether the mobility involved a change in employer (Box 3.4). 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. These four types of organisational mobility are adopted directly from labour market theories (Althauser and Kalleberg, 1981; Doeringer and Piore, 1971; Eyraud et al., 1990; Marsden, 1986). This measure is intensively used in the studies on job mobility. However, we are not aware of any existing survey that links this measure directly with knowledge and skill development to study PhD labour markets. 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 3.7).

Box 3.4: Questions in the questionnaire that construct the types of organisational mobility in each job transition. In the questionnaire, the respondent was asked to fill in his or her job history as below and in each job, whether he or she got promoted from the previous job and whether the mobility involved a change in employer were asked.

Job History (Please provide information about *all your previous jobs* you have done since you obtained your PhD *in chronological order*.)

Time (e.g. From May 1999 to Dec 2001)	(Continued…)	Did the transition from last job involve promotion?	Did the transition from last job involve changing employer?	(Continued…)
From --------------------------- To ---------------------------		Not applicable	Not applicable	
From --------------------------- To ---------------------------		❑ Yes ❑ No	❑ Yes ❑ No	
(Continued…)		(Continued…)	(Continued…)	

Table 3.7: Distribution of the types of organisational mobility

Type of organisational mobility	%(a)
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: (a) Analysis is based on the design-based descriptive data analysis. The number of observations is 157 and the analysing unit is the job transition.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates, 7-10 years after graduation.

3.3.5 Types of occupational mobility

Section 3.3.1 has discussed the measures of occupations and labour market segments used in this thesis and pointed out that we adopted the idea that labour market segments may cut vertically across the occupational hierarchy (Reich et al., 1973). That is, we argued that the three different types of S&E PhD employment settings (i.e. academic/public research, technical positions in the private sector manufacturing and employment outside the conventional occupations) might be regarded as different occupations, as well as different labour market segments. Hence, types of occupational mobility are constructed based on information given by respondents on the labour market segments that have been discussed in Section 3.3.1. 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 occupational mobility are possible: being a researcher in the academic/public research in the previous job and remaining the same after the job mobility, being a researcher in the academic/public research and becoming an industrial scientists or engineers in manufacturing, being a researcher in the academic/public research and becoming a worker in employment outside the conventional technical occupations, being an industrial scientist or engineer in manufacturing and becoming a researcher in academic/public research, being an industrial scientist or engineer in manufacturing in the previous job and remaining the same after the job mobility, being an industrial scientist or engineer in manufacturing and becoming a worker in employment outside the conventional technical occupations, being a worker in employment outside the conventional technical occupations and becoming a researcher in academic/public research, being a worker in employment outside the conventional technical occupations and becoming an industrial scientist or engineer in manufacturing and being a worker in employment outside the conventional technical occupations in the previous job and remaining the same after the job mobility. Because the concept of S&E PhD occupations and labour market segments developed in this thesis is unique, the measure of the types of occupational mobility in this thesis is also unique.

However, the distribution of the types of occupational mobility shows that only five types of them are significant. They comprise three types of intra-occupational mobility:

1) being a researcher in the academic/public research in the previous job and remaining the same after the job mobility (19%), 2) being an industrial scientist or engineer in manufacturing in the previous job and remaining the same after the job mobility (11%) and 3) being a worker in employment outside the conventional technical occupations in the previous job and remaining the same after the job mobility (47%), and two types of inter-occupational mobility: 4) being a researcher in the academic/public research and becoming a worker in employment outside the conventional technical occupations (8%) and 5) being an industrial scientist or engineer in manufacturing and becoming a worker in employment outside the conventional technical occupations (9%) (Table 3.8). Thus, this thesis focuses mainly on the 5 types of occupational mobility to assess the S&E PhD labour market features.

Table 3.8: Distribution of the types of occupational mobility

Type of occupational mobility	%[a]
A researcher in academic/public research → A researcher in academic/public research	19
A researcher in academic/public research → An industrial scientist or engineer in manufacturing	2
A researcher in academic/public research → employment outside the conventional technical occupations	8
An industrial scientist or engineer in manufacturing → A researcher in academic/public research	1
An industrial scientist or engineer in manufacturing → An industrial scientist or engineer in manufacturing	11
An industrial scientist or engineer in manufacturing → employment outside the conventional technical occupations	9
Employment outside the conventional technical occupations → A researcher in academic/public research	1
Employment outside the conventional technical occupations → An industrial scientist or engineer in manufacturing	2
Employment outside the conventional technical occupations → employment outside the conventional technical occupations	47
Total	100

Note: (a) Analysis is based on the design-based descriptive data analysis. The number of observations is 157 and the analysing unit is the job transition.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates, 7-10 years after graduation.

4 S&E PhD Labour Market Segments and S&E PhD Competences

This chapter aims at answering the first set of research questions:

- What are the S&E PhD labour market segments?
- To what extent are different types of competences acquired from doctoral training relevant to different labour market segments?

In Cheng and Kalleberg's (1996) definition, "*occupation refers* to *technical work activities that are transferred among employers and to skills that are transportable from firm to firm*" (pp.1238). Reich et al. (1973) argued that labour market segments are *"distinguished by different labour market characteristics and behavioral rules"* (pp. 359) and labour market segments may cut vertically across the occupational hierarchy. Therefore, in Section 2.2.3 we have proposed that if different employment contexts can be differentiated by their specific work-related competences, these employment contexts may be regarded as different occupations. Furthermore, based on labour market theories that stress the relationship between knowledge and skill development and job mobility (Althauser and Kalleberg, 1981; Baron, et al., 1986; Doeringer and Piore, 1971; Kalleberg and Sørenson, 1979; Marsden, 1986), differences in work-related competences in different employment settings would lead to different patterns of job mobility. Therefore, with distinctive work-related competences and patterns of job mobility, these employment contexts may also be regarded as different labour market segments. Section 2.3.1 has pointed out a potential classification of labour market segments: academic/public research, technical positions in private sector manufacturing and employment outside the conventional technical occupations, for exploring S&E PhD labour markets. Our argument is that because individuals shape and are shaped by the three labour market segments that might be characterised by different routines, rules and norms, individual PhDs will have different experiences in knowledge and skill development and further in job mobility in different labour market segments. Based on this potential classification of labour market segments, Section 4.1 reviews the reward systems and the routines of how knowledge may be used in the suggested three labour market segments. This confirms that knowledge and skill development indeed seems to differ in the suggested three labour market segments for S&E PhDs. This further points out the usefulness of adopting this classification of labour market segments to analyse careers of S&E PhDs in order to explore dynamics of careers and knowledge and skill development of S&E PhDs in the knowledge economy.

Section 4.2 presents the results based on information from our survey of respondents of the 1998-2001 PhD graduates from the University of Manchester in science and engineering disciplines. The significance of the proposed S&E PhD labour market segments is verified by the empirical evidence of the distribution of S&E PhDs in these segments and the differences in the perceived usefulness of the various types of knowledge and skills that are acquired from S&E doctoral training.

4.1 Characteristics of the use of knowledge in the proposed labour market segments

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

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

Industrial scientists generally work with very different expectations and demands from academic/public research. It is argued that industrial scientists often face tensions between professional science and industrial organisation (Kornhauser, 1962). Professional science concerns mainly contributions to knowledge, quality research and long-term programs. On the other hand, industrial organisation favours profits, cost savings and normally short-term results. In industry, the key goal (a final target or product) is clear, teamwork is essential and deadlines are often very tight. Because manufacturing industry is highly product-oriented and because of the high uncertainty and risks involved in developing new products, firms normally adopt parallel strategies (Abernathy and Rosenbloom, 1969) for product development. This implies that an industrial scientist is likely to be involved in several research projects at the same time. As the success or failure in controlling new products' time to market will eventually translate into the performance of individual scientists, industrial scientists' abilities to handle research projects are vital. This reveals a crucial dimension differentiating the use of more general and transferable skills between industrial researchers and academic or public sector researchers.[1]

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

[1] Although academics and public sector researchers are also often involved in several research projects at the same time and need to produce research results, strictly speaking they do not have the same level of pressure of getting products ready for market as industrial scientists. Furthermore, although they need to be team players, they often work with other researchers. By contrast, industrial scientists need to work with very diversified groups such as marketing, sales and production (in particular they often work closely with front-line production workers). This makes projects more difficult to control.

scientists is more likely to be general in certain subject areas rather than specific (as are PhD topics).

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

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

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

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

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

4.2 Empirical findings

4.2.1 Dominance of employment outside the conventional technical occupations

Based on descriptive data analysis at the individual level, for the University of Manchester’s 1998-2001 home S&E PhD graduates, academic/public research appears to be the most popular career option for their first jobs (42%) (Table 4.1). However, among those who were in this labour market segment for their first jobs, only one quarter (27%) secured permanent positions initially (Table 4.2). The other three quarters were in fixed term contracts, mostly in post-doctoral research positions. Whether this choice is viable for long-term career development is uncertain. Indeed, 7-10 years after graduation, around 67% of those who initially were in this labour market segment remain in academic/public research. For those who are most recently in this labour market segment, 36% are still in fixed term contracts. 28% of those who initially were in this labour market segment have moved to employment outside the conventional technical occupations. Overall, 7-10 years after graduation, the percentage of PhDs in this labour market segment has decreased from 42% to 30%. Over one third of those who remain in this labour market segment (36%) do so even though they have not been able to secure permanent positions, a fact highlighting the lengthening of stages for many academic careers. Moreover, the alternative for respondents who move out of this labour market segment seems to lie in employment outside conventional technical occupations (Table 4.1). Thus, in a long-term perspective, this labour market segment cannot be seen as the dominant one for our survey respondents.

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

More than one third of our respondents (37%) initially took employment outside the conventional technical occupations when they first graduated. 7-10 years after graduation, there is little sign of our respondents in this labour market segment moving out, as 91% of them still remain in this labour market segment; that is, those who initially were in this labour market segment continue to stay (Table 4.1). This labour market segment is not only the most stable one, but also the main destination for many respondents moving from the other two labour market segments. Indeed, for our respondents, 7-10 years after graduation, this labour market segment accounts for 58% of all employment.

Therefore, academic/public research cannot be regarded as the main labour market segment for the University of Manchester's 1998-2001 home S&E PhD graduates. Similarly, very few of our surveyed S&E PhDs are actually working as industrial scientists in large corporate R&D laboratories in manufacturing, although many of them are working in industry. These results highlight the significance of jobs outside the conventional technical occupations for S&E PhDs. Indeed, although employment outside the conventional technical occupations might not account for the largest proportion of the survey respondents' first employment, it was however only 5% behind the largest employment segment. Moreover, 94% of first jobs in this labour market segment were permanent (in terms of employment contract) and 91% of those who were in this labour market segment remain in this segment. Furthermore, over time, it appears to be the main destination for movers from the other two labour market segments. Thus, it is not surprising that 7-10 years after graduation, this labour market segment accounts for 58% of total employment of our respondents and has become the dominant labour market segment. The employment dynamics inside and outside the conventional technical occupations is invisible if the discussion mainly focuses on employment dynamics inside and outside academic/public organisations. Table 4.3 shows the stable career patterns of our S&E PhDs over time when the analysis is based on the latter case and the significant increase in unconventional jobs within both the academia/public organisations and the private sector over time.

Table 4.1: Distribution of labour market segments, tabulation by first job and by the most recent job

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

Notes: (a) Row percentage; (b) Column percentage; (c) The analysing unit is the individual.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates, 7-10 years after graduation.

Table 4.2: Distribution of labour market segments by employment condition, first job and the most recent job

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

Notes: (a) The number used in the distribution excludes cases of those who are self-employed; those who are self-employed are classified as working in employment outside the conventional technical occupations; there is one self-employed case in terms of first job and are four self-employed cases in terms of the most recent job; (b) The analysing unit is the individual.

Source: Survey of this thesis based on the University of Manchester's home 1998-2001 S&E PhD graduates, 7-10 years after graduation.

Table 4.3: Employment inside and outside academic/public organisations for S&E PhDs

	First job[(a)]		The most recent job[(a)]	
	Column percentage	Percentage of unconventional jobs within this type of employment	Column percentage	Percentage of unconventional jobs within this type of employment
Academic/public organisations	47	15	41	28
Private sector	53	59	59	80

Note: (a) The analysing unit is the individual.

Source: Survey of this thesis based on the University of Manchester's home 1998-2001 S&E PhD graduates, 7-10 years after graduation.

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

4.2.2 Different competences mix for different labour market segments

Overall, based on scores (Table 3.5) given by the survey respondents, knowledge directly tied to subject areas, particularly "specialist knowledge in the PhD topic", is regarded as of great importance in academic/public research. It is less important in technical positions in private sector manufacturing, although "general knowledge in PhD subject area" is quite important in this labour market segment. It is of limited significance in employment outside conventional technical occupations. In general, knowledge/skills acquired from doctoral education related to general and transferable skills receive higher scores by respondents working in employment outside the conventional technical occupations, lower scores by respondents in technical positions in private sector manufacturing and even lower scores by respondents in academic/public research positions. However, “general analytical skills” and “problem solving capability” are important in all labour market segments, but to different degrees.

Design-based logistic regressions are applied to test whether perception of the relative importance of each specific competence in different labour market segments is significantly different. In this way, we are able to identify specific PhD competences for different labour market segments. For each type of knowledge/skills acquired from doctoral education, a logistic regression using “important competence” as dependent variable (Section 3.3.2 for the details of the construction of the variable) and “labour market segment” (comprising the three possible labour market segments as categories and the labour market segment of academic/public research as reference category; Section 3.3.1 for the details of the construction of the variable) as explanatory variable is applied.[2] The regression aims at evaluating how the propensity of S&E PhDs’ ranking of a specific type of knowledge as “among the three most valuable PhD knowledge/skills in a job”, compared to the propensity to rank this type of knowledge as “not among the three most valuable PhD knowledge/skills in a job”, varies in different labour market segments. The analysing units are individual jobs, and thus the total valid 268 jobs are all used in the analysis. Whether the respondents are from engineering or science disciplines might affect their perception of usefulness of knowledge in jobs and therefore, the variable “engineering” (science disciplines as reference category) is used as control variable. Results are shown in Table 4.4. Additional control variables such as gender, year of graduation and location (UK or other EU) are explored, but they do not change the impression of the association between labour market segments and the perceived usefulness of each specific type of PhD knowledge/skills in a job. The results from the linearised methods and the jackknife methods are very similar but the jackknife methods result in wider range of confidence intervals (CI). All regressions pass the STATA svylogitgof goodness-of-fit tests.

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

Table 4.4: Relative perceived usefulness of PhD competences by labour market segments

		The linearised method		The jackknife method	
		Odds ratio[(a)]	90% CI	Odds ratio[(a)]	90% CI
Specialist knowledge in PhD topic	Labour market segment				
	Technical positions in private sector manufacturing	0.130 ***	0.052-0.322	0.130 ***	0.049-0.344
	Employment outside the conventional technical occupations	0.071 ***	0.031-0.159	0.071 ***	0.029-0.170
	Engineering	2.968 **	1.315-6.699	2.969 **	1.238-7.116
General knowledge in PhD subject area	Labour market segment				
	Technical positions in private sector manufacturing	0.540	0.238-1.227	0.541	0.226-1.292
	Employment outside the conventional technical occupations	0.171 ***	0.090-0.326	0.171 ***	0.087-0.335
	Engineering	1.639	0.799-3.364	1.693	0.764-3.520
Application of information technology and data processing	Labour market segment				
	Technical positions in private sector manufacturing	1.623	0.557-4.730	1.623	0.481-5.484
	Employment outside the conventional technical occupations	2.139	0.946-4.833	2.139	0.894-5.114
	Engineering	0.442	0.174-1.122	0.442	0.157-1.264
General analytical skills	Labour market segment				
	Technical positions in private sector manufacturing	1.369	0.557-3.363	1.369	0.529-3.545
	Employment outside the conventional technical occupations	2.091 *	1.056-4.140	2.091 *	1.029-4.247
	Engineering	1.498	0.756-2.969	1.498	0.724-3.098
Report writing and presentation skills	Labour market segment				
	Technical positions in private sector manufacturing	1.369	0.591-3.171	1.369	0.565-3.319
	Employment outside the conventional technical occupations	1.258	0.656-2.410	1.258	0.642-2.464
	Engineering	0.795	0.395-1.599	0.795	0.381-1.659
Project management skills	Labour market segment				
	Technical positions in private sector manufacturing	3.501 **	1.334-9.189	3.502 *	1.216-10.085
	Employment outside the conventional technical occupations	5.173 ***	2.462-10.871	5.173 ***	2.341-11.432
	Engineering	0.527	0.226-1.226	0.527	0.205-1.356
Problem solving capability	Labour market segment				
	Technical positions in private sector manufacturing	2.151	0.861-5.374	2.151	0.800-5.780
	Employment outside the conventional technical occupations	2.672 **	1.366-5.266	2.672 **	1.330-5.370
	Engineering	0.613	0.308-1.221	0.613	0.296-1.269
N observations: 268					

Notes:

(a) Comparison uses academic/public research as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as "among the three most valuable types of PhD knowledge/skills in a job" rather than not been selected at all by labour market segments using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates with 7-10 years job histories.

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

A further comparison between technical positions in private sector manufacturing (as reference category) and employment outside the conventional technical occupations using design-based logistic regressions (Table 4.5) shows that it is possible to distinguish between the two labour market segments in terms of “general knowledge in PhD subject area”, which is perceived as more valuable for technical positions in private sector manufacturing but is less in employment outside the conventional technical occupations. Apart from the difference in the perceived usefulness of “general knowledge in PhD subject area”, there is no significant difference in the perceived usefulness of all other PhD knowledge/skills between the two labour market segments (Appendix Table 4). This implies that although PhD competence in technical positions in private sector manufacturing also relies on knowledge that is directly tied to subject areas, compared to employment outside the conventional technical occupations, it is the general type of knowledge in the subject area, rather then the specific type of knowledge in the PhD topic, where the competence resides.

Thus, for the University of Manchester’s 1998-2001 home S&E PhD graduates, PhD competences in academic/public research relatively lie in knowledge that is directly tied to subject areas. In contrast, PhD competences in employment outside conventional technical occupations lie in the more general and transferable skills. PhD competences in technical positions in private sector manufacturing lie in both knowledge that is directly tied to subject areas but in a more general form of knowledge in the PhD subject area (rather than specialist knowledge in PhD topic) and in a less intensive level of the general and transferable skills than it is used in employment outside the conventional technical occupations. In absolute terms, “general analytical skills” and “problem solving capability” acquired from doctoral education are valuable for jobs regardless of labour market segments.

We also explored whether the perception of the usefulness of a specific type of knowledge/skills acquired from doctoral education in a specific labour market segment is affected by respondents’ previous employment in different labour market segments. The results indicate that there is no significant difference (details in Appendix Table 5-7).

Table 4.5: Relative perceived usefulness of “general knowledge in PhD subject areas” between technical positions in private sector manufacturing and employment outside the conventional technical occupations

		The linearised method		The jackknife method	
		Odds ratio(a)	90% CI	Odds ratio(a)	90% CI
General knowledge in PhD subject area	Labour market segment				
	Employment outside the conventional technical occupations	0.317 **	0.142-0.703	0.317 **	0.134-0.746
	Engineering	1.683	0.752-4.017	1.683	0.659-4.297

N observations: 185

Notes:

(a) Comparison uses technical positions in private sector manufacturing as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as “among the three most valuable types of PhD knowledge/skills in a job” rather than not been selected at all by the two labour market segments using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester’s 1998-2001 home S&E PhD graduates with 7-10 years job histories.

However, in order to assess how different subgroups in employment outside the conventional technical occupations might be seen as a (quasi-)segment, the perceived usefulness of different types of knowledge and skills acquired from doctoral training by these subgroups is assessed. Among all jobs in this segment, dedicated managerial positions account for 29%, technical positions in service (including technical writers and patent attorneys) and consultants account for 49%, school teaching or other types of lecturing positions account for 8%, sales, marketing or business analysis positions account for 4% and all others ranging from being a chef to a property developer account for 10 %. These jobs are diversified and ideally they could be studied separately. However, due to limited number of cases in our sample, further categorisation is unlikely to yield any satisfactory conclusion. Hence, apart from some traced common features in literature (details in Section 3.3.1), there is a practical reason to group them together. Nonetheless, the heterogeneity within the unconventional jobs must be assessed.

Since dedicated managers and technical positions in services and consultants account for nearly 80% of jobs in employment outside the conventional technical occupations, heterogeneity is assessed mainly based on these two subgroups. Furthermore, because “application of information technology and data processing” and “report writing and presentation skills” are inadequate to be used as criteria to distinguish different S&E PhD employment segments as discussed earlier, these two types of knowledge and skills will not be further discussed. The mean scores of the perceived usefulness of the remaining types of knowledge and skills acquired from doctoral training by these two subgroups are listed in Table 4.6.

Two assessments are conducted. The first assessment is to repeat the comparisons shown in this section previously (results in Tables 4.4 and 4.5). The only difference is that this time we pick only each of the two subgroups (dedicated managers and technical positions in services and consultants) for the comparison, rather than using the whole group of unconventional jobs. Results are summarised in Tables 4.7 to 4.8 (detailed statistics in Appendix Tables 8 to 11).

Compared to the perception of academic/public research, the dedicated managers’ perceived usefulness of the several types of knowledge is fully consistent with the conclusions made in this chapter. That is, the pattern of dedicated managers’ perceived relative usefulness of each assessed type of knowledge (compared to the perception of academic/public research) is the same as the pattern of the whole segments' perception (Table 4.7; summarised from Appendix Table 8 and Appendix Table 9). Technical positions in services and consultants also share a very similar pattern. Although technical positions in services and consultants do not seem to value project management skills more than academic/public research, the main difference between technical positions in services and consultants and academic/public research remains to be the observation that the former value more transferable skills, while the latter value more substantive knowledge in PhD subject areas (Table 4.7). Hence, the overall impressions in the perceived usefulness of knowledge by each of the two assessed subgroups and by the whole of the unconventional jobs are consistent. That is, compared to academic/public research, the unconventional jobs value more transferable skills, in particular general analytical skills and problem solving capability, rather than substantive knowledge in PhD subject areas.

Table 4.6: Perceived usefulness of knowledge by selected subgroups within employment outside the conventional occupations

	Selected type of knowledge and skills Mean score[a] (Standard error)				
Group	Specialist knowledge in PhD topic	General knowledge in PhD subject area	General analytical skills	Project management skills	Problem solving capability
Dedicated managers	0.125 (0.089)	0.275 (0.129)	1.875 (0.180)	1.225 (0.154)	1.925 (0.162)
Technical positions in services, consultants	0.343 (0.106)	0.571 (0.126)	1.686 (0.130)	0.257 (0.067)	1.686 (0.143)

Note: (a) The analysing unit is the job.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Table 4.7: Relative perceived usefulness of PhD competences: each of the groups is compared to academic/public research

	Dedicated managers	Technical positions in services and consultants	Whole unconventional jobs
Specialist knowledge in PhD topic	Less likely to value	Less Likely to value	Less Likely to value
General knowledge in PhD subject area	Less likely to value	Less likely to value	Less likely to value
General analytical skills	More likely to value	More likely to value	More likely to value
Project management skills	More likely to value	No significant difference	More likely to value
Problem solving capability	More likely to value	More likely to value	More likely to value

Previously we have pointed out that, regarding the relative perceived usefulness of knowledge, when the whole of the unconventional jobs are compared to technical positions in private sector manufacturing, the conclusion is that, while transferable skills are important, at least the technical positions in private sector manufacturing still value knowledge in PhD subject areas. Table 4.8 (summarised from Appendix Table 10 and Appendix Table 11) clearly shows that the perceived usefulness of knowledge by both subgroups (dedicated managers and technical positions in services and consultants) is in line with this conclusion. The only variation is that dedicated managers are even less likely to value substantive knowledge in PhD subject areas, and even more likely to value transferable knowledge. This variation however does not change the conclusion pointed out previously. In any case, the general impression is that when these two subgroups' perceived usefulness of knowledge is compared to that of technical positions in private sector manufacturing, the difference lies in their lack of appreciation of general knowledge in PhD subject areas. This is fully in line with the conclusion in this chapter.

Table 4.8: Relative perceived usefulness of PhD competences: each of the groups is compared to technical positions in private sector manufacturing

	Dedicated managers	Technical positions in services and consultants	Whole unconventional jobs
Specialist knowledge in PhD topic	Less likely to value	No significant difference	No significant difference
General knowledge in PhD subject area	Less likely to value	Less likely to value	Less likely to value
General analytical skills	No significant difference	No significant difference	No significant difference
Project management skills	More likely to value	No significant difference	No significant difference
Problem solving capability	No significant difference	No significant difference	No significant difference

The second test is to assess directly whether there is any difference in the perceived usefulness of the various types of knowledge between the subgroups of "dedicated managers" and "technical positions in services and consultants". The result of the designed-based logistic regression analysis (Table 4.9; summarised on the basis of Appendix Table 12) shows that their perceived usefulness of knowledge is extremely similar. Although project management skills are more important for dedicated managers, this difference mainly implies that dedicated managers value transferable skills to a greater extent (hence are perhaps even more likely to have inter-organisational job mobility), but has no impact on the general impressions formed in this chapter.

Therefore, overall, we might acknowledge that heterogeneity exists within the (quasi-)segment of employment outside the conventional technical occupations. However, when compared to the heterogeneity that exists within the three proposed segments (in terms of the perceived usefulness of knowledge), the internal heterogeneity within the unconventional jobs becomes relatively homogeneous. In other words, the internal heterogeneity within the main unconventional jobs does not change the main observations outlined in this chapter. These observations are: 1) academic/public research values more knowledge directly tied to subject areas, 2) technical positions in private sector manufacturing value both knowledge directly tied to subject areas (but the more general type rather than that in the PhD topics) and the more general and transferable skills, and 3) the unconventional jobs value mainly the more general and transferable skills. What is striking is that our respondents perceive the substantive and the transferable dimensions of knowledge from doctoral training in such a different way in the three proposed segments. Because the indicator of the perceived usefulness of the substantive and the transferable dimensions of knowledge from doctoral training in jobs is indeed able to distinguish between the three proposed segments, this in turn reassures the idea that they are very likely to be segmented.

Table 4.9: Relative perceived usefulness of PhD competences between dedicated mangers and technical positions in services and consultants

Specialist knowledge in PhD topic	No significant difference
General knowledge in PhD subject area	No significant difference
General analytical skills	No significant difference
Project management skills	More valuable for dedicated managers
Problem solving capability	No significant difference

Furthermore, the respondents' mobility pattern also points out that: 1) those who are in the conventional technical segments might move out of the segments at some point of their career, 2) the direction of the move is towards the unconventional jobs and 3) those who are once in the unconventional jobs almost stay and do not move out of this employment type. This implies that the unconventional jobs indeed share some common features in job mobility. This reassures the potential for the unconventional jobs to be seen as a distinct emerging (quasi-)segment. Further exploration of the segmentation of the S&E PhD jobs is outlined in Chapter 5.

4.3 Summary

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

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

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

5 The S&E PhD Labour Markets

Chapter 4 has discussed the significance and usefulness of adopting the classification of the three labour market segments in the S&E PhD labour markets to enhance our understanding of knowledge and skill development of S&E PhDs in the knowledge economy. In Chapter 4, we focus mainly on developing the concept of S&E PhD labour market segments in the knowledge economy by exploring the differences in the perceived usefulness of the various types of knowledge and skills acquired from doctoral training.

In this chapter, we draw on the developed S&E PhD labour market segments to discuss features of S&E PhD labour markets. The discussion is based on the two observed labour market characteristics: job mobility and perceived work-related competences. The research questions to be answered are:

- To what extent do existing labour market models apply to S&E PhDs?
  - What types of job mobility do S&E PhDs have? Does job mobility vary by labour market segment?
  - What types of knowledge and skills are perceived to be useful and are rewarded in the S&E PhD labour market/labour market segments?

The chapter is organised as follows. Section 5.1 reviews the labour market features of the three labour market segments. Based on the existing literature reviewed, the labour market features of the three segments are expected to be different. However, as what has been pointed out previously (Section 2.3.3), the existing literature on careers of the highly skilled often has research settings focusing on a single sector, an industry or an organisation. Furthermore, the existing literature on careers of S&E PhDs also focuses mostly on early stage of their careers, i.e. normally 3-4 years in the labour markets. S&E PhDs' career/job mobility across different labour market segments in a longer term is little known. Aiming at exploring the dynamics of the labour markets of S&E PhD knowledge workers, in this chapter, we study real job histories of respondents from our survey to investigate S&E PhD labour markets in a cross-organisational and cross-occupational perspective. By exploring answers to the research questions, ultimately, we are able to reveal the extent to which the norms of the ILMs and the OLMs are relevant to the S&E PhD knowledge workers. Empirical findings are based on a smaller sample of S&E PhD professional workers with UK addresses from our survey of PhD graduates from the University of Manchester in science and engineering disciplines between 1998 and 2001. Results are presented in Section 5.2.

5.1 S&E PhD labour market features

The conventional technical occupations, i.e. researchers in academic/public research or industrial scientists and engineers in manufacturing, are traditionally associated with the ILMs. Farnham (1999) reported that in the UK academic labour market trajectory, initial appointments are open, while promotions are made in the ILMs. This account is consistent with the traditional analysis stating that public organisations and universities are typical “bureaucratic administration” type of labour market structure with recruitment at the bottom and promotions from within (Stinchcombe, 1979; McGee, 1971). Stinchcombe (1979) also theorised that mobility features of skilled workers in large-scale engineering-based industries are similar to those of “bureaucratic administration” type labour markets, in that these skilled workers’ positions often share a common basis in physical science and they are often situated within large enterprises. Others indicated that because specialist expertise of technical personnel is rare and firms would try to retain them as long-term investment by employers for competitiveness, consequently technical occupations are more likely to be arranged according to the ILMs (Cullen, 1978).

Some recent studies, however, argue that the stereotype of the conventional technical occupations based on the norm of ILMs has been challenged by market-driven force. For instance, some studies have pointed out that the academic environment is becoming more market-driven, and in order to obtain flexibility, deregulation is ongoing and results in decrease in employment security. Schuster and Finkelstein (2006) showed that in the US, faculty members on the non-tenure track increased from 3.2% in 1969 to 14.5% in 1998, and non-tenured off track appointments for new hire reached 58.6% in 2003. Gilliot et al. (2002) stressed that such high degree of temporary positions might undermine universities' ability to attract the most talent, and Tolbert (1996) was concerned that the traditional norm of long-term employment for the college faculty is now being eroded. For industrial scientists and engineers in manufacturing, Causer and Jones (1993) also pointed out that traditional perception of stability and employment security associated with industrial scientists and engineers might be challenged, due to reasons such as the growing competition in the high-tech sector (therefore firms might have to withdraw or restructure some production lines and consequently technical personnel are affected), the fast advancement in technology (therefore employers prefer fresh graduates) and firms' dependence on external funding for R&D (therefore long-term planning for R&D personnel is difficult), particularly in the electronic industry. Indeed, empirical evidence shows that many firms see a certain level of turnover of technical staff as a positive effect on the firms (McGovern, 1995; Causer and Jones, 1993).

The stereotype of the conventional technical occupations and the suggested changes in the employment relationships might indicate that labour market features in the conventional technical occupations have become less ILM-like, compared to those of the past. However, it still tells very little about "how" internal or external the labour market features are, particularly the labour market features in these occupations in comparison to those of others. This indeed highlights the need of systematic comparisons of labour market features across different segments.

Similarly, the literature regarding employment outside the conventional technical occupations pointed out that the segment is more likely to be associated with external labour markets. For instance, dedicated managers are found to gain better financial reward through an external labour market career strategy (Brett and Stroh, 1997). Furthermore, even in an internal labour market environment, higher-level managerial employees are likely to possess transferable competences and easily move around organisations (Doeringer and Piore, 1971). For workers in knowledge intensive business services, employment relations in these firms have been identified as possessing several features. As professional service workers work closely with their clients, they are found to exhibit a certain extent of confusion regarding loyalty towards their employers and clients. Alvesson (2000) reported that IT consultants often know the client companies better than their employers and thus may have less loyalty to their hiring employers than their loyalty to the clients. The problem of the lack of loyalty often results in the move of a whole division or department out of an IT consultancy to a client company. May et al. (2002) studied system developers in a multinational telecommunication company with sites in the US, Japan and Australia and pointed out the lack of formal human resources management policies for these employees. The same study also indicated that because an internal career ladder is basically absent in the company (but the lack of internal career ladder is compensated by a generous pay package) and individuals often have to seek their own opportunities for personal learning, turnover problems are recognised by both management and employees. Hence, careers in employment outside the conventional technical occupations seem to be more boundaryless (DeFillippi and Arthur, 1994) or correspond to the OLM norm. However, again, "how" boundaryless or "how" external the labour market features are, particularly their comparison to those of other labour market segments, remains to be explored.

By exploring job mobility and knowledge/skill development across segments within the S&E PhD labour markets, an analysis of directions of job mobility and the privileged types of knowledge that facilitate the mobility in the various labour market segments is possible. It also implies that the link between careers of PhD knowledge workers and the types of knowledge that are transferred by their job mobility can be established. This area is otherwise studied extremely little in the existing literature. Findings of the empirical investigation that fill the literature gaps are outlined below.

5.2 Empirical findings

5.2.1 Mixed labour market features for the S&E PhD labour markets

5.2.1.1 Organisational life is still important

We use the following definitions to describe trajectories of 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 occupational mobility of being a academic/public sector researcher before and after each job transition). Similarly, stayers in technical positions in private sector manufacturing refer to respondents who have always been working as industrial scientists or engineers in manufacturing since graduation (indicating a sequence of occupational mobility of being an industrial scientist or engineer before and after each job transition). Stayers in employment outside the conventional technical occupations refer to respondents who have been in this labour market segment since PhD awards (indicating a sequence of occupational mobility of being an knowledge worker in employment outside the conventional technical occupations before and after each job transition). On the other hand, movers refer to respondents who have had job mobility across labour market segments (mostly from the conventional technical occupations to employment outside the conventional technical occupations and then remaining in this labour market segment, as discussed in Chapter 4). Hence job transitions of movers might involve many types of occupational mobility.

Descriptive data analysis based on individual respondents of the 1998-2001 PhD graduates from the University of Manchester in science and engineering disciplines shows that, 7-10 years after graduation, the majority of stayers in the conventional technical segments (in academic/public research and in technical occupations in private sector manufacturing) have worked for only one employer since they graduated, and particularly for stayers in technical positions in private sector manufacturing, 72% are still with their first employers (Table 5.1). The mean number of employers for stayers in academic/public research is 1.48 and the figure for stayers in technical positions in private sector manufacturing is 1.43. A t-test (p=0.886; two-tailed) shows that there is no significant difference in the number of employers between these two segments. The mean number of employers for stayers in the conventional technical segments is 1.46. Even for stayers in employment outside the conventional technical occupations, 66% have worked for at most two employers and around 95% have worked for at most three employers (Table 5.1). The mean number of employers for stayers in employment outside the conventional technical occupations is 2.05 (Table 5.2). A t-test indicates that there is a significant difference in the number of employers that our respondents have served between stayers in the conventional technical segments and stayers in employment outside the conventional technical occupations (p=0.017; two-tailed). Overall, the majority of stayers have worked for only one or two employers if they have not moved out of their original labour market segments since graduation.

Those who have job mobility across labour market segments (movers) appear to be more likely to work for more employers (Table 5.1). The mean number of employers for movers is 2.48 (Table 5.2). A t-test indicates that there is no significant difference in the number of employers that our respondents have worked for between movers and stayers in employment outside the conventional technical occupations (*p*=0.143; two-tailed). Hence, overall, there is a strong evidence indicating that movers and stayers in employment outside the conventional technical occupations experience more employers than stayers in the conventional technical segments.

Table 5.1: The number of employers

	Number of employer(s)[e] Row percentage			
Labour market segment trajectory	1	2	3	>=4
Stayers in the conventional technical segments [a]	64%	25%	11%	0%
Stayers in academic/public research [a1]	62%	29%	9%	0%
Stayers in technical positions in 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%

Notes: (a) N=28; (a1) N=21; (a2) N=7; (b) N=21; (c) N=31; (d) N=78; (e) The analysing unit is the individual.
Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

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 5.3). 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 transitions involve a change in employer (49% inter-organisational mobility). These general features show that career progression in the S&E PhD labour markets is upward in general, indicate that organisational life remains important and point out the relevance of the OLMs and the potential of the boundaryless career concept (Table 5.3).

Table 5.2: The mean number of employers

Labour market segment trajectory	Mean (e)	Standard error	95% confidence interval
Stayers in the conventional technical segments (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 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

Notes: (a) N=28; (a1) N=21; (a2) N=7; (b) N=21; (c) N=31; (d) N=78; (e) The analysing unit is the individual.
Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

5.2.1.2 The conventional technical segments show stronger 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 5.1). 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 5.3) 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 5.4).

Table 5.3: Distribution of types of organisational mobility by types of occupational mobility (labour market segment trajectory)

Labour market segment trajectory	Type of organisational mobility Row percentage (e) 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 segments (a)	63%	11%	12%	14%	25%
Stayers in academic/public research (a1)	60%	10%	11%	19%	29%
Stayers in technical positions in private sector manufacturing (a2)	67%	12%	15%	6%	18%
Stayers in employment outside the conventional technical occupations (b)	37%	29%	9%	25%	54%
Movers (c)	29%	20%	7%	44%	64%
Overall (d)	42%	20%	9%	29%	49%

Summary statistics: Pearson uncorrected X^2 (6) = 18.872; Design-based F(5.42, 357.75)=2.148; P = 0.054.

Notes: (a) N=44; (a1) N=29; (a2) N=15; (b) N=42; (c) N=55; (d) N=141; (e) Analysis is based on the design-based descriptive data analysis and the analysing unit is the job transition.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

For each job transition, stayers in technical positions in private sector manufacturing are also more likely to experience more ILM-like mobility: 72% of those who have always been in this labour market segment have served for the same employers since doctoral training; for each job transition, the opportunity of getting promoted within the same organisation (67%) is greater than in other types of organisational mobility (Table 5.3). 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 the 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%). On the other hand, general skills are perceived to be rather important (37%) (Table 5.4). 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 be strongly associated with the more specific and less portable knowledge (i.e. knowledge acquired from doctoral training or organisation-specific skills), their career behaviour is not as typical as would be expected in the ILMs, where knowledge and skill development is expected to be less portable across organisations.

Table 5.4: Distribution of types of skills that are perceived to be the most valuable by types of occupational mobility (labour market segment trajectory)

	Type of knowledge most useful for a job Row percentage[e] (Column percentage)			
Labour market segment trajectory	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 segments [a]	60% (66%)	12% (28)	13% (15%)	15% (19%)
Stayers in academic/public research[a1]	72% (52%)	14% (14%)	11% (8%)	3% (3%)
Stayers in technical positions in private sector manufacturing [a2]	37% (14%)	7% (4%)	19% (7%)	37% (16%)
Stayers in employment outside the conventional technical occupations [b]	10% (12%)	19% (29%)	40% (45%)	31% (39%)
Movers [c]	16% (22%)	27% (43%)	30% (40%)	27% (42%)
Overall [d]	28%	20%	28%	24%

Summary statistics: Pearson uncorrected X^2 (6) = 35.187; Design-based F(5.72, 377.51)=3.541; P =0.002.

Notes: (a) N=44; (a1) N=29; (a2) N=15; (b) N=42; (c) N=55; (d) N=141; (e) Analysis is bsed on the design-based analysis and the analysing unit is the job transition.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

The interrelationship between job mobility and work-related competences for stayers in each of the conventional technical segments is illustrated in Figure 5.1 and Figure 5.2.

Figure 5.1: The interrelationship between job mobility and work-related competences for stayers in academic/public research

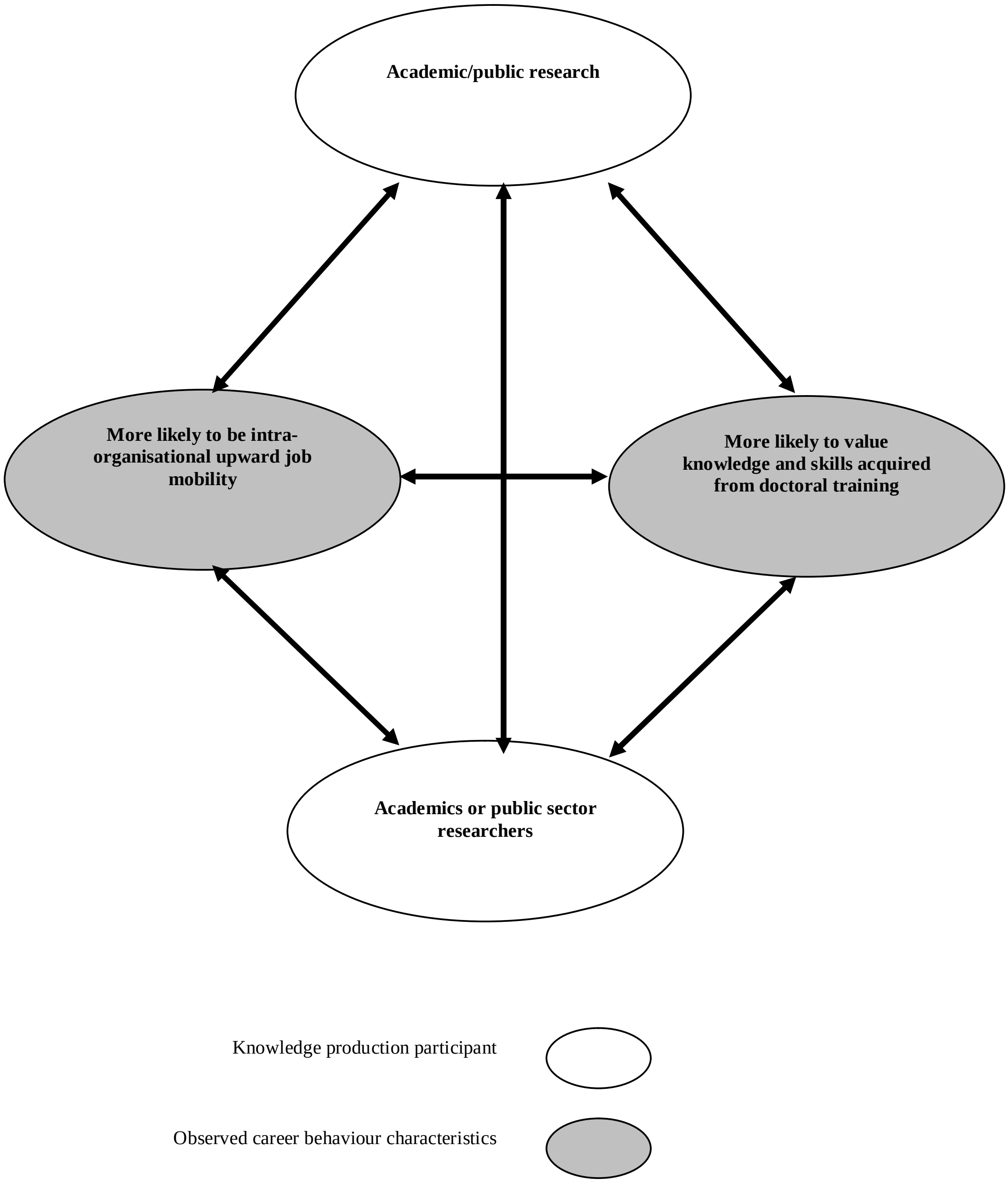
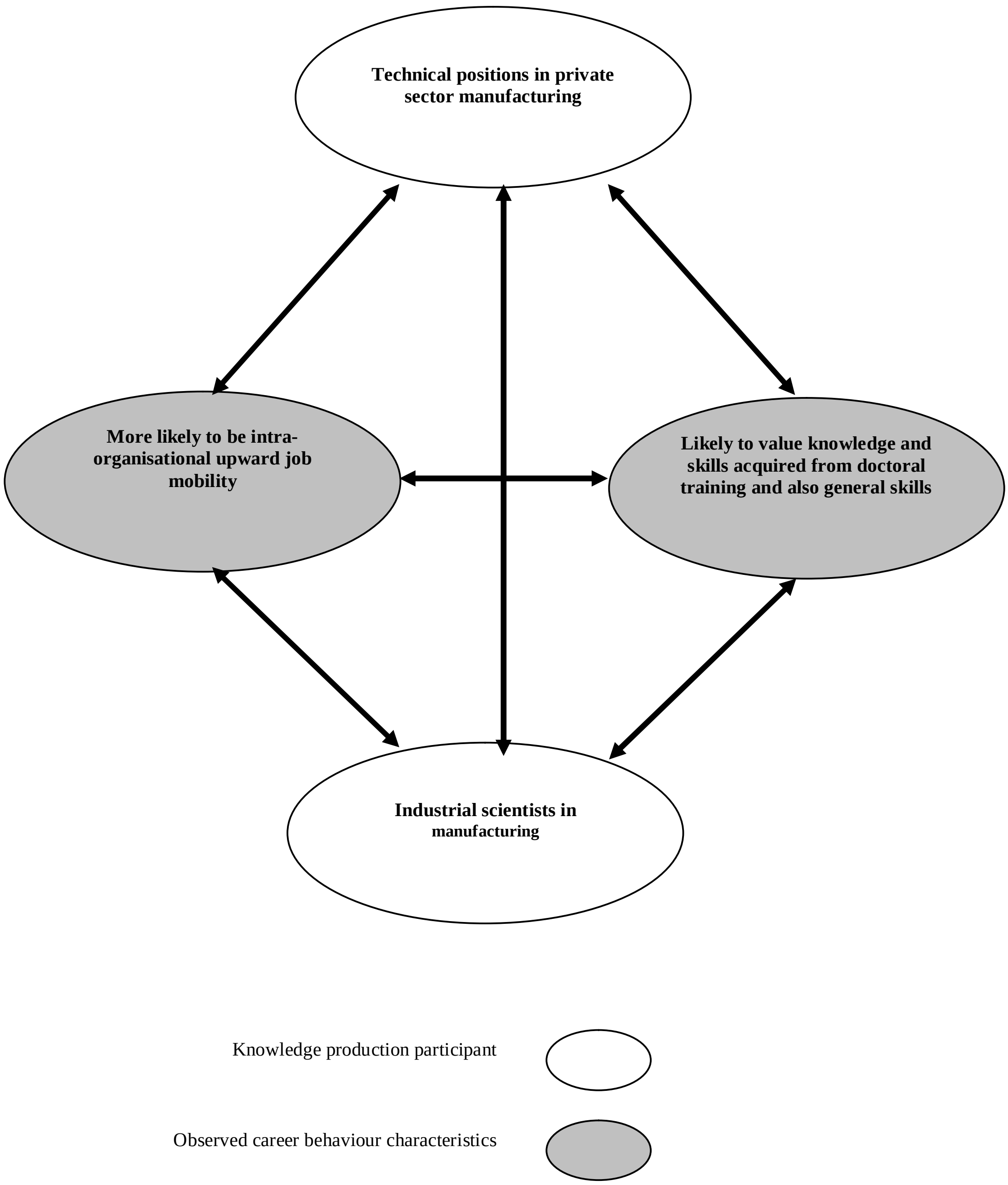


Figure 5.2: The interrelationship between job mobility and work-related competences for stayers in technical positions in private sector manufacturing



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

As mentioned in Chapter 4, once a S&E PhD works in employment outside the conventional technical occupations, the propensity to switch back to the conventional technical segments later on is very rare. Therefore, job mobility of workers in employment outside the conventional technical occupations is highly restricted to this occupational group/labour market segment (see details on how we suggest that the proposed classification of occupational groups can be considered as classification of S&E PhD labour market segments in Section 3.3.1). 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 5.3). Moreover, 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 (sector-specific skills 40%, general skills 31%), compared to stayers in the conventional technical segments (sector-specific skills 13%, general skills 15%) (Table 5.4; row percentage). Finally, stayers in this segment tend to have relatively shorter job tenure with an employer (Table 5.1), compared to stayers in the conventional technical segments. Therefore, we are able to conclude that the career behaviour of stayers in this labour market segment shows stronger OLM features, because their job mobility is more likely to be inter-organisational but confined within this occupational group/segment, and their knowledge and skill development features the more general and portable types of knowledge.

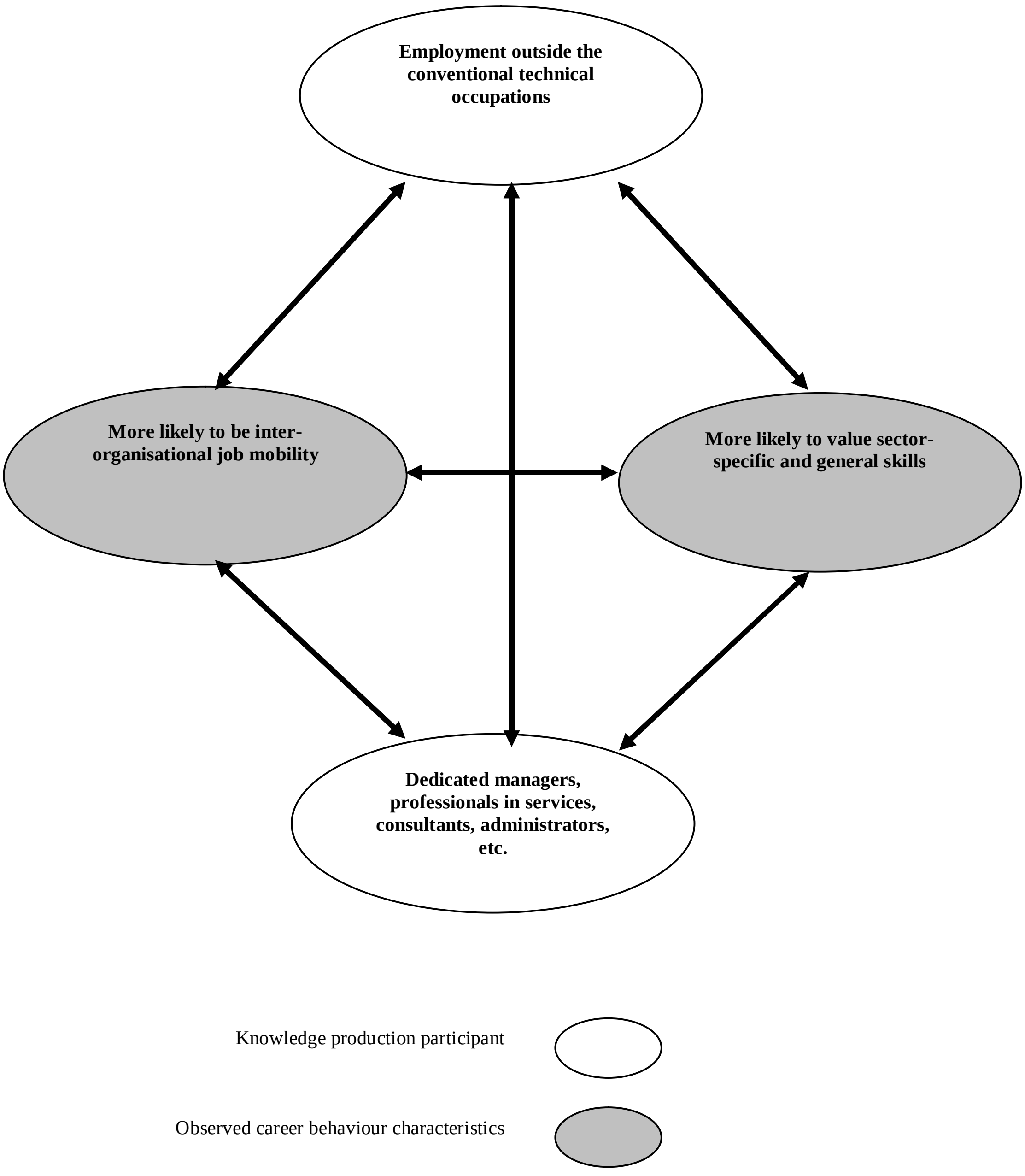
Indeed, a design-based chi-square test for independence indicates that types of organisational mobility are associated with different labour market trajectories, i.e. stayers in the conventional technical segments, stayers in employment outside the conventional technical occupations and movers (p=0.054). Perceived 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 stronger OLM features, workers are still more likely to have promotions internally within organisations

(37%), rather than externally (29%) (Table 5.3); hence in this OLM featured segment, organisational life nonetheless remains important.

The interrelationship between job mobility and work-related competences for stayers in employment outside the conventional technical occupations is illustrated in Figure 5.3.

Figure 5.3: The interrelationship between job mobility and work-related competences for stayers in employment outside the conventional technical occupations



5.2.1.4 Job transitions of movers out of the conventional technical segments is highly external to organisations

In reality, many S&E PhDs change employers and occupations across labour market segments. It appears that 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 5.3). It also seems that on average, movers are more likely to consider knowledge and skills that are more easily portable more useful (Table 5.4). Hence career behaviour of movers shows stronger OLM features. However, because movers' mobility actually often involves changes in occupations, strictly speaking, their career behaviour does not fit exactly the OLM definitions. Therefore, career behaviour of movers might be described as highly external to organisations and are associated with less chance of upward job mobility, compared to that of stayers.

Movers encounter many types of occupational mobility that involves segment-crossing. Tables 5.1-5.4 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 occupational mobility/segment-crossing which movers might encounter for each job transition and their corresponding organisational mobility and perceived work-related competences are discussed below.

Although job mobility of stayers in academic/public research appears to be very stable (62% have stayed with the same employers since graduation and 60% have enjoyed promotions within the same organisations), job transitions of researchers moving out of academic/public research to become a knowledge worker in employment outside the conventional technical occupations by contrast appear to be the most turbulent. There is evidence indicating that these two types of occupational mobility have different patterns of organisational mobility (design-based chi-square test for independence p=0.086). Job mobility moving out of academic/public research is the only type of occupational 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%, if intra-organisational non-promotion mobility is also considered (Table 5.5). This type of job mobility is most likely to do with the high proportion of fixed-term post-doctoral researchers in academia (details in Chapter 4). There is also evidence indicating that stayers' perceived usefulness of knowledge in job transitions within academic/public research differs from movers' perception of useful knowledge in job transitions of moving out of academic/public research to employment outside the conventional technical occupations.

Table 5.5: Stayers' job transitions within academic/public research and movers' job transitions of moving out of this segment

	Type of organisational mobility Row percentage [(c)]				
Type of occupational mobility	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 [(a)]	60%	10%	11%	19%	29%
Movers' occupational mobility: A researcher in academic/public research → Employment outside the conventional technical occupations [(b)]	16%	16%	13%	55%	71%

Summary statistics: Pearson uncorrected X^2 (3) = 26.665; Design-based F(2.93, 193.30)=2.247; P =0.086.

Notes: (a) N=29; (b) N=12; (c) Analysis is based on the design-based descriptive data analysis and the analysing unit is the job transition.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

Compare to the pattern of movers' job transitions of moving out of academic/public research, the pattern of movers' job transitions of moving out of technical positions in private sector manufacturing shows a different story. Based on a case-by-case investigation, movers of industrial scientists and engineers in manufacturing moving out of the occupation normally become dedicated managers in manufacturing (54%) or professionals in the knowledge intensive business service firms (38%). 52% of job transitions in this type of inter-occupational mobility 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%. A design-based chi-square test for independence shows that there is a difference in the pattern of organisational mobility between stayers' job transitions in technical positions in private sector manufacturing and movers' job transitions of moving out of technical positions in private sector manufacturing to employment outside the conventional technical occupations (p=0.052) (Table 5.6). However, there is no evidence indicating the perceived usefulness of knowledge is different in these two types of job transitions.

Table 5.6: Stayers' job transitions within technical positions in private sector manufacturing and movers' job transitions of moving out of this segment

	Type of organisational mobility Row percentage [c]				
Type of occupational mobility	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 [a]	67%	12%	15%	6%	18%
Movers' occupational mobility: An industrial scientist or engineer in manufacturing → A knowledge worker in employment outside the conventional technical occupations [b]	19%	36%	8%	37%	73%

Summary statistics: Pearson uncorrected X^2 (3) =45.187; Design-based F(2.62, 173.22)=2.740; P =0.052.

Notes: (a) N=15; (b) N=12; (c) Analysis is based on the design-based descriptive data analysis and the analysing unit is the job transition.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

Therefore, although stayers in the conventional technical segments show more ILM-like labour market features, when movers' job transitions out of the conventional technical segments are also considered, the main difference between these two segments appears. Academic/public research exhibits a high proportion of contract researchers (details in Chapter 4) who have to move out of the segment with very low propensity for promotion because of the end of their contracts. On the other hand, fixed-term employment is very rare for our respondents in technical positions in private sector manufacturing (details in Chapter 4). Industrial scientists in manufacturing move out of the segment mainly because of their promotion to dedicated managers or their change of career track to services. In other words, these two conventional technical segments correspond to two quite different labour market segments.

An interesting question is whether movers' job transitions within employment outside the conventional technical occupations and stayers' job transitions in this segment share a similar pattern of organisational mobility. Our investigation suggests that segment-crossing transitions (i.e. transitions from academic/public research or technical positions in private sector manufacturing to employment outside the conventional technical occupations) show different characteristics from transitions within segments 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' job transitions within this segment and those of stayers who have always been in this segment (the chi-square test for independence p=0.702) (Table 5.7), nor is there a difference in the perceived usefulness of knowledge. That is to say, movers' transitions from the conventional technical occupations to employment outside the conventional technical occupations are highly external to organisations. Furthermore, the mobility pattern of such transitions is significantly different from the mobility pattern in the original segments where the movers are from. However, once movers move into employment outside the conventional technical occupations, there is no difference in mobility pattern between movers who move into and stayers who have always been in this segment.

To sum up, Section 5.2.1 has outlined the segmentation of the S&E PhD labour markets and pointed out the labour market features of the segments. The interrelationships between job mobility and work-related competences for the conventional and the unconventional segments are shown in Figures 5.1, 5.2 and 5.3. They show the characteristics of stayers. Table 5.8 summarises the findings and further illustrates movers' shift in the pattern of job mobility and in work-related competences when they move out of the conventional technical segments.

Table 5.7: Stayers' job transitions within employment outside the conventional technical occupations and movers' job transitions within this segment

Type of occupational mobility	Type of organisational mobility Row percentage (c) 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 (a)	37%	29%	9%	25%	54%
Movers' occupational mobility: Employment outside the conventional technical occupations → Employment outside the conventional technical occupations (b)	32%	22%	5%	41%	63%

Summary statistics: Pearson uncorrected X^2 (3) = 4.141, Design-based F(2.87, 187.17)=0.457; P =0.702.
Notes: (a) N=42; (b) N=22; (c) Analysis is based on the design-based descriptive data analysis and the analysing unit is the job transition.
Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

Table 5.8: Labour market features of the S&E PhD labour market segments

Labour market trajectory	**The conventional technical segments** **Academic/public research**	**Private sector manufacturing**	→	**Movers**	→	**Employment outside the conventional technical occupations**
Job mobility	More likely to have intra-organisational upward mobility; existence of a high proportion of contract researchers at early career stage	More likely to have intra-organisational upward mobility	(b) ↘ (a) →	More likely to have inter-organisational mobility	→	More likely to have inter-organisational mobility
Work-related competences	More likely to perceive more specific and less portable knowledge to be useful ↘	More likely to perceive less specific and more portable knowledge to be useful	→	More likely to perceive less specific and more portable knowledge to be useful	→	More likely to perceive less specific and more portable knowledge to be useful
Summary	Strong ILM features	ILM-like features with knowledge and skill development less specific than that of the typical ILMs		Highly external labour markets		Stronger OLM features, but promotions are still more likely to occur internally

Notes: (a) The transition is likely to do with the termination of research contracts and unlikely to be upward; (b) The transition is likely to be associated with promotion to dedicated managers or a change of career track to services.

5.2.1.5 Job mobility of industrial scientist-turned-dedicated managers seems to be upward within or outside organisations

As mentioned earlier, existing literature suggests that mobility features of skilled workers in large-scale engineering-based industries are similar to those of "bureaucratic administration" type labour market, which is ILM-like, as these skilled workers' positions often share a common basis in physical science and they are often situated within large enterprises (Stinchcombe, 1979). It is also argued that because specialist expertise of technical personnel is rare and firms would try to retain them as long-term investment by employers for competitiveness, consequently technical occupations are more likely to be arranged according to the ILMs (Cullen, 1978). Labour market behaviour of our sample of stayers in technical positions in private sector manufacturing (illustrated in Section 5.2.1.2) is fully in line with this argument. However, many industrial scientists in manufacturing turn to dedicated managers at some point of their careers. For them, If the transitions to dedicated managers and their job mobility in the managerial track should continue to follow the "bureaucratic administration" type labour market (ILM-like) as suggested by Stinchcombe (1979), then our attempt to classify industrial scientist-turned-dedicated managers in manufacturing into the labour market segment of employment outside the conventional technical occupations will not sustain. On the other hand, some literature on managers' career strategies suggests that managers get better returns by pursuing external strategies, i.e. by moving outside of existing organisations (Brett and Stroh, 1997). Furthermore, even in an internal labour market environment, higher-level managerial employees are likely to possess transferable competences and easily move around organisations (Doeringer and Piore, 1971). Under this rationale, the classification proposed in this thesis would be justified. Due to these uncertainties, this section specifically discusses the career behaviour of industrial scientist-turned-dedicated managers in manufacturing. However, due to the sample size of dedicated managers, the following discussion is based on case-by-case investigations and the results should be treated as hints.

The discussion focuses on three aspects. The first is whether promotions from industrial scientists/engineers in private sector manufacturing to dedicated managers are more likely to be internal or external to existing organisations. The second is whether job mobility of these industrial scientist-turned-dedicated managers in the managerial track is more likely to be internal or external to existing organisations. Third, we wish to compare whether job mobility of these industrial scientist-turned-dedicated managers in the managerial track differs from that of managers among stayers in employment outside the conventional technical occupations. Based on a detailed case-by-case investigation, we found that promotions from industrial scientists/engineers in private sector manufacturing to dedicated managers are equally likely to be inter-organisational upward and intra-organisational upward. We also found that the propensities for job mobility of these industrial scientist-turned-dedicated managers in the managerial track to be inter-organisational upward or to be intra-organisational upward are equal. Finally, we found that job mobility of dedicated managers among stayers in employment outside the conventional technical occupations has twice the chance to have inter-organisational upward job mobility, rather than intra-organisational upward mobility.

These results indicate that, based on our sample, the transitions of industrial scientists in private sector manufacturing to dedicated managers and their job mobility in the managerial track are not organised according to the ILMs; career behaviour of industrial scientist-turned-dedicated managers differs from that of scientists and engineers in private sector manufacturing. For these industrial scientist-turned-dedicated managers, although the odds of getting inter-organisational upward mobility rather than intra-organisational upward mobility (1:1) might not be as high as the propensity for managers among stayers in employment outside the conventional technical occupations (where inter-organisational upward mobility to intra-organisational upward mobility is 2:1), it is closer to the odds for all stayers in employment outside the conventional technical occupations (where inter-organisational upward mobility to intra-organisational upward mobility is 29:37) (Table 5.3). Therefore, from our point of view, it is more suitable to classify jobs of this specific population in the managerial track (including the transition to managerial track) into employment outside the conventional technical occupations, rather than into the conventional technical segments, regardless of their proportion in the sample. Even if their proportion in the sample is considered, the figures are as follows. Among the 12 individuals who have switched from technical positions in private sector manufacturing to the unconventional S&E PhD jobs, 6 have experienced promotions to dedicated managers. This means that when they move out of the segment, not all private sector manufacturing scientists become dedicated managers. This also means that industrial scientist (in manufacturing)-turned-dedicated managers account for less than 11% of those who are eventually in unconventional occupations (6/55; Table 4.1). Similarly, among 141 job transitions used in the analysis, 6 are transitions from industrial scientists in private sector manufacturing to dedicated managers. These dedicated managers experience 6 further job transitions in the managerial track. Job transitions of this specific population account for less than 10 % of those used in the analysis. Therefore, although industrial scientist-turned dedicated managers are a significant type of career transitions for those who move out of the segment of technical positions in private sector manufacturing, there are however few of them in the whole sample.

However, it is worth noticing that overall, promotions for stayers in employment outside the conventional technical occupations are more likely to be internal rather than external to organisations (Table 5.3). This is caused by the fact that 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 result is that the whole segment shows a high level of inter-organisational mobility, but promotions are still more likely to occur within organisations.

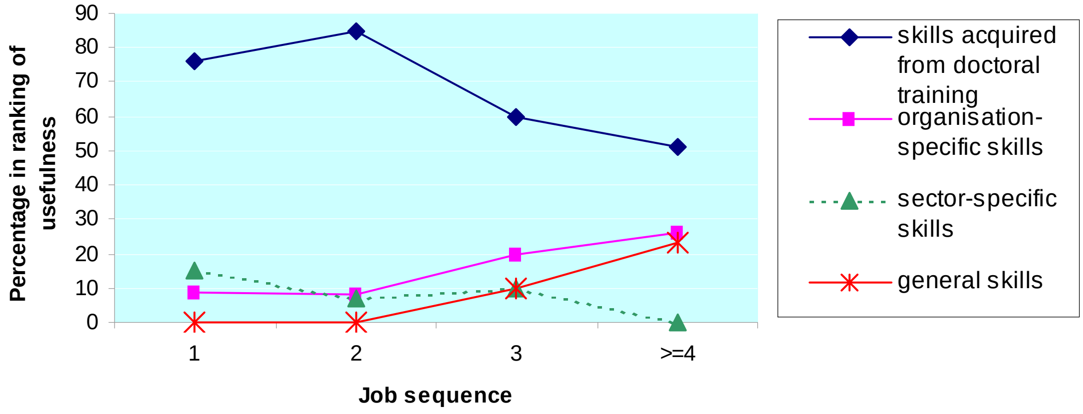
5.2.2 Patterns of individual knowledge flow are non-random

5.2.2.1 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. We also know very little about how such perceived difference varies 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 5.4 to Figure 5.8 (data details in Appendix Table 13). Due to the sample size, in particular the number of jobs held by stayers in technical positions in manufacturing, we suggest that these results are treated with caution. Nonetheless, 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 5.4 illustrates the perceived usefulness of different types of knowledge by job sequence for stayers in academic/public research. From 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 5.4 shows that, for researchers in academic/public research, throughout the survey period, knowledge and skills from doctoral training is considered as the most useful type of knowledge in their jobs, 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 seems to increase over job changes.

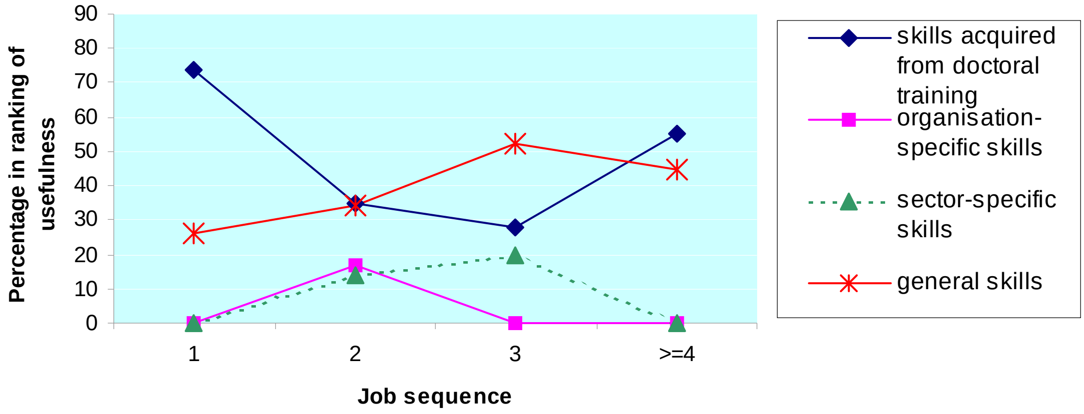
For stayers in technical positions in private sector manufacturing, we found that knowledge and skills acquired from doctoral training and general skills are considered as more useful for their jobs throughout the survey period (Figure 5.5). This is consistent with findings in Section 5.2.1.2 that, although career behaviour in this segment is characterised by stronger 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 very important.

Figure 5.4: Perceived usefulness of knowledge by job sequence for stayers in academic/public research



Source: Data from the survey of this thesis 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.

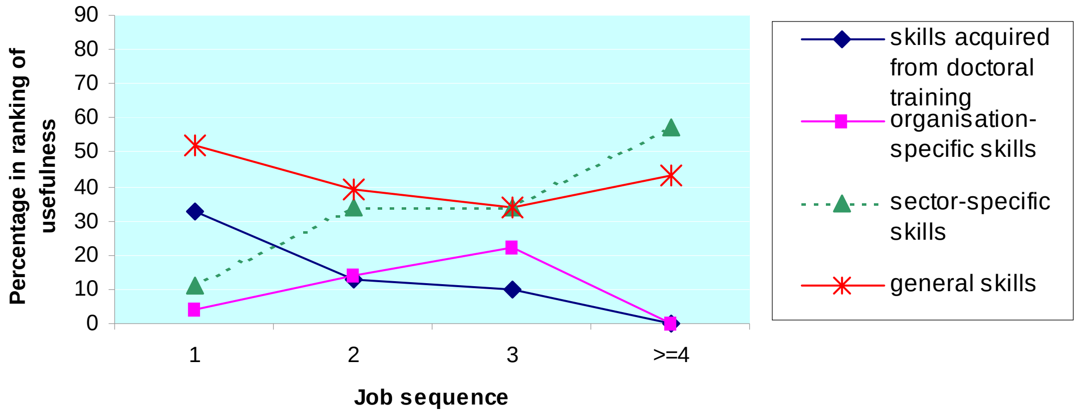
Figure 5.5: Perceived usefulness of knowledge by job sequence for stayers in technical positions in private sector manufacturing



Source: Data from the survey of this thesis 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 jobs 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 5.6). These results are in line with findings in Section 5.2.1.3 which show 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, to have greater importance.

Figure 5.6: Perceived usefulness of knowledge by job sequence for stayers in technical positions in employment outside the conventional technical occupations

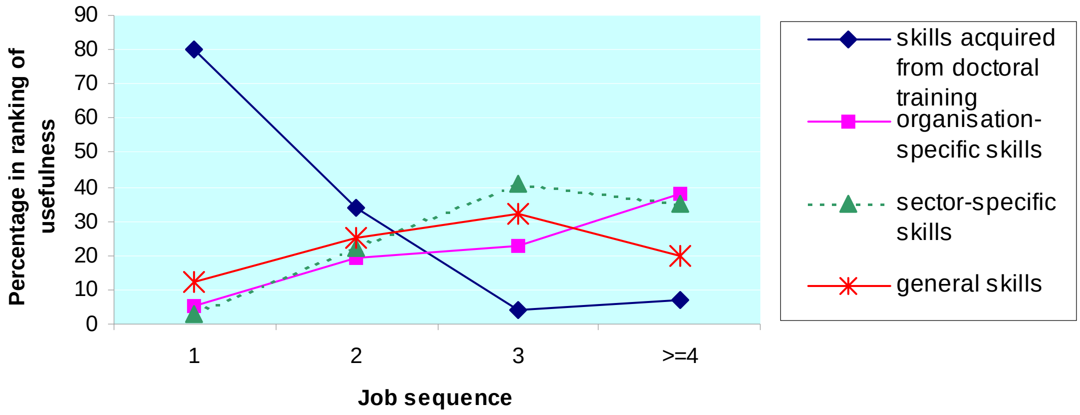


Source: Data from the survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation, and design-based descriptive data analysis. Analysing unit: the job. N observations=72.

Figures 5.4 to 5.6 further inform us that knowledge from doctoral training is important for respondents in the conventional technical segments, particularly in their early career stage. On the other hand, throughout the surveyed period, this type of knowledge is never really perceived to be very important for respondents in employment outside the conventional technical occupations. This reassures the notion of the special characteristics of the unconventional jobs (Section 3.3.1 and Section 4.2.2), even if the effect of career stage is also taken into account.

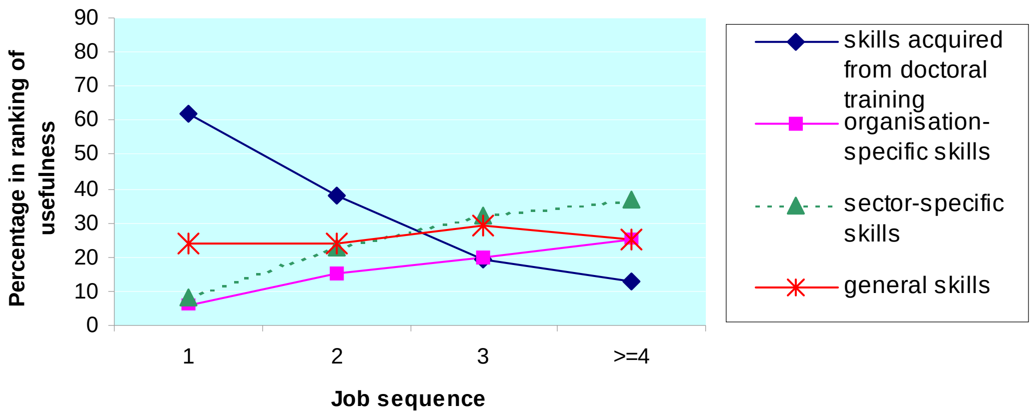
Interestingly, the pattern of the perceived usefulness of the various types of knowledge and skills by job sequence for movers is rather similar to the pattern perceived by all respondents (Figure 5.7 and Figure 5.8). Similarities between the two patterns are not surprising and they could be explained as follows. First, the conventional technical segments highlight knowledge and skills from doctoral training. Second, 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. Third, the direction of mobility for movers is from the conventional technical segments to employment outside the conventional technical occupations and the direction of job mobility of all respondents is the same (details in Chapter 4). Therefore, 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 generally an increased importance of sector-specific skills. For movers specifically, organisation-specific skills seem to become very important as the number of job changes increases. Based on a case-by-case investigation, this is due to the following reasons. First, only 13 out of 27 movers had more then four jobs. Among them, four had 5 jobs and only one had 6 jobs. Among those who had more than 4 jobs, the high flyers (a sequence of promotions for 5-6 jobs in the survey period) happen to be one industrial scientist-turned-dedicated manager who had 5 jobs with promotions within the same organisation and one scientist-turned-dedicated manager who initially was an academic fixed-term researcher and then had 5 other managerial 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 happened 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. However, the combined perceived usefulness of general skills and sector-specific skills still accounts for the majority in this category. Indeed, a 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-organisational upward job mobility may increase, inter-organisational job mobility remains more prominent.

Figure 5.7: Perceived usefulness of knowledge by job sequence for movers



Source: Data from the survey of this thesis 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.

Figure 5.8: Perceived usefulness of knowledge by job sequence for all respondents



Source: Data from the survey of this thesis 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=239.

5.2.2.2 Knowledge acquired from doctoral training and organisation-specific skills are rewarded and largely kept within organisations

Section 5.2.2.1 discussed how the perceived usefulness of the various types of knowledge and skills differs by segment and by career stage. The following sections, we focus on how the various types of knowledge and skills might be involved in different types of job mobility and transitions. As predicted in the 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 5.9). 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%.

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 5.9).

5.2.2.3 Academic/public research is the main channel to circulate skills acquired from S&E doctoral training, while sector-specific and general skills flow more easily across and within occupations

The main channel to circulate skills acquired from doctoral training by individuals' job mobility is through stayers' job mobility within academic/public research; for those surveyed, job transitions that rank skills acquired from doctoral training as the most useful type of skills in the subsequent jobs, 52% are associated with stayers in academic/public research (Table 5.4; column percentage).

Table 5.9: Types of organisational mobility and knowledge that is perceived to be the most valuable

Type of knowledge most useful for a job	Type of organisational mobility Row percentage[f] Intra-organisational upward mobility	Inter-organisational upward mobility	Intra-organisational non-promotion mobility	Inter-organisational non-promotion mobility
Skills acquired from PhD[a]	50%	18%	10%	22%
Organisation-specific skills acquired from previous position[b]	71%	10%	4%	15%
Sector-specific skills acquired from previous position[c]	25%	18%	18%	39%
General skills[d]	27%	33%	2%	38%
Overall [e]	42%	20%	9%	29%

Summary statistics: Pearson uncorrected X^2 (9) = 25.5462; Design-based F(8.02, 529.05)=2.337; P = 0.018.

Notes: (a) N=39; (b) N=28; (c) N=39; (d) N=35; (e) N=141; (f) Analysis is based on the design-based descriptive data analysis and the analysing unit is the job transition.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

On the other hand, when sector-specific skills acquired from the previous jobs are considered as the most useful skills in the subsequent jobs, 85% of such instances occur in job transitions of stayers' job mobility within employment outside the conventional occupations (45%) or movers' job mobility (40%). Similarly, when general skills are considered as the most useful skills in the subsequent jobs, 81% such instances occur in job transitions of stayers' job mobility within employment outside the conventional occupations (39%) or movers' job mobility (42%) (Table 5.4; column percentage). In a further investigation on movers' segment-crossing/inter-occupational job transitions (i.e. transitions from academic/public research to employment outside the conventional technical occupations and from technical positions in private sector manufacturing to employment outside the conventional technical occupations), general skills are perceived to be very useful for both types of transitions and sector-specific skills are also considered very useful in the latter case (Table 5.10; row percentage). This suggests that individual scientists' sector-specific and general skills flow more easily within and across labour market segments.

Table 5.10: Movers' perceived work-related competences by types of occupational mobility (labour market segment trajectory)

	Type of knowledge most useful for a job Row percentage[(g)] (Column percentage)			
Labour market segment trajectory	Skills acquired from PhD	Organisation-specific skills acquired from previous position	Sector-specific skills acquired from previous position	General skills
A researcher in academic/public research → A researcher in academic/public research[(a)]	46% (11%)	54% (7%)	0% (0%)	0% (0%)
A researcher in academic/public research → Employment outside the conventional technical occupations[(b)]	31% (45%)	24% (20%)	9% (7%)	36% (31%)
An industrial scientist or engineer in manufacturing → An industrial scientist or engineer in manufacturing[(c)]	30% (23%)	54% (24%)	15% (6%)	0% (0%)
An industrial scientist or engineer in manufacturing → Employment outside the conventional technical occupations[(d)]	8% (11%)	19% (15%)	35% (25%)	38% (30%)
Employment outside the conventional technical occupations → Employment outside the conventional technical occupations[(e)]	4% (10%)	23% (34%)	46% (62%)	27% (39%)
Overall [(f)]	42%	20%	9%	29%

Notes: (a) N=2; (b) N=12; (c) N=7; (d) N=12; (e) N=22; (f) N=55; (g) Analysis is based on the design-based descriptive data analysis and the analysing unit is the job transition.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

For those job transitions that rank organisation-specific skills from the previous jobs as the most valuable type of skills for the job transitions, 71% are involved with promotions within organisations (Table 5.9). The perceived usefulness of organisation-specific skills is not particularly associated with movers or stayers' job transitions, as 43% are movers' and 57% are stayers' job transitions (stayers in the conventional technical segments: 28%; stayers in employment outside the conventional technical occupations: 29%) (Table 5.4; column percentages). A detailed investigation among these promotions within organisations reveals that the majority of them occur in movers' promotions from researchers or engineers to dedicated managers (20%), promotions in the managerial track (25%) and promotions in the technical track in services (20%).

It might be expected that when job mobility involves inter-occupational/segment-crossing mobility, more portable and general skills would be perceived to be more valuable. This seems to be the case in movers from technical positions in private sector manufacturing to employment outside the conventional technical occupations. However, for job transitions in another type of inter-occupational/segment-crossing mobility, from academic/public research to employment outside the conventional occupations, skills from doctoral training are perceived to be very useful in such transitions (31%) (Table 5.10, row percentage). This type of job transitions also appear to be the most important segment-crossing channel to disseminate skills acquired from doctoral training (45%) (Table 5.10, column percentage). However, due to our limited cases of movers, this should be treated as a hint with caution.

Section 5.2 has explored how S&E PhDs' individual knowledge flow is inextricably linked with their career mobility and pointed out the extent to which individual knowledge might be portable across organisations and occupations. The findings are summarised in Table 5.11.

Table 5.11: The pattern of individual knowledge flow

	Types of individual knowledge			
	Skills acquired from PhD	Organisation-specific skills acquired from previous position	Sector-specific skills acquired from previous position	General skills
More difficult to flow across organisations	√	√		
Less difficult to flow across organisations			√	√
More difficult to flow across occupations	√			
Less difficult to flow across occupations		√	√	√

It is worth noticing that it is less difficult for organisation-specific skills to flow across occupations, as around half of those who ranked such skills as the most valuable for their jobs are movers whose job mobility involves segment/occupation-crossing. While at the same time, it is more difficult for organisation-specific skills to flow across organisations. This can be explained by examples such as promotion within the same organisations from industrial scientists to dedicated managers, from researchers in public research organisations to higher-level administrators, managers or government officials and, in some cases, from post-doctoral researchers to senior university administrators. All these types of intra-organisational upward mobility involve occupation/segment-crossing and they are plausible career trajectories for S&E PhDs. This is in line with research by Cheng and Kalleberg (1996). They illustrated that more highly educated workforce in large firms are likely to experience within-firm-across-occupation type of job mobility.

5.3 Summary

In this chapter, we studied real histories of job mobility of individuals and labour market theories to explore the S&E PhD labour markets in a cross-organisational and cross-occupational perspective. By doing so we also demonstrated the interrelationship between career patterns and knowledge and skill development.

We found that as a whole, organisational life is still a prominent feature of the S&E PhD labour markets experienced by our survey respondents. As on average, promotion opportunities are still more likely to occur within organisations rather than externally, organisational career life is still an important feature in the knowledge economy, no matter whether the S&E PhD workers are working within or outside the conventional technical occupations. We also found that, as a whole, the concepts of the OLMs and of boundaryless careers are also relevant to the S&E PhD labour markets, as inter-organisational job mobility accounts for about half of the surveyed job transitions and many job changes involve segment/occupation-crossing. However, because job mobility that involves segment/occupation-crossing is towards the direction of from the conventional technical occupations to the unconventional jobs, careers of S&E PhDs are not really boundaryless.

The results resonate with the concept of "compound labour markets" by DiPrete and McManus (1993), as some segments show more ILM features while some others show relatively more OLM or external labour market features. For instance, the conventional technical segments show more ILM-like labour market features (but they correspond to two rather different labour market segments), while the dominant features of employment outside the conventional technical occupations are more towards the OLMs. 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 moving into employment outside the conventional technical occupations and stayers who have always been in this labour market segment.

Heterogeneity within the S&E PhD labour markets reveals that there are relatively better chances to obtain upward progression in some segments. 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 upward in general. When job mobility involves segment-crossings, the mobility is less likely to be upward. For example, when academic researchers move out of academic/public research, most of them do not experience promotions in this specific type of transitions. When industrial scientists or engineers in manufacturing move out of the occupations, they have about half the chance of getting promoted (Table 5.6). Relatively, these types of job mobility do not experience upward job mobility as high as the average figure of the sample, as 62% of the total surveyed job transitions involve promotions.

The pattern of knowledge flow is found to be non-random. 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. The flow of skills acquired from S&E doctoral training through individual scientists and engineers' job mobility is to a large extent kept and circulated within organisations and within the conventional technical segments. The flow of organisation-specific skills is very much localised within organisations. Sector-specific skills and general skills flow more easily across organisations, occupations and labour market segments.

There is a hint that the main channel for knowledge and skills acquired from doctoral training to flow from the conventional technical segments to employment outside the conventional technical occupations might be through academic or public sector researchers' job mobility out of academic/public research. There is also a hint indicating that the portability of sector-specific skills and general skills across labour market segments might appear to be greater for the case of industrial scientists and engineers' move out of the conventional technical segments. On the other hand, the portability of these types of knowledge and skills appears to be less for the case of academic or public sector researchers' move out of academic/public research. However, these findings are constrained by the limited number of movers involved in these types of transitions. Further investigation with a larger sample of movers will be helpful in verifying these features.

6 Discussion

This study has attempted to uncover how knowledge flow and careers of S&E PhDs are inextricably linked. This is explored by investigating the interrelationships among S&E PhD labour market segments, work-related competences and job mobility. For each of the labour market theory components that uncover the interrelationships, we have addressed the deficiencies in the existing literature and offered solutions to amend it.

Firstly, we have developed the concept of S&E PhD labour market segments and demonstrated the significance of S&E PhD employment outside the conventional technical occupations by means of the emerging segment's distinctive characteristics in the perceived usefulness of knowledge and the skills acquired from doctoral training. We have also pointed out the increasing dominance of this emerging segment in the knowledge economy. Secondly, in order to reveal the extent and the types of knowledge and skills that are potentially transferred within and across labour market segments through S&E PhDs job mobility, we have further unpacked the various types of S&E PhDs' knowledge and skills in the labour markets and their relationships to different employment contexts. The study has indicated that the pattern of individual knowledge flow is non-random and each type of knowledge and skills has its unique pattern of portability. Thirdly, we have overcome the methodological difficulties by obtaining real job histories of S&E PhDs to explore the segmentation of the S&E PhD labour markets and to further compare the differences in job mobility and knowledge and skill development among segments. The study has revealed that each S&E PhD labour market segment shows distinctive labour market features and therefore the S&E PhD labour markets are heterogeneous and segmented. These findings have wider implications and are discussed below.

6.1 The significance of employment outside the S&E PhD conventional technical occupations

The study started with questions about what the impact of the knowledge economy might be on employment and on knowledge dynamics of S&E PhDs. This leads to our question regarding the adequacy of the traditional classification of S&E PhDs' employment sectors, i.e. the public and private or the research and non-research distinction, in capturing knowledge dynamics of S&E PhDs in the knowledge economy. We therefore hypothesised that there must be an emerging segment that is "different" from the segments of the conventional S&E PhD occupations such as academics, public sector researchers or industrial scientists or engineers in large corporate laboratories in manufacturing. Since we know very little about the emerging segment, which explains the exploratory nature of the study, we defined it as employment outside the conventional technical occupations to highlight the distinction between the emerging segment and the conventional PhD technical segments. In order to explore the differences, we adopt the concept that, because learning (and knowledge) is contextual (Kogut, 2008; Nelson and Winter, 1982), individuals' work-related competences therefore depend on the employment contexts (DeFillippi and Arthur, 1994; Nordhaug, 1993). Hence, knowledge and skill development differs in different labour market segments. Kogut (2008) proposed that "capabilities" could be seen as the determining factor for the boundaries of the firm. Similarly, we consider that work-related competences could be seen as boundaries of the labour market segment. This is in line with the essence of the labour market theories where Reich et al. (1973) defined that labour market segments are *"distinguished by different labour market characteristics and behavioral rules"* (pp. 359).

Our hypothesis is verified by the significant differences in knowledge dynamics among segments. The findings also pointed out that there is an increasing significance of employment in non-technical occupations in both the public and the private sectors and there is a significant proportion of technical positions in service sector. In the former case, we have found that many S&E PhDs are working as administrators or managers in academia or public research organisations, while in the latter case, we have seen many engineering and IT consultants in consultancy firms and IT programmers or computer simulation specialists in the financial sector with doctoral degrees in science and engineering. Indeed, 7-10 years after graduation, the majority of our survey respondents are working in employment outside the conventional technical occupations. The study also indicated that the trend of employment shift is from the conventional technical segments towards employment outside the conventional occupations as careers progress.

Therefore, it is not surprising that the features of the S&E PhD labour market segments revealed in this study tell quite a different story than those of an earlier UK case in radioastronomy by Martin and Irvine (1981). In their study, for PhDs trained in two UK radioastronomy observatories (Jodrell Bank and Cambridge) between 1945 and 1978, the first jobs for their respondents were 55% in academia, 22% in government and 17% in industry. Compared to Martin and Irvine's (1981) study, Mason and Wagner's (1994) report showed that for first jobs of the 1991 UK PhD graduates in physics, 42% were estimated in education sector, 7% were in public sector and 51% were in industry. The shift of the dominance of employment of PhDs in physics from academia to industry can be seen from the two studies. Mason and Wagner's (1994) report also showed that for first jobs of the 1991 UK PhD graduates in all disciplines in science and engineering, 40% were estimated in either education or public organisations and 60% were in industry. The same report further pointed out that, among the 60% in industry, 37% were estimated to be in manufacturing and 23% were in other private employment outside manufacturing. Compared to Mason and Wagner's (1994) report, this thesis showed that for the first jobs of our respondents, 42% were in academia or public research. This figure is very similar to that of Mason and Wagner (1994). However, this thesis further showed that 21% of our respondents' first jobs were in technical positions in manufacturing and 37% were in employment outside academia, public research and technical positions in the private sector manufacturing. In this respect, this study differs from results presented in the Mason and Wagner's (1994) report. That is, for the 37% of first jobs in the private sector manufacturing in Mason and Wagner's (1994) report, it would be very unlikely for them to be dedicated managerial positions. Therefore, this figure is more equivalent to our figure of first jobs in technical positions in manufacturing (our figure is 21%). Hence, our study further showed that in industry, it is very likely that there is a shift of jobs away from technical positions in manufacturing.

That is to say, firstly, the study revealed the dominance of jobs for S&E PhDs outside academia and public research. This is in line with many studies that suggested that, over time, there has been a shift for S&E PhDs to work outside academia and industry has become the major employment destination (Ender's, 2002; Stephan, 1996; Stephan et al., 2004). Furthermore, our study further explored the employment dynamics within industry and uncovered the significance of S&E PhDs' employment outside technical positions in private sector manufacturing. The findings pointed out not only the importance of employment outside the conventional technical occupations for first jobs but also its increasing dominance as respondents' careers progress. The findings correspond to the PPARC survey (DTZ Pieda Consulting, 2003) that indicates the dominance of employment outside the industrial R&D laboratories.

Could these trends then be regarded as universal? It is widely believed that the national innovation systems in which firms are embedded influence both the vigour and the direction of innovative activities, stressing the importance of national employment of science and engineering PhDs (Freeman, 1987; Lundvall, 1992; Nelson, 1993). It is also argued, however, that globalisation is increasing the interdependence between countries, even regarding innovation, and that it may be eroding national differences in innovation patterns. Globalisation demands matching global knowledge networks with the localised launch of major innovations, leading to increased international mobility of science and engineering personnel, and increasing use of multinational teams to launch new products and services. This raises the question as to whether careers of scientists and engineering PhDs can be treated as somewhat universal across nations or whether important national differences still remain.

Although not the main focus of this study, nonetheless, some international differences could be found by comparing our UK case with Mangematin's (2000) recent French case. The French case indicated that, in engineering science, a larger proportion of PhDs secured permanent academic positions (among those graduated between 1984 and 1996, in 1997, 44% secured permanent positions in academia) and most of the French PhDs working in the private sector were in research positions (37%). On the other hand, our UK case showed that less than 20% of the survey respondents secure permanent positions in academia/public research 7-10 years after graduation (based on Table 4.2) and only 12% of them are in technical positions in manufacturing. The similarity between the UK and the US cases and the difference with the French case indicate that, although scholars in many countries are concerned with the decrease in academic jobs, international differences in career patterns of S&E PhDs remain.

6.2 Compound S&E PhD labour markets

The study has also unpacked the interrelationships among S&E PhD labour market segments, job mobility and work-related competences. In Chapter 5, we have found that, as a whole, features of the S&E PhD labour markets experienced by our survey respondents can be explained by both the ILM and the OLM labour market models because, as a whole, promotion opportunities are more likely to occur within organisations rather than externally while, on the other hand, inter-organisational mobility accounts for almost half of the surveyed job transition type (Table 5.3). Hence, the average S&E PhD labour market features, based on the survey respondents' 7-10 years job histories, are a mixture of both the ILM and the OLM features.

The study has also pointed out that some S&E PhD labour market segments show more ILM while some others show more OLM or external labour market features. Thus the results regarding the segmentation of the S&E PhD labour markets resonate with DiPrete and McManus' (1993) concept of the "compound labour markets", which highlights that some labour markets may simultaneously be situated in both the ILMs and the OLMs. The concept of the compound labour markets may also be applied in an individual labour market segment and we have found that each of the S&E PhD labour market segments shows a distinctive mixture of the ILM and the OLM features. They are labelled as "the contrast", "the hybrid" and "the structured". The details are discussed as follows.

6.2.1 The contrast

Our findings indicated that working as researchers in academic/public research appears to be the most stable (as stayers in the segment experience strong ILM-like labour market features) and the most turbulent type of occupation at the same time. Chapter 4 has shown that more than two thirds 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. Moreover, among all types of occupational mobility, moving out of academic/public research is the only type of occupational mobility that involves a significant proportion of non-promotion moves. The strong contrast between the permanent and the fixed-term members indicates that many universities and public research organisations are organising their employment strategies according to the Flexible Firm Model (Atkinson, 1984; Atkinson and Meager, 1986; Ledwith and Colgan, 1996), which emphasises the adoption of the various employment systems to segment their labour force into the “core” and the “peripheral” groups in order to adjust the changing market conditions. The core workers, such as the faculty members, are organised according to the typical ILM arrangements, while the peripheral workers, such as the fixed-term researchers, are organised according to more competitive and less secure measures (Camuffo, 2002; Osterman, 1988). This S&E PhD labour market segment therefore could be label as “the contrast” to highlight the sharp contrast of the “core” and the “peripheral” workers in the segment. However, in this interpretation, it is a puzzle why some of the S&E PhDs go higher on the job ladder and get recruited as core employees, while some other equally qualified S&E PhDs become the peripheral workers. Although the explanation is beyond the objectives of this study and is probably to do with supply and demand, it may still be possible to understand the S&E PhDs’ career patterns based on individual motivations. This will be discussed later; at the moment, the discussion continues on the features of the S&E PhD labour market segments.

6.2.2 The hybrid

The study has pointed out that, although employment outside the conventional technical occupations shows stronger OLM features, promotions are still more likely to occur internally within organisations. 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 promotions. Hence, this finding is particularly significant, because these occupations are often considered to be associated with the boundaryless careers (Barley et al., 2004; DeFilippi and Arthur, 1998; Jones, 1996; May et al., 2002; Saxenian, 1996; Vinodrai, 2006). Careers of members in this segment may be free from organisational control to a certain extent, they are often still organised according to the ILMs. 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 be naïve to discuss boundaryless careers or the OLMs without reference to the ILMs. We may, therefore, describe this OLM-featured S&E PhD labour market segment as an ILM embedded OLM. This highlights the fact that employment relation in the emerging knowledge-intensive industries is probably stickier than is suggested by the boundaryless careers concept. That is, to retain employees and their individual knowledge within the organisations, more efforts might need to be made by employers situated in the project-based network organisations that are widely adopted in services and in many other parts of employment in the knowledge economy. This finding is consistent with many recent studies that stressed the continuous importance of the ILMs and the stickiness of employment relation 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 finding 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. The mixed labour market features of this segment are likely to be the result of the internal or the external hybrids. 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 many firms have introduced new incentive instrument such as performance pay (Foss, 2003; May et al., 2002). This implies that there is a lack of internal career ladders in project-based organisations. Similarly, Marsden (2010) pointed out the growing use of entry tournaments to regulate labour market in project-based organisations. One reason is associated with the quality problem. That is, in project-based organisations, 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 reputations or "stars" becomes the key human resource measure. Hence, it is competitive to obtain a project job and 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.

The 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, Pfeffer and Sutton (2006) argued that because work always requires coordination, performance improves with team and time continuity. Beechler and Woodward (2009) also pointed out that great systems are often more important than great people. Therefore, individual competences will always be sticky to organisation to a greater or lesser extent. This could explain why organisational life remains important in the segment.

Overall, this S&E PhD labour market segment could be labelled as "the hybrid", indicating that the boundary between the internal and the external labour market features within the segment might not be able to be so clearly defined.

6.2.3 The structured

While the academic/public research segment shows sharp contrast between the core and peripheral workers, and employment outside the conventional technical occupations exhibits a highly hybrid organisational form, technical positions in private sector manufacturing seem to have labour market features whose explanation is relatively straightforward. They are not so obviously organised according to the "core-periphery" model, and they are not as hybrid as employment outside the conventional technical occupations, as industrial scientists or engineers in manufacturing largely experience promotions internal to their organisations until they get promotions (internally or externally) to become dedicated managers or decide (voluntarily or involuntarily) to switch career track to 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 as suggested by Marsden (2010), and have certain personal flexibility in terms of their career progression. Hence, we label this labour market segment as “the structured”.

6.3 The increasingly hybrid S&E PhD labour markets

Although the descriptions of “the contrast”, “the hybrid” and “the structured” fit the three S&E PhD labour market segments in each time point, they however does not fully depict the dynamics regarding how the boundary between the ILM-featured segments and the more OLM-featured segments within the S&E PhD labour markets shifts during the period of the survey respondents’ 7-10 years careers. To highlight this specific dynamics, it is helpful to combine findings from Chapters 4 and 5 to further specify the S&E PhD labour markets. In Chapter 4, we have pointed out that over time, as the respondents’ careers progress, employment outside the conventional technical occupations has become the dominant labour market segment and the flow of employment is from the conventional technical segments to this labour market segment. In Chapter 5, we have also revealed that the conventional technical segments show more ILM-like features (but they correspond to two rather different segments), while the dominant features of occupations in employment outside the conventional technical occupations are more towards the OLMs. In Section 6.2.2, we have pointed out that we could label this OLM-featured segment as “the hybrid” because of the coexistence of the highly ILM embedded features. Hence, in a longitudinal perspective from the cohort we studied, we may consider the dynamics of the S&E PhD labour markets towards the hybrid. The specification emphasises that over time, the “direction” of the boundary between the ILM-featured and the OLM-featured segments is shifting to the OLM-featured (but ILM embedded) employment outside the conventional technical occupations due to its dominance.

6.4 Implications of the S&E PhD labour markets

The features of the S&E PhD labour markets, the heterogeneity within them and their interrelationship with knowledge and skills development lead to several implications. Because career behaviour of the structured labour market segment of technical positions in private sector manufacturing follows is more or less in accordance with literature on the managerial/technical ladder transition, here we focus on the implications of the S&E PhD labour market segments of academic/public research and employment outside the conventional technical occupations.

The relative chance of getting upward job mobility and the comparison of employment conditions among segments pointed out that academia and public research organisations may face challenges in the "war for talent" (EI-Khawas, 1994; Gilliot et al., 2002; Michaels et al., 2001; Reponen, 1994), which emphasises that the new way of managing talent is as follows: companies need talented people and compete to retain them by means of disproportionate rewards. This may leave academic and public research organizations with the question of how they could compete with the private sector to attract the most talented PhD graduates (Gilliot et al., 2002), as the hazard of reaching the bottom of the academic career ladder seems enormous and transitions from fixed-term researcher positions 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.

Nonetheless, for 39% (Table 4.1) of the survey respondents, their first jobs were academic/public research positions. This indicates that many S&E PhDs might be willing to try to have their careers in academic/public research, in spite of knowing the difficulties. This in turn implies that it would be 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 to upward progression or material rewards only. The protean career model (Hall, 1976, 1996, 2002) thus addresses the crucial role of subjective meaning of work that is particular to each individual. Hall (1996) explained that the term "protean" was borrowed from the Greek god "Proteus", who could change into any shape at will. Applied to the careers theory, a protean career 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

1) value-driven in the sense that the individual's internal value acts as guidance and measure for the success of his/her career and 2) 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 protean careers could be useful in explaining why so many doctoral graduates are willing to stay in fixed-termed positions in academic/public research due to their personal interests in research and the academic environment, regardless of the relatively less secure employment contracts and the disadvantages regarding career prospects for upward progression. An example is the account given by a post-doctoral researcher in mechanical engineering at one of the top UK research-based universities in our preliminarily interviews:

"I have been doing post-doctoral research since I got my PhD in 2002 (interviewed in 2008)...Many of my (fellow PhD) friends are working in engineering consultancy or BAE Systems. Here (department of mechanical engineering at a UK leading research-based university), at least 4 fellow PhDs I know went to banking. They are modelling the stock market using the same methods we are using here. The money is very good in banking but for me that kind of job is boring. I have never considered going there. I guess that a PhD gives you a lot of opportunities…My only choice for my career is doing research. I like academia because I like to learn. I knew that permanent academic positions are difficult to get from the beginning, and now my salary is not even as good as that of my wife, who is a teacher, but I choose to pursue an academic career because of my passion for research. I have been prepared for it. I guess that I like the freedom of research in academia..."

On the other hand, however passionate in research careers in academia or public research organisations, many talented S&E PhDs may be flexible in terms of career options, especially when opportunities in academia are limited. This has been pointed out in one of our preliminary interviews by a writing-up PhD student in mechanical engineering at a UK top research university stating that, although he likes research and laboratory life, he is not going to look for academic jobs:

"I am not interested in academia. A permanent academic position is too difficult to get and post-doctoral research is too poorly paid. Post-doctoral research is for someone dedicated to finding an academic job – not for me. I would like to go to industry for better pay. I would really like to go to work in a company where I can use the skills and knowledge I acquired in my PhD… I have not really started to look for jobs yet. All I have got so far is an invitation from Barclays asking me to send them my CV."

The number of S&E PhDs who leave academic/public research because of the relatively disadvantaged job conditions is unknown. As pointed out in this study, S&E PhDs contribute to knowledge absorption and production in many sectors and industries in the private sector. Hence talented PhD scientists and engineers' career choice towards industry is certainly positive to industry. However, form the viewpoint of academic/public research, the special labour market features revealed in the study indeed pointed out a potential challenge for researchers and policymakers: the human resource problem of how the segment could become competitive in the "war for talent". At the same time, it is also important to acknowledge that the S&E PhD labour markets actually comprise three distinctively different labour market segments. They are probably guided by distinctively different sets of employee incentives and employment relationship. Hence, regarding the competition in the "war for talent", it would be risky for any segment to adopt human resource practices from other segments without a thorough assessment. For instance, it might be tempting to adopt aggressive staffing approaches, as it would appear quite reasonable to retain star employees with disproportional material incentives. However, several problems such as high turnover rates, high cost and low employee morale have been reported in organisations that adopt such human resource practices (Camuffo, 2002; O'Reilly and Pfeffer, 2000; Pfeffer and Sutton, 2006). Although our interviews indicated that there are indeed some talented S&E PhDs who are driven to industry due to the less secured fixed-term positions and difficulties in finding permanent positions in academia, the interview of the post-doc nonetheless pointed out that for those who stay in academia, passion for research and the desire for autonomy and flexibility are probably more relevant for their career decisions. Within this context, if disproportional material incentives or practices aiming at recruiting "stars" come at the expense of reducing employee morale and result in generalised low research incentive, autonomy or flexibility, they might not necessarily work well in academia, particularly when a proper mechanism for recognising who should be granted disproportional rewards or who should be considered as a star (a star researcher, a star lecturer, a star administrator, a star project manager or a star fundraiser?) is not in place or the mechanism is not transparent.

Regarding the hybrid segment of employment outside the conventional technical occupations, the ILM embedded features of the S&E PhD labour markets indicated that the scenario which portrays knowledge workers as free agents (Reed, 1996) having expert power (Pink, 2001) to move freely around employers is an ideal type where experts are assumed to be able to work completely independently without coordination and socialisation with others or the environment. We have applied theories on organisational knowledge and learning to demonstrate that members in a labour market segment share norms and rules and act according to bounded rationality. The very same theories can also be applied to the level of the boundary of a firm, a university or a laboratory. Hence, as long as experts and knowledge workers remain employed, to a certain extent, they 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 resource practices targeting these personnel should not just focus on stars but also on good systems that enhance coordination (Beechler and Woodward, 2009; Pfeffer and Sutton, 2006). Indeed, Teece (2003) showed how the successful expert service firm Law and Economics Consulting Group (LECG) established a transparent compensation model that has no pay-off for employees who lobby management, introduces fair competition among the experts working in the firm and simultaneously rewards star performers.

6.5 Implications for knowledge flow

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, S&E PhDs' job mobility and S&E PhDs' knowledge and skill development. As the labour market features of the S&E PhD labour markets and their implications have been discussed above, in this section we focus on the implications for knowledge flow. In particular, attention is paid to 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, as this has special implications resonate with the human resource training effect of public funded basic science (Larédo, 2007; Mangematin, 2001; Martin and Irvine, 1981; Mowery and Sampat, 2005; Pavitt, 1991).

The concept of knowledge flow is measured by the perceived usefulness of the various types of knowledge and skills acquired from the previous job in the subsequent job (such as organisation-specific or sector-specific skills) or knowledge and skills that the ways to acquire them are more or less out of the control of working organisations or sectors (such as knowledge and skills acquired from PhD training and general skills). When an individual's knowledge and skills developed in a previous job and perceived to be useful in the subsequent job, knowledge spillovers through the individual's job mobility occur (Griliches, 1992; Rogers, 1995). Given this fact, our measures are able to indicate the portability of the various types of knowledge and skills and the pattern of individual knowledge flow.

The human resource training effect of public funded basic science could be discussed in two ways. First, knowledge and skills acquired from doctoral training are multi-dimensional. In Chapter 4, we have outlined how the study uses subjective measures to investigate the perceived usefulness of different knowledge/skills acquired from doctoral education in different labour market segments. The findings pointed out that S&E PhDs in different labour market segments perceive different types of knowledge bases to be valuable in their jobs. Knowledge directly tied to PhD subject areas is regarded as more valuable in academia/public research; both knowledge directly tied to subject areas (but more general type of knowledge rather than specialist knowledge in PhD topics) and the more general and transferable skills are considered valuable in technical positions in private sector manufacturing; the general and transferable skills are considered more valuable in employment outside the conventional technical occupations. In absolute terms, general analytical skills and problem solving capability acquired from doctoral education are considered valuable in all three S&E PhD labour market segments.

The diversity in the perception of the usefulness of different knowledge/skills acquired from doctoral education in our case may be interpreted as the effectiveness of the modern doctoral education, which emphasises the advancement of knowledge in the PhD subject areas we well as the ability to conduct independent research through training in a wide variety of research methods, in providing an adequate knowledge base for employment across different labour market segments. This interpretation is not only in line with the suggested social and economic effect of human resource aspect of public funded basic science, but also reveals how and what types of knowledge produced in academia is transferred to different sectors through PhDs' career mobility. However, as most of our surveyed PhDs eventually are working in employment outside the conventional technical occupations and as PhD competences in this labour market segment mainly lie in more general and transferable skills, this may raise the questions of the uniqueness of the PhD path to acquire such skills and of how exactly a doctoral qualification may enhance a PhD graduate's employability if the person intends to enter employment outside the conventional technical occupations. These questions are open for debate.

Second, knowledge and skills acquired from doctoral training form only part of PhDs' work-related competences in the labour markets. Hence, in this study, we have further explored the "substance", i.e. the various types, of work-related competences, and the "extent" to which the various types of work-related competences might be able to flow across employers, occupations or labour market segments through individual S&E PhDs' job mobility. We unpack the substance of work-related competences of S&E PhDs because the traditional distinction between the organisation-specific and general skills in the labour markets (Becker, 1964; Eyraud et al., 1990; Williamson, 1981) is far from adequate to grasp S&E PhDs' knowledge and skill development. For instance, the very specific quality of S&E PhDs, i.e. knowledge and skills acquired from S&E doctoral training, is invisible in such distinction because they are neither organisation-specific nor can they be seen as general skills. Furthermore, in an attempt to capture the occupational dynamics, we have also highlighted the dimension of sector-specific skills, as they are more general but within the context of a sector.

The pattern of individual knowledge flow in the labour markets through S&E PhDs' job mobility has been discussed in Chapter 5. 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, such knowledge flow pattern would have been able to conclude straightforwardly 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. Findings in Chapter 4 strongly indicated that employment outside the conventional technical occupations has become the major labour market segment for S&E PhDs as careers progress and members in this segment often emphasise the usefulness of sector-specific or general skills, rather than knowledge and skills acquired from doctoral training, particularly the subject-specific dimension of doctoral training.

Also, Chapter 5 has pointed out that there is a hint indicating that a more significant channel to transfer knowledge acquired from doctoral training is through job mobility of fixed-term academic or public sector researchers moving into employment outside the conventional occupations, as a moderate proportion of job transitions in this type of mobility indicates that skills acquired from doctoral training are the most useful in the subsequent jobs after the transitions. However, the significance of this channel to disseminate knowledge produced in academia needs further verification, as the number of our cases in this type of job transitions is not large enough. This nonetheless points out two possibilities. The first is that the hint indicated above is a true statement. This then indicates a potential dilemma for policy makers between the maximisation of the human resource training effect of the public funded basic science to foster knowledge flow from academia or the public research sector to the emerging occupations in the knowledge economy for S&E PhDs and employment security/career prospects of those S&E PhDs with fixed-term contracts as most of such job transitions involve nonpromotional moves. The second possibility is that the hint is misleading. In that case, this means that knowledge and skills acquired from doctoral training might not be easily transferred to employment outside the conventional technical occupations through individual PhD scientists or engineers' employment in industry, particularly the subject specific dimension. The substance of S&E doctoral training that is more relevant to the human resource training effect of public funded basic science in the increasingly important S&E PhD employment outside the conventional technical occupations lies in the more general and transferable dimension of S&E doctoral training, such as general analytical skills and problem solving capabilities, as discussed in Chapter 4. This goes back to the questions of the uniqueness of the PhD path to acquire such skills and of how exactly a doctoral qualification may enhance a PhD graduate's employability if the person intends to enter employment outside the conventional technical occupations discussed above.

6.6 Rethinking careers and competences of S&E PhDs in the knowledge economy

Dosi (1994) and Freeman (1992) pointed out that having qualified scientists and engineers working in technology related occupations is one of the key factors contributing to national competitiveness. This study indeed has revealed how S&E PhDs in the conventional technical segments draw knowledge from the subject-specific dimension of S&E doctoral training in their jobs. More significantly, this study has also indicated that, with the dominance of employment outside the conventional technical occupations and given that segment's emphasis on general analytical skills and problem solving capabilities, in order to fully understand the role of S&E PhDs in the knowledge economy, more work needs to be done to uncover the interrelationship between the articulation of their procedural knowledge and their substantive or subject-specific knowledge.

For scientists and engineers at the level of doctoral training, it is suggested that their employment in industry represents the flow of academic knowledge to industry (Larédo, 2007; Mangematin, 2001; Martin and Irvine, 1981; Mowery and Sampat, 2005; Pavitt, 1991) because S&E PhDs themselves are involved in scientific knowledge production. Regarding this, this study used a direct measure of knowledge flow and showed that this interpretation could be applied directly to industrial scientists in manufacturing. By contrast, although S&E PhDs in employment outside the conventional technical occupations are a lot more mobile, knowledge and skills acquired from doctoral training, especially the subject-specific dimension of doctoral training, do not easily perceived to follow them and to be used directly in other jobs. A potential but yet to be confirmed channel for having efficient individual knowledge flow from academia to employment outside the conventional technical occupations is job mobility of the fixed-term academic researchers when their contracts in academia end. However, this might come at the expense of those researchers' career progression, as industrial employers might consider them as fresh from doctoral training; this, in turn, leads to their lateral job mobility when moving out of academia.

The extent to which fluid job mobility contributes to S&E PhDs' individual knowledge flow depends on the types of knowledge in discussion. It is not surprising that the emerging occupations associated with the knowledge economy are characterised by high inter-organisational mobility and by emphasis on sector-specific and general knowledge. However, even for sector-specific and general knowledge, we have demonstrated that, to a certain extent, it is sticky to organisations. Hence, S&E PhD experts and knowledge workers' careers and individual knowledge flow are not really boundaryless (DeFillippi and Arthur, 1994) but moderately localised within organisations.

7 Conclusions

Based on a retrospective survey of science and engineering (S&E) PhDs from a UK research-based university with 7-10 years job histories and the design-based non-parametric analysing methods, this thesis drew on theories on careers, organisational knowledge and learning and labour markets to explore the interrelationship between knowledge flow and careers of S&E PhDs. The work contributes to innovation studies in several distinctive ways. We have pointed out that, although labour market theories have outlined the interrelationships among labour market segments, job mobility and knowledge and skill development, the existing literature is inadequate in terms of informing us of the knowledge and career dynamics of S&E PhDs in the knowledge economy. Hence we have addressed the deficiencies of the existing literature firstly by combining careers theories and proposing a new classification of the S&E PhD labour market segments, one that renders the distinctive difference in knowledge dynamics in the unconventional S&E PhD occupations visible. Secondly, we have also unpacked the various types of knowledge and skills in the S&E PhD labour markets and revealed the extent to which they are relevant to different labour market segments. Thirdly, we have drawn on real job mobility histories to explore the S&E PhD labour markets in a cross-organisational/occupational/labour market segment perspective.

The study advanced our understanding of the impacts of the knowledge economy on S&E PhDs' employment, and in turn revealed the role of science and technology doctoral training in the labour markets in the knowledge economy. It is possible to conclude that, although as careers progress, employment outside the conventional technical occupations has become the dominant employment segment for our survey respondents, science and technology training at doctoral level remains valuable to all segments of the labour markets of the S&E PhDs, especially the more general and transferable dimension of doctoral training.

The study also enriched our understanding of the human resource training effect of public funded basic science and the extent to which academic knowledge could possibly be transferred through individual PhD scientists and engineers' job mobility to industry. Respondents in the conventional technical occupations in industry, i.e. technical positions in private sector manufacturing, still draw quite a lot of the knowledge and skills required in their jobs from their doctoral training, even knowledge and skills directly tied to PhD subject areas. On the other hand, respondents in employment outside the conventional technical occupations, such as dedicated managers, consultants or other professionals in services, are less likely to perceive knowledge and skills from doctoral training to be useful in their jobs.

The study further concluded that the concept of the boundaryless careers would not be sufficient without reference to organisational life. Indeed, the study pointed out that although our surveyed dedicated managers, consultants and other professionals in services are more likely to have inter-organisational mobility, on average for this segment promotions are more likely to occur within organisations rather than externally. Similarly, the concept of the boundaryless careers of S&E PhD dedicated managers, consultants and other professionals in services would not be sufficient without reference to other S&E PhD labour market segments. Hence, the study used real job histories to trace the surveyed S&E PhDs' job mobility across organisations, occupations and labour market segments. The comparison revealed the distinctive labour market features of different S&E PhD labour market segments: the sharp contrast of the core and peripheral workers in academic/public research, the highly hybrid labour market form in employment outside the conventional technical occupations and the relatively more structured labour market features in technical positions in private sector manufacturing. This further contributes to literature in the following two ways: 1) the findings provide strong implications for research policy and human resource management of the highly skilled S&E personnel and 2) the specific methodology used introduces a novel research approach in both the innovation studies and literature on work organisation and employment. The implications and the contribution to methodology are further outlined below.

Several implications could be drawn from this research. The first is the importance and the dominance of employment outside the conventional technical occupations as S&E PhDs' careers progress. The challenge is how to fully realise the S&E PhDs' potential in this type of employment. We have suggested further research on the articulation between substantive knowledge and the more general and transferable knowledge and on how exactly S&E PhDs use the more general and transferable knowledge outside the conventional technical occupations. Nonetheless, for government policy makers and employers, the rationale for the demand of S&E PhDs in the knowledge economy seems to be justified. Even in many professional services, because job tasks are often highly complex, doctoral education in science and engineering actually provides valuable training in analytical skills and problem solving capabilities. This can be seen in our cases, e.g. in how a team leader in an engineering consultancy solves technical problems that no one in the company can solve and how some PhDs with the most sought after analytical and programming skills in mechanical engineering are highly valued in banking. Regarding universities, however, although they benefit from research input from doctoral students and fixed-term researchers, they should consider how to provide career guidance to these researchers. Information about possibilities of employment outside the conventional technical occupations and about the corresponding work-related competences should be made widely available. Furthermore, we suggest that universities could actively provide relevant training in management and transferable skills to their S&E PhD students and fixed-term researchers. Similarly, individuals including doctoral students and fixed-term researchers could pay more attention to different career paths in different types of employment and their corresponding work-related competences. By understanding the possibilities outside the conventional technical occupations (and the difficulty in securing faculty positions), we believe that it would be possible to generate more incentives for individuals who are highly science-oriented to acquire more management knowledge and transferable skills; otherwise they might have no interest in acquiring these types of training. In this way, it would also be easier for them to make a smoother transition to dedicated managers or work in professional services when they want or need to, especially for those doctoral students and contract researchers who wish for but are unable to secure faculty positions eventually.

The second is the diversified S&E PhD labour market segments. In particular, the sharp contrast in employment conditions between faculty members and the academic fixed-term researchers. This points out the need to balance the benefits of research inputs contributed by academic contract researchers and the potential costs of these researchers' careers. Obviously, government policy makers could make immediate impact by taking appropriate measures. For instance, in France, there is only a limit of period that a PhD could work as a contract researcher in academia, as many academic temporary contracts cannot be renewed more than once (Musselin, 2005). However, because the overall costs and effects that the society, the universities and the individuals will gain or lose are far beyond the scope of this thesis, we suggest that more research needs to be done. Nonetheless, for individual S&E PhDs and fixed-term academic researchers, it is important that they are aware of the relatively more unstable employment conditions in academia and are prepared for it.

Furthermore, the highly hybrid features in employment outside the conventional technical occupations and the implication of the stickiness of knowledge provide direct inputs into the competing views regarding reward systems in this type of employment. On the one hand we have the belief that individual knowledge workers have the expert power (Reed, 1996; Pink, 2001) and an organisation's performance depends on getting individuals' incentives right by using performance-based pay (Lazear and Shaw, 2007). On the other hand there is the focus on groups and the emphasis on the fact that the stability of employment relationship is based on structured organisational career ladder, which is organised according to knowledge and skill development and seniority (Osterman, 2009) and enhances coordination among different groups within the organisation (Beechler and Woodward, 2009; Pfeffer and Sutton, 2006). The former is often associated with project-based organisations and is likely to result in a high degree of inter-organisational job mobility, which might not be upward because many who failed to become stars would be sliding to other organisations without promotion (Marsden, 2010). By contrast, the latter would feature a high degree of intra-organisational upward mobility and therefore there would be stickiness of knowledge to organisations. As results in this research revealed that the stickiness of knowledge in organisations remains, we suggest that employers might wish to take more careful steps in adopting aggressive stuffing systems. This also indicates that some caution might be needed if the organisations in the conventional technical segments wish to follow such human resource measures. For universities in particular, there might be some questions that need to be answered first. For instance, are there convincing measures for performance in place? Could pay be the most important factor to motivate the large majority of science-oriented researchers? Furthermore, by adopting such human resource measures, is it possible that universities will actually attract a completely new breed of researchers who are very different from the conventional ones? For instance, the new breed of academic researchers might be more success-oriented, i.e. focusing on measures to get promotion quicker, rather than more science-oriented, i.e. focusing on intrinsic satisfaction in pursuing scientific advancement. We suggest that policy makers should thoroughly assess the impacts and consequences.

In terms of research design, the specific research design of obtaining retrospective job histories for longitudinal event history data applied in this study illustrates an innovative approach to explore dynamics in transitions between employment and knowledge states. Moreover, the clustered sampling strategy and survey-based non-parametric analysing methods maximised the potential of analysis at different levels (individual, job and job transition). Both the data collection and the analysing methods so far have rarely been seen in innovation studies and we have shown how studies might benefit from them. Hence, due to the outlined strength of longitudinal and event history data in interpreting dynamics, research areas such as knowledge dynamics in regional systems of innovation or project-based networks, impacts of innovation policies at firm, sectoral, regional or national levels or the determinants of the survival opportunities of science-based start-ups or spin-off firms shall benefit tremendously from using such data and methods.

Last but not the least, the study approached innovation studies through the lens of individuals because, to a certain extent, career and learning are driven by individual motivations. However, the study also drew theories on organisational knowledge and learning and adopted the concept that learning is socially bounded. Hence competences, or "capabilities" (Kogut, 2008), can be regarded as boundaries of labour market segments. The epistemological foundation of the study therefore is based on an integrated individual and social account. This is different from the mainstream of innovation studies that focus mainly on firms. The study offered an alternative that is able to link individual learning, knowledge dynamics and careers in the labour markets. This is so far largely neglected in innovation studies.

The work in this study can be extended in many directions. Since the study has indicated the increasingly important role of the more general and transferable dimension of S&E doctoral training in the knowledge economy, further research may focus on in-depth investigations of how the more general and transferable dimension of doctoral training (such as general analytical skills and problem solving capabilities) is articulated in employment outside the conventional technical occupations by S&E PhDs. Furthermore, another possible way to extent the research on careers and competences of S&E PhDs is that, perhaps instead of approaching the question by measuring what type of knowledge is considered useful, further studies could by contrast explore what S&E PhDs in different labour market segments expect to gain from their S&E PhD training. For instance, the question of what dedicated managers, consultants and other professionals in services have gained from S&E doctoral training, apart from the very much emphasised general analytical skills and problem solving capabilities, might rest on the fact that doctoral training has provided them with the channels and networks to access academic knowledge. The social network dimension of S&E doctoral training, i.e. the "knowing whom" competence (DeFillippi and Arthur, 1994), requires further exploration.

Moreover, due to the exploratory nature of the study, there are several areas of it that could be further enhanced. For instance, the study departed from the hypothesis that in the knowledge economy, there could be an emerging S&E PhD labour market segment whose knowledge dynamics differs from that of the conventional S&E PhD technical segments, and we defined the segment roughly as "employment outside the conventional technical occupations". Although the differences in knowledge dynamics are confirmed in the study, the definition of this emerging and increasingly dominant segment remains debatable and could be further refined. The study indicated that, although jobs outside the conventional technical occupations range from sales to school teaching, most of them are dedicated managerial positions, consultancy, programming or software developing positions in business services, and non-research positions in academia or public organisations. Hence, an in-depth examination to further untangle the heterogeneity of this labour market segment, particularly the roles of S&E PhDs as dedicated managers and experts or consultants in business services (examining e.g. how they articulate their knowledge and skills in jobs and how S&E doctoral training is considered useful for their careers) will provide valuable information to further advance our understanding of the role of S&E PhD knowledge workers in the knowledge economy.

We also acknowledge some limitations of this study. We focus on S&E PhD knowledge workers from the University of Manchester with employment histories 7-10 years in the labour markets only. The inferences do not go beyond the survey population. Hence, career behaviour described in this thesis cannot be generalised to a general pattern of all S&E PhD knowledge workers, and in particular career behaviour of knowledge workers at a more senior stage of their careers. However, some generalisations based on results from this thesis might be made. Although based on respondents from a UK research-based university, the results in career patterns, job mobility and work-related competences from our study are significant. We believe that the change in career patterns revealed in this thesis is likely to be the general trend of employment of PhDs in science and engineering from UK research-based universities, as the PPARC survey of the council funded students pointed to a similar direction. However, we suspect that an even greater extent of S&E PhDs from UK non-research-based universities would be working in industry and there would be even more diversified types of employment for them. Hence, implications of the importance and the dominance of unconventional S&E PhD jobs over career stages derived from this research are significant and valuable. For S&E PhDs in other countries, the findings would also be relevant if the trend in the shift of employment patterns is occurring. On the other hand, the perceived usefulness of different types of knowledge and skills for jobs and the observed patterns of job mobility are likely to be rather independent from the research design (which focuses on a single university) but are associated more with labour market segments. The reason is that these features are organised according to rules, routines and shared norms of the segments. Although individuals are also capable of affecting these features, there is no particular reason to suspect that once they are employed in a specific segment, S&E PhDs trained in different universities would behave differently in terms of the perceived usefulness of knowledge and skills in jobs and hence job mobility. Nonetheless, a larger scale of investigation involving PhD graduates from more universities and even more disciplines with a longer survey period will certainly enrich our understanding of career and knowledge dynamics of S&E PhD knowledge workers, in particular since, as illustrated in this study, some interesting findings could not be confirmed because of the limited number of observations. Furthermore, the study has explored the reward systems as one of the main dimensions affecting knowledge dynamics in different S&E PhD labour market segments. Future research could go further to explore more details about the underlining institutional mechanisms that shape segment differences. In Chapter 6, we have demonstrated that the career pattern uncovered in the UK context in this study is rather different from that of the French case. Therefore, research on careers and knowledge dynamics of S&E PhD knowledge workers could also benefit from international comparative studies that aim at investigating how national institutional mechanisms shape similarities or differences in S&E PhD careers and knowledge dynamics in different national contexts.

Finally, because promotion opportunities can only be measured if job transitions occurred, those who have not experienced any job transition are unfortunately lost in some part of the analysis when job transitions are employed as analysing units. However, overall, we believe that our research does shed light on the understanding of career behaviour of S&E PhD knowledge workers, provide useful information about the circulation of the various types of individual knowledge and bridge the current debates on organisational life from a cross-organisational and occupational perspective.

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 2: The questionnaire developed in this study

University of Manchester

CAREER TRAJECTORY SURVEY OF FORMER PhD STUDENTS IN SCIENCE AND ENGINEERING DISCIPLINES

The alumni office of the University of Manchester is carrying out a survey on behalf of an ESRC (Economic and Social Research Council) funded project, led by Professor Marcela Miozzo and Professor Philippe Laredo, at Manchester Business School. The purpose of the survey is to investigate the career trajectories of former PhD students in science and engineering disciplines and how their knowledge is used in the knowledge based economy.

PLEASE RETURN BY MONDAY 30 JUNE 2008

PLEASE RETURN TO: MS HF LEE, PGR OFFICE, MBS, BOOTH STREET WEST, MANCHESTER M15 9BU, UK

If you would like to speak to someone about this survey, please contact Ms Hsing-fen Lee (doctoral research student for this project) by e-mailing hsing-fen.lee@postgrad.mbs.ac.uk. Best efforts will be made to ensure that we reply your e-mails within 24 hours.

Part A: About You and Your PhD

Please tick √ one answer only (unless specified) in box for each question

A1: Are you…	❑ Male ❑ Female
A2: How old are you?	(e.g. 35)
A3: In which year were you awarded your PhD?	❑ 1998 ❑ 1999 ❑ 2000 ❑ 2001
A1: What was the main subject area of your PhD?	(e.g. Chemical engineering)
A2: How many journal publications or patents resulted from your PhD project?	Please write the exact number (e. g. 3, 5, etc) Journal: ------------------ Patent: ----------------------
A3: Did ***your supervisor*** during your PhD engage in any of the following activities (not necessarily related to your project)? ***Please √all that apply.***	❑ Joint research project with industry ❑ University spin-offs ❑ Industrial consortium ❑ Licensing/patenting ❑ Research project solely commissioned by industry ❑ None
A4: Was your PhD project part of any of the following activities? ***Please √all that apply.***	❑ Joint research project with industry ❑ University spin-offs ❑ Industrial consortium ❑ Licensing/patenting ❑ Research project solely commissioned by industry ❑ None
A5: Which of the following best describes the content of your PhD project? ***Please √one box only.***	❑ Seek a solution to a specific technical problem identified within a firm's or a group of firms' operations. ❑ Explore a high-risk concept identified by a firm or a group of firms – outside the firms' mainstream activities ❑ Develop design specifications or prototypes for new or improved industrial products or processes. ❑ Generating knowledge on topics of broad interest to your PhD subject area

A6: ***In the context of your subject area***, how would you quantify ***your supervisor's*** and ***your*** PhD research? Please give a score from 1 to 5. 1 = the least applied; 5 = the most applied.	Not at all applied 1	Small possibility of application 2	Not directly tied to but with potential 3	Close to application 4	Directly tied to application 5
▪ ***Your supervisor's*** research in your opinion?	❑	❑	❑	❑	❑
▪ ***Your*** PhD research in your opinion?	❑	❑	❑	❑	❑

A7: Have you ever presented/discussed your PhD project to/with your industrial partners during your PhD?	❑ No, my project was not sponsored by industry ❑ No, I have never presented/discussed my work to/with my industrial partner(s). ❑ Yes. How many times? Please specify (e.g. 1, 2) ------------------------------
A8: Did you spend any time in an industrial placement for your PhD?	❑ No ❑ Yes. For how long? Please specify (e.g.6 months) ----------------------------------
A9: Did the group/laboratory where you did your PhD have any contact with firms?	❑ Yes, regular contact – Continue **A10, A11.** ❑ Yes, occasional contact – Continue **A10, A11.** ❑ No - Go to **Part B.**
A10: Did you use any such contacts to obtain your first job?	❑ Yes ❑ No
A11: Have you ever worked/collaborated with these firms later in your work?	❑ Yes ❑ No

Part B: Current Job Please tick √ one answer only (unless specified) in box for each question

B1: Which of the following activities best describes what you are doing now?	In paid employment (full or part-time)	❑ Go to question **B2**
	Self-employed/have own company	❑ Go to question **B9**
	Unemployed and available for work	❑ Go to **Part C**
	Other. Please specify ----------------	❑ Go to **Part C**
B2: When did you start your current job?	Please specify (e.g. Jan 2000). If you changed ***rank or job title*** while working for ***the same employer***, count it as a ***change of job***.	
B3: Which of the following activities best describes what you are doing now? You are working for…	A university	❑ Go to question **B4**
	A government/public/voluntary organisation (e.g. a research establishment, a government department/agency, a local authority, a school/college, a health authority/hospital, a voluntary organisation/charity)	❑ Go to question **B5**
	A private sector firm or company	❑ Go to question **B6**
	Other. Please specify ----------------	❑ Go to question **B13**
B4: Which of the following best describes your current position?	❑ Professor ❑ Reader ❑ Senior lecturer ❑ Lecturer ❑ Research fellowship holder with own grant ❑ Research fellow ❑ Postdoctoral researcher	❑ Other. Please specify (e.g. administration, IT support). ----------------

Please go now to question B13

B5: Which of the following best describes your job and duties?	❑ Postdoctoral research assistant ❑ Research fellow ❑ Research scientist	❑ Other (e.g. administration, civil servant, teacher etc). Please specify. ----------------

Please go now to question B13

B6: Which type best describes the company you work for?	❑ Service. Please specify (e.g. Banking, IT consultancy…) ---------------- ❑ Manufacturing. Please specify (e.g. Aerospace, Chemical…) ----------------	❑ Other. Please specify. ---------------- ----------------
B7: What is your job title?	Please specify.	
B8: What is the nature of the work you undertake?	Please describe your job and responsibility. ---------------- ----------------	

Please go now to question B13

B9: When did you start up your own business?	Please write the month and year (e.g. Jan 2000)
B10: Which of the following best describes your current position? *Please √ one box only.*	❑ I created my own company. ❑ I acquired/took over a company. If you created or acquired/took over a company, could you provide the following information regarding your company (based on 2007 or nearest figures that available)? ▪ Did the start up involve university spin-off? ❑ Yes ❑ No ▪ Did the start up link to the academic group/laboratory where you gained your PhD? ❑ Yes ❑ No Turnover ---------------- Industrial sector SIC (92) code ---------------- Description of products or services sold ---------------- ---------------- Position in the market ---------------- ❑ I work on a freelance basis for different companies/organisations ❑ Other. Please specify. ----------------

Please go now to question B13

B13: Is this job full-time or part-time?	❑ Full-time ❑ Part-time
B14: Is this job a permanent or fixed-termed position?	❑ Permanent ❑ Fixed-term contract
B15: What are the most valuable skills you gained from your PhD for this job? 1= the most valuable; 2= the second most valuable. ***Please Rank the 3 most valuable.***	( ) Specialist knowledge in PhD topic ( ) General knowledge in PhD subject area ( ) Application of information technology and data processing ( ) General analytical skills ( ) Report writing and presentation skills ( ) Project management skills ( ) Problem solving capability
B16: In this job, do you have any managerial duties?	❑ Yes, managerial duties ***not*** involving research or technical development ❑ Yes, managerial duties involving research or technical development ❑ No
B17: Does this job involve scientific research/development?	❑ Yes, within PhD subject area ❑ Yes, but outside PhD subject area ❑ No
B18: Which type of skills would you say is the most useful for this job? ***Please √one box only.***	❑ Skills acquired from PhD ❑ ***Organisation*** specific skills acquired from previous position ❑ ***Sector*** specific skills acquired from previous position ❑ General skills
B19: Does your job explicitly require a PhD qualification?	❑ Yes ❑ No
B20: In positions similar to yours, what is the proportion of your colleagues who have a PhD qualification?	Please estimate (e.g. 75%)
B21: How many people does your company/organisation employ?	❑ 1-9 ❑ 10-49 ❑ 50-249 ❑ 250-499 ❑ ≥ 500
B22: Did the transition from your previous job to this job involve promotion?	❑ Yes, within the same employer ❑ Yes, but the promotion involving changing employer ❑ No ❑ This is my first job.

B23: To what extent would ***each*** of the following experiences provide you with a sense of accomplishment? Please give a score from 1 to 4. 1 = the least; 4 = the most.	Not at all 1	A little 2	Much 3	A great extent 4
▪ Contributing to a product of high commercial success	❑	❑	❑	❑
▪ Publishing a paper which adds significantly to the technical literature	❑	❑	❑	❑
▪ Developing concrete answers or solutions to important technical problems	❑	❑	❑	❑
▪ Developing new theoretical insights or solutions	❑	❑	❑	❑
▪ Contributing to a product of distinctly superior technical quality	❑	❑	❑	❑
▪ Coming up with a highly innovative idea or solution	❑	❑	❑	❑

Part C: Your Job History (Everyone please answer)

Defining a job:

- Include any job (including self-employment), full-time or part-time, which you did for at least 6 months.
- If you changed **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.

Employment Code

01	University faculty position (professor, reader, senior lecturer, lecturer)	04	Private sector company - service	07	Research position in a government/public/voluntary organisation	09	Running own company
02	University research position (research assistant, research fellow)	05	Private sector company - manufacturing	08	Other position in a government/public/voluntary organisation	10	Freelance worker
03	Other university post	06	Private sector company - Other			11	Other type of employment

Job History (Please provide information about ***all your previous jobs*** you have done since you obtained your PhD ***in chronological order***.)

Time (e.g. From May 1999 to Dec 2001)	Employment code	***Main*** responsibility in this job Please √ one box only.	Employment condition of this job (I)	Employment condition of this job (II)	Did the transition from last job involve promotion?	Did the transition from last job involve changing employer?	Did this job need a PhD qualification to get it?	How many people did your company/organisation employ?	What are the most valuable skills you gained from your PhD for this job? **Please Rank the 3 most valuable.**	Which skills are the most useful for this job? **Please √ one box only.**
From --------- To ---------	☐☐	❑ Managerial ❑ Research/ Development ❑ Other. Specify --------------- ---------------	❑ Full-time ❑ Part-time	❑ Permanent ❑ Fixed-term ❑ Self-employed/ freelancing	Not applicable	Not applicable	❑ Yes ❑ No	❑ 1-9 ❑ 10-49 ❑ 50-249 ❑ 250-499 ❑ ≥ 500	( ) Specialist knowledge in PhD topic ( ) General knowledge in PhD subject area ( ) Application of information technology and data processing ( ) General analytical skills ( ) Report writing and presentation skills ( ) Project management skills ( ) Problem solving capability	❑ Skills acquired from PhD ❑ ***Organisation*** specific skills acquired from previous position ❑ ***Sector*** specific skills acquired from previous position ❑ General skills
From --------- To ---------	☐☐	❑ Managerial ❑ Research/ Development ❑ Other. Specify --------------- ---------------	❑ Full-time ❑ Part-time	❑ Permanent ❑ Fixed-term ❑ Self-employed/ freelancing	❑ Yes ❑ No	❑ Yes ❑ No	❑ Yes ❑ No	❑ 1-9 ❑ 10-49 ❑ 50-249 ❑ 250-499 ❑ ≥ 500	( ) Specialist knowledge in PhD topic ( ) General knowledge in PhD subject area ( ) Application of information technology and data processing ( ) General analytical skills ( ) Report writing and presentation skills ( ) Project management skills ( ) Problem solving capability	❑ Skills acquired from PhD ❑ ***Organisation*** specific skills acquired from previous position ❑ ***Sector*** specific skills acquired from previous position ❑ General skills
From --------- To ---------	☐☐	❑ Managerial ❑ Research/ Development ❑ Other. Specify --------------- ---------------	❑ Full-time ❑ Part-time	❑ Permanent ❑ Fixed-term ❑ Self-employed/ freelancing	❑ Yes ❑ No	❑ Yes ❑ No	❑ Yes ❑ No	❑ 1-9 ❑ 10-49 ❑ 50-249 ❑ 250-499 ❑ ≥ 500	( ) Specialist knowledge in PhD topic ( ) General knowledge in PhD subject area ( ) Application of information technology and data processing ( ) General analytical skills ( ) Report writing and presentation skills ( ) Project management skills ( ) Problem solving capability	❑ Skills acquired from PhD ❑ ***Organisation*** specific skills acquired from previous position ❑ ***Sector*** specific skills acquired from previous position ❑ General skills
From --------- To ---------	☐☐	❑ Managerial ❑ Research/ Development ❑ Other. Specify --------------- ---------------	❑ Full-time ❑ Part-time	❑ Permanent ❑ Fixed-term ❑ Self-employed/ freelancing	❑ Yes ❑ No	❑ Yes ❑ No	❑ Yes ❑ No	❑ 1-9 ❑ 10-49 ❑ 50-249 ❑ 250-499 ❑ ≥ 500	( ) Specialist knowledge in PhD topic ( ) General knowledge in PhD subject area ( ) Application of information technology and data processing ( ) General analytical skills ( ) Report writing and presentation skills ( ) Project management skills ( ) Problem solving capability	❑ Skills acquired from PhD ❑ ***Organisation*** specific skills acquired from previous position ❑ ***Sector*** specific skills acquired from previous position ❑ General skills

Appendix 3: The revised 2009 DRUID summer conference paper

The impact of university-industry collaborations on academic research training and career of PhDs in science and engineering: a UK case

Revised version based on the paper presented in the 2009 DRUID summer conference

Abstract

Drawing on a survey of PhD training and retrospective employment history of PhD graduates in science and engineering from a UK research-based university, the paper investigates how the changing context of research towards greater applicability and industrial relevance affects academic research training and the career of PhD students. The results suggest differences in a number of dimensions between traditional research projects and projects with industrial involvement: objective, degree of applicability of PhD projects, and industrial contact. There is no difference in scientific productivity (although with greater standard deviation for projects with industrial involvement). Career outcomes in the private sector are positively affected by industrial contact during PhD training, while the only relevant dimension for career outcomes in the public sector is scientific productivity. The nature of the projects, i.e. objective and degree of applicability, is not directly relevant for career outcomes in both the private and the public sector. However, there is a hint that scientific productivity might be affected by research objectives, i.e. whether PhD research projects aim at solving specific technical problems, testing high-risk concepts or generating knowledge in a broader sense. Hence, career outcomes in the public sector might be affected indirectly.

Keywords: university-industry collaborations, industrial relevance, applicability, academic research training, career, PhDs in science and engineering

1 Introduction

The objective of this paper is to examine how the increasingly institutionalised expectation for university-industry collaborations affects academic research training and the career of PhD students. In the past twenty years, literature on knowledge production has come to recognise that universities, in interaction with business firms, public sector research establishments, financial and legal institutions, all play a part in the systems of innovation (Edquist, 1997; Freeman, 1987; Lundvall, 1992; Nelson, 1993), but not in the isolated world of "republic of science" (Merton, 1973) or in the linear "scientific push" model (Kline and Rosenberg 1986). This has provided, at the policy level, the rationale for encouraging universities to contribute to national competitiveness through broader interactions with external and diversified organisations, particularly direct interactions and collaborations with industry (Larédo, 2007; The Dearing Report, 1997). Other factors such as the shorter product life cycles and the catching up of less developed countries, mean that competition among countries for science and technology advance has been fiercer. Developed countries face problems not only associated with high labour costs and competition from the catching-up countries, but also with constraints on government expenditure in various areas such as health, education and social care. Public expenditure on all sectors, including science and technology, is subject to basic concerns regarding efficiency, value for money and specific return. Consequently, academic researchers who were in the "ivory tower" are now officially asked to identify potential users of their research output and channels of knowledge transfer when submitting projects. According to Gibbons et al. (1994), academic research is shifting to "mode 2" knowledge production that is based on the requirement for applicability of research, leading to the blurring of boundaries between the public and private sector and between science and society. Although scholars have pointed out that "mode 2" has always existed in academia even before "mode 1" (Martin, 2003; Mowery, et al., 2004; Pavitt, 2001; Pavitt, 2003), there is some consensus that the call for academic research to draw more attention to application and to the transfer of the research to serve social and economic needs has become more formal and institutionalised (Hessels and Van Lente, 2008; Lawton Smith, 2006; Larédo and Mustar, 2004).

Many conceptual or empirical studies regard the role of universities as contributing to firms' performance, regional development or national competitiveness through collaborations with industry (Baba et al., 2009; Cooke, 2001; Giuliani and Arza, 2009; Goldstein and Renault, 2004; Mansfield and Lee, 1996; Zucker et al, 2002. On the other hand, there is also concern about possible negative unintended consequences of this change in role of universities, including the changing objective of academic research, the role of universities in society and how academic research activities should be organised and implemented (Blumenthal et al., 1997; Geuna, 2001; Geuna and Nesta, 2006; Gluck et al., 1987; Kenney, 1987; Slaughter et al., 2002;). In order to understand the growth and nature of university-industry collaborations, there has been a spate of research focusing on the various channels through which university-industry collaborations are strengthened (Bekkers and Freitas, 2009; Cohen et al., 2002; D'Este and Patel, 2007; Meyer-Krahmer and Schmoch, 1998) and on the incentives or determinants of such collaborations (Arvanitis et al., 2008; Bruno and Orsenigo, 2003; Fontana et al., 2006; Giuliani and Arza, 2009; Gregorio and Shane, 2003; Jain et al., 2009; Krabel and Mueller, 2009; Shane and Stuart, 2002; Tornquist and Kallsen, 1994). Moreover, those concerned with possible unintended consequences of university-industry collaborations have assessed the effects of these on academic research or productivity (Estabrooks et al., 2008; Gulbrandsen and Smeby, 2005; Louis et al., 2001; Lowe and Gonzalez-Brambila, 2007; Van Looy et al., 2004) These studies try either to identify the potential effects of university-industry collaborative research on firms, the economy or science, or to characterise how the behaviour of scientists, universities or firms affect university-industry collaborations. Little attention has been paid to the effect of university-industry collaborations on individual academic scientists, who are the workforce directly involved in the activities as part of their profession. As, on the one hand, academic scientists have to conform to traditional norms for carrying out research, and, on the other hand, they receive increasing incentives to work with industry, the consequences of university-industry collaborations on the development of research personnel is still largely unexplored particularly in terms of their career. An exception is the study by Lam (2007), which explores the emerging "overlapping internal labour market" between firms and academia scientists.

Two kinds of university members are directly involved in the interaction between research and education: the faculty members and the PhD research students. Very often, the researchers who are directly tied to the research projects are the PhDs, especially in science and engineering disciplines. The increasingly institutionalised academic research environment that is in favour of university-industry collaborations implies a changing academic training provided to PhD students. Empirically, many studies have stressed the benefits of doing projects with industry involvement for the career development of PhDs (Dany and Mangematin, 2004; Giret and Recotillet, 2004; Mangematin, 2000; Martinelli, 1999; Robin and Cahuzac, 2003). Nevertheless, other studies have argued that graduate students can be regarded as tokens exchanged to industry by their supervisors (Slaughter et al., 2002). In any case, it is not clear how different dimensions of doctoral training with industrial involvement affect the career of PhDs. Our intention is to fill this gap, and to answer the following research questions:

1. Is there any difference in academic training between projects with and without industrial involvement?
2. Does the difference in academic training between the two types of projects affect PhDs' career? How does this difference manifest itself in the career of PhDs in the private and in the public sectors?

The paper is organised as follows. First, we discuss the evolution of UK academic research policy and the implication for doctoral training. Next, we identify the dimensions that affect academic research training. Furthermore we explore the effects of the identified dimensions on career outcome of PhDs. Conclusions are then drawn from an analysis based on a survey targeting PhD graduates from a UK research-based university.

2 The UK academic research policy and funding source

2.1 Academic research policy

The rise of the research university started in the UK in the 1870s and 1880s and the ability to make original contributions to their subject became an essential criterion for appointing a chair. At that time, research grants were rare and they usually did not come from the state, nor to any large extent from industry, but from college resources at Oxbridge or from individual endowments. The intervention of state policy in university can be traced back only to 1919 when the University Grants Committee (UGC) was funded. However, it was not until 1923 that grants extended to universities outside Oxbridge (Anderson, 2006). Although historically endowments had been the main source of universities' income, since the 1920s, grants from the government had become more and more important, and by 1980, the main source of universities' income was the government. Until the early 1980s, universities in the UK were governed by the academics themselves as self-governed organisations, as UGC only provided gentle guidelines (Høstaker, 2006). Two key factors that led to a re-structuring of UK universities from previous developments are the post-war expansion of higher education and the reforms introduced by Mrs Thatcher's Conservative government beginning in 1979 known as "New Public Management".

After the Second World War, following the Robbins Report[3] of 1963, there was a major expansion of higher education. The Robbins Report was a socio-cultural critique that focused on social class and social mobility to avoid universities being the training ground for the elites (Anderson, 2006). Thus there was a call to expand higher education to open for all those who were qualified (Høstaker, 2006). At the time of the report, there were 31 universities in the UK. By 1992, through the Further and Higher Education Act to upgrade polytechnics, the number of universities was raised to 88 (Anderson, 2006). The number continues to grow. However, as the number of student increased, although expenditure in higher education has been increased since then, the money spent on each student has been actually declining (Bauer and Kogan, 2006).

Another turning point in the UK science and technology policy, which involved administrative reform, is largely associated with Mrs Thatcher's Conservative government that began in 1979. Before that, it was commonly accepted that it was the government's responsibility to procure scientific and technological assistance for public good through public research organisations (Boden et al., 1999). This consensus started to shift in the late 1970s when budgets were squeezed and concerns arose regarding the efficiency of the state. Critics suggested that government should learn from business to run the state more economically, efficiently and effectively. Though the shift in thinking was tangible in the late 1970s, the practice of major reforms took place in the late 1980s and 1990s. This led to the privatisation of various public research organisations and the request for efficiency and accountability across all public sector including universities (Boden et al., 2004, Georghiou, 2001). According to Shattock and Berdahl (1984),

[3] This was produced by the committee on Higher Education appointed by the Prime Minister under the Chairmanship of Lord Robbins 1961-1963.

between 1979 and 1984, the Conservative government brought 11-15% cut in grants in higher education. Meanwhile, the importance of a relationship between university and industry was recognised by the establishment in 1986 of the Council for Industry and Higher Education, sponsored by firms as an independent body, to encourage higher education and industry to work together (Pratt, 1992). Indeed the 1987 white paper in higher education called for closer links with industry and commerce (Department of Education and Science, 1987).

The 1997 Dearing Report [4] revealed that in the past twenty years, the number of students in higher education had doubled, while public funding had increased only 45%. Universities' competition for core funding was fierce. The conclusion was that new sources of income had to be found; part of the burden of the finance must pass to students and universities must seek alternative sources of income in the marketplace (The Dearing Report, 1996). Following the linear model, it was proposed that the distance between academic research and the eventually socially and economically useful knowledge was too long, so that the Dearing Report therefore suggested that higher education institutions should be able to bid for regional sources of funds, should "*be responsive to the needs of local industry and commerce*" (The Dearing Report, 1997, pp. 198), and should "*examine ways of giving firms, especially small and medium sized enterprises, easy and co-ordinated access to information about higher education services in their areas*" (The Dearing Report, 1997, pp. 200). The report also recommended policies designed to help foster entrepreneurship among students and staff in higher education (The Dearing Report, 1997).

By examining the officially defined objectives of the higher education system, the paradigm shift can easily be detected. The current version puts more emphasis on the practical applications of knowledge and its service to national competitiveness and the society. The objectives of higher education system as defined by the 1963 Robbins Report were: 1) "*instruction in skills*", 2) "*to promote the power of mind…*", 3) "*the search for truth…*" and 4) "*the transmission of common culture and common standards*

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

of citizenship" (The Dearing Report, 1997, pp. 71). In contrast, in the 1997 Dearing Report, the objectives have become: 1) "*to enable individuals to develop their capabilities…*", 2) "*to increase knowledge and understanding both for their own sake and for their practical applications*", 3) "*to serve the needs of a knowledge-based economy*" and 4) "*to play a major role in shaping a democratic, civilised and inclusive society*" (The Dearing Report, 1997, pp. 72).

In brief, the administrative and structural reforms in higher education resulted in general shortage of university funding and encouragement for sourcing external funding through the market mechanism. Together with the realisation that academic research could contribute to regional and national competitiveness, the call for universities and academic research to be accountable, to be efficient, to consider user needs, to secure income from other sources and to collaborate with industry to foster knowledge transfer has become formal and institutionalised, through policy statements as well as through government funding mechanism directly.

2.2 Funding source

Unpacking the funding sources of UK academic research reveals further insights into the financial relation among universities, industry and the government in academic research. Statistics shows that the share of industrial funding that contributes to academic research grants and contracts in the UK had actually fallen from 15% in 1988/89 to 8.5% in 2004/05, while the contribution from UK Research Councils, which has been the largest and most prestigious, was steady (26-33%) throughout the period.[5]

The importance of academic research funding from Research Councils can be revealed from the government funding mechanism. After 1981, the University Grant Committee (UGC) abolished the block grant system, which had supported both teaching and research in the universities, and introduced the so-called "dual support" system. The block grant was then split into a core funding supporting teaching and operation of universities, and a research-related funding from Research Councils as reward for research-intensive universities by open competitions based on academic researchers'

[5] Data source from DTI SET Statistics (http://www.dti.gov.uk/files/file38816.xls).

biddings for contracts through panel reviews. The allocation of the core funding is based on the number of students and the performance of the competition based Research Assessment Exercise (RAE), which was introduced in 1985 (Anderson, 2006). Since the introduction of the "dual support" system, the functions of research and teaching in higher education have been officially separated. In 1988 the UGC was replaced by the Universities Funding Council (UFC), and in 1992 the UFC was replaced by the Higher Education Funding Councils (HEFCs). The "dual support" system has been the main funding mechanism for the UK higher education since then (HEFCE website).[6]

The EPSRC (Engineering and Physical Sciences Research Council) is the Research Council that is responsible for grants in engineering and physical sciences in the UK. Compared to the declining share of industrial funding in higher education, EPSRC expenditure on collaborative research grants leading to knowledge transfer was estimated to be £200 million and accounted for 40% of the EPSRC budget in 2006 (Research Council's Evidence for the Economic Impact Group –24 April 2006). In the EPSRC Strategic Plan 2003-2007, a target of 50% of the portfolio was set for collaboration with industry, commerce and the service sector,[7] while in the earlier EPSRC policy statements, knowledge transfer were rarely mentioned explicitly. That same figure (the share of EPSRC funding allocated in university-industry collaboration) just before 2006 was 35% (Lawton Smith, 2006).

Other sources of research grants and contracts include government departments, charities and foreign sources such as the EU. Funding from the EU is one of the fast growing sources and it had grown from less than 5% in 1989/909 to 10% in 1998/99; the figure in 2004/05 was around 8.5%.[8] The EU Seventh Framework Programme (FP7) has announced that the core of the programme would be the Cooperation Programme that accounts for three-fourth of the FP7 and is dedicated to promote consortia between academia and industry.[9] As for the share of UK academic research grants and contracts from charities, although it had grown from 19% in 1988/89 to 24% in 2004/05, the most renowned UK charity - the Welcome Trust that spent £391millions in research grants in

[6] http://www.hefce.ac.uk.
[7] EPSRC website: http://www.epsrc.ac.uk.
[8] Data source from DTI SET Statistics (http://www.dti.gov.uk/files/file38816.xls).
[9] Source from EU community research and development information service website: http://ec.europa.eu/research/fp7/pdf/fp7-inbrief_en.pdf.

2004[10] - is mainly dedicated to biomedical research and is less relevant to physical sciences and engineering.

Indeed, in 2002, in science and engineering, sources of research grants and contracts in higher education institutions were estimated[11] to be 36.9% from DTI-OST (Department of Trade and Industry - Office of Science and Technology[12]) (Research Councils mainly and the EPSRC largely), 9.2% from the EU, 10.8% from industry, 15.4% from government departments, 21.5% from charities and 6.2% from other sources.[13] Based on this estimation, research grants and contracts from the EPSRC and the EU along could account for almost 50% of academic research in science and engineering. Therefore, in these fields, the shift in funding allocation in these organisations could really change the academic research landscape.

The importance of the EPSRC and the EU funding in science and engineering and their patterns of budget allocation indicate that influence of direct industrial funding on academic research is decreasing, while the influence of government and super-national organisations such as the EPSRC and the EU on university-industry collaborations is increasing. As projects require PhD students, the institutionalisation of university-industry linkages imply that the proportion of PhDs who are involved in projects with industrial involvement is likely to be comparable to the proportion of those who are not (as UK home students[14] are less likely to do doctoral studies without financial support from projects). As a result, two equally dominant but different types of academic training - projects without industrial involvement and projects with industrial involvement - are thus possible. Surprisingly, we know extremely little about how industrial involvement affects PhDs' training and career.

3 Impact of university-industry collaborations on academic research

[10] Welcome Trust 2005 annual report; source from Welcome Trust website: http://www.wellcome.ac.uk/stellent/groups/corporatesite/@msh_publishing_group/documents/web_document/wtx028616.pdf.
[11] Figures are synthesised using funding related to research grants and contracts; funding from HEFCs is excluded in that it is used for staff salary and infrastructure mainly.
[12] OST is responsible for science budget allocation in the UK.
[13] Source from EPSRC schemes interface coordinator John Farrow's presentation at the network for water conservation and recycling, December 2002, http://www.watersave.uk.net/Presentations/john%20farrow.ppt; OST was moved to the Department of Innovation, Universities and Skills that was created in 2008.
[14] Includes UK and other EU students.

Universities' industrial collaboration activities comprise direct academic research commercialisation such as university spin-off companies and licensing of university held patents. Alternatively, universities generate income by providing industry with technical consultancy, by conducting contract research commissioned by firms to solve specific technical problems independently, by means of joint research with firms and by the creation of research consortia targeting more general industry related problems so that a whole group of companies/members can benefit from the research outcome. Different goals of collaborative activities involve the generation of different types of knowledge. Perkmann (2008) provided a helpful typology of university-industry collaboration projects. For projects initiated purely by firms, the objectives of such research are generally to “seek a solution to a technical problem arising within a firm’s R&D, manufacturing or other operations”, to “develop design significations or prototypes for new or improved products or processes, or to “provide advice on R&D projects and develop projects pursued within firms”. The objective of “exploring a high-risk concept on behalf of a firm – outside the firm’s main stream activities” is generally initiated by both academia and industry. The objective of generating knowledge in general - “carrying out research on topics of broad interest to a firm”- is often mainly the interest of the academics. It would be meaningful to examine the proportion of university-industry collaboration projects by their objectives to investigate to what extent such projects are mainly industry initiated and to what extent they are initiated by academia. For those initiated by firms, we could expect that they would be more industrially relevant in that the reason for firms to initiate the collaboration is more likely that firms have specific commercial aims to achieve. On the other hand, projects that are initiated by academics are more likely to be based on researchers’ interest in combining their research in an industrial context. The latter category may fall into the research-driven type of academic consulting by Perkmann and Walsh (2008) and is less industrially relevant. On the other hand, (traditional) projects without any industrial involvement are very unlikely to even face such differentiation. Therefore, the first potential impact of industrial involvement on academic research is that the objectives of projects with industrial involvement may be likely to show higher industrial relevance.

Another concern focuses on the possible changing context of academic research profile, or the so-called "skewing problem" (Geuna, 2001). This relates to the concern that research in universities may have been gradually biased towards short-termed applied research. Empirical evidence is divided regarding this. The Norwegian case by Gulbrandsen and Smeby (2005) showed that university professors' industrial funding is related to applied research. However, Behrens and Gray (2001) found no evidence supporting the underlying skewing problem. Nevertheless, the term “applied” research is somehow an ambiguous concept as demonstrated by Stoke (1997), who argued that Pasteur’s type of research could be aiming at application and fundamental understanding at the same time. However, in response to the increasingly institutionalised request for the consideration of user needs and applications in academic research, the degree of applicability of a project becomes crucial. This implies a possible distinction in academic training between projects that are purely driven by curiosity (blue-sky research) and projects that involve a consideration of application. As projects with industrial involvement often require the support or involvement of users, thus the potential second impact of industrial involvement on academic research is that projects with industrial involvement may be likely to exhibit higher degree of applicability.

Moreover, collaboration between university and industry can lead to conflicts. There might be a conflict between the nature of the industrial ethics and that of academic ethics. Kenney (1987) pointed out that industrial ethics and academic ethics are fundamentally different. The objective of business operation is to make a profit; firms seek to maximise the appropriation of any knowledge they generate in order to gain market competence. On the other hand, academic research in science is driven by openness. Therefore, when academic research is involved with industry, academic researchers might be requested by firms to delay scientific publications in order to secure patent applications (Blumenthal et al., 1997; Geuna and Nesta, 2006; Gluck et al., 1987), or to some extent, academic researchers might not be allowed to conduct scientific communication regarding the content of the commissioned research (Gluck et al., 1987). It implies that researchers' publications might potentially be delayed or hindered by industrial contracts and the spirit of open science might be challenged. However empirically, in terms of scientific productivity, Estabrooks et al. (2008), Gulbrandsen and Smeby (2005), Louis et al. (2001), Lowe and Gonzalez-Brambila

(2007) and Van Looy et al. (2004) reported that academics that receive industrial funding are as productive as or even more productive than those who do not.

Given the divided outcome regarding scientific productivity between theoretical reasoning and empirical findings, a potential answer is what Perkmann and Walsh (2008) proposed in their conceptual framework: different types of academic consulting may be likely to result in different impact on scientific productivity; opportunity-driven consulting may be likely to have a negative impact, while research-driven consulting may be likely to have a positive impact. This proposition implies heterogeneity in scientific productivity within university-industry collaborations and leads to an expectation of different levels of scientific productivity in different types of university-industry collaborations. This raises attention to the types of industrial involvement, rather than whether the projects involve industry, when considering the third potential impact, that on scientific productivity, of industrial involvement on academic research projects.

4 The impact on the career of PhDs

For projects with industrial involvement, PhD candidates may report to supervisors from both academia and industry. This suggests that these PhDs will have earlier chances to build networks within industry than their counterparts working on projects without academic involvement and therefore gain an advantage, particularly if they intend to enter the private sector (because of earlier industrial contacts). Indeed, based on in-depth interviews, Lam (2007) demonstrated how private firms access strategically the young bright candidates through collaborations with academia. Thus, the fourth potential impact of industrial involvement on academic research is that training through projects with industrial involvement provides PhDs earlier industrial contact, while training through projects without industrial involvement provides little such contact.

Based on early career stage outcome evidence, academic training through projects with industrial involvement seems to have positive impact on French PhDs. Giret and Recotillet (2004) assessed the impact of the French CIFRE (Industrial Agreement for Training Through Research) programme on the salary of the 1996 PhD graduates. They found that three years after graduation, those who were sponsored by the programme received higher pay, particularly in industry. Robin and Cahuzac (2003) used duration analysis modelling determinants of getting first permanent positions by following French PhDs in life science (who completed their PhDs between 1984 and 1997) 5 years after they completed their PhDs (time to first permanent positions). They found that academic training through projects with industrial involvement increases the propensity of getting permanent positions in the private sector. Martinelli (1999) (using descriptive data) also reported that French PhDs who were sponsored by this programme not only got higher pay, but were also more likely to get permanent positions and less likely to be unemployed. Mangematin (2000) applied a multinomial logistic model to analyse the determinants affecting French PhDs' job positions at the time of survey (1997), based on a French survey of 399 PhD candidates graduated between 1984 and 1996. The study indicated that compared to those who are not industrially-sponsored, those who are industrially-sponsored are more likely to be in permanent positions in the private sector (rather than in permanent positions in academia). This implies that in the current climate that exhibits difficulty in securing permanent academic positions, doing projects with industry may help PhDs obtain permanent positions in the private sector.

Even if we assume that such career advantage is universal, we do not know exactly which aspect of university-industry collaborations contributes to the career advantage of the PhDs and whether the advantage holds also for the public sector such as universities and public/non-profit organisations. Our proposition is that PhDs who are involved in traditional research projects and those who are involved in research projects with industrial involvement are provided with different kinds of academic research training in terms of objective, applicability, scientific productivity and social network. Consequently, they leave universities with different skills for their career. Based on this proposition, the impact of these four potential dimensions that are related to industrial involvement on the career of PhDs can be assessed and thus specific aspects of university-industry collaborations that contribute to the career advantage of PhDs in both the private and the public sectors can be identified.

5 Data source and analysing methods

The research setting is a UK research-based university, the University of Manchester. The University of Manchester provides an ideal research setting for this study for the following reasons. First, it 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 of samples from well-presented engineering and physical science disciplines. Second, it is among the top universities in the UK in attracting industrial funding, government funding, EU funding and the highly privileged EPSRC funding (around 26% of the University's total income in 2007/2008 is from contract research). Its high dependence on contract research means the shift in funding rationale should be well reflected in its faculty members' research profiles. Third, it is one of the leading research universities in the UK (ranked as the third place in the 2008 UK research assessment in terms of the number of full-time equivalent staffs that are judged to be "world leading" or "internationally excellent").[15] Its leading position in research means that it is in the centre of the on-going debate in the changing context of science and makes itself an excellent example to examine the impact of industrial involvement. A survey on PhD training and retrospective employment history (covering 7-10 years employment history) was conducted between April and July 2008. The sampling frame is a list of PhD graduates awarded during the period 1998-2001 by the University of Manchester in science and engineering disciplines with UK and other EU addresses. The advantages of using such sampling frame are:

1. Each PhD represents a research project. When we analyse PhD's projects, we are using each "project" as an analysing unit. Attributes of projects associated with university-industry collaborations could thus be measured directly. This measure is an advantage in analysing attributes of university-industry collaborations when compared to other studies that use measures such as the individual academic as an analysing unit, as an individual academic could be involved in funding from various sources at the same time.

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

2. By tracing the life career of PhDs, we can conduct a longitudinal analysis of how doing projects with industrial involvement affects PhDs' career. This analysing method is far powerful than cross-sectional analysis.

The survey was conducted by post and a total of 512 questionnaires were sent to UK addresses and 84 to other EU addresses through the help of the alumni office. A self-addressed return envelope with a stamp was provided for each UK address and without a stamp for each other EU address. The strategy for using the survey method, rather than interviews, was based on the fact that after the UK 1998 Data Protection Act, direct contact between the researchers and the alumni is not possible. A total of 91 UK and 11 other EU responses were obtained. There were 38 UK and 7 other EU undelivered returned questionnaires. The estimated response rate is 19.20% for UK addresses and 15.3% for other EU addresses. The overall response rate is 18.51%. The response rate is comparable to Zellner's (2003) survey that achieved a 16.4% response rate from PhDs who had left the Max Plank Society in Germany for 8-11 years. However, the exact response rate should be higher; these PhD graduates have left the University for 7-10 years and, as young people are particularly mobile, many of these PhD graduates probably have never received the questionnaires.

After 1 UK and 1 EU responses that fall out of the 1998 to 2001 graduation criterion are excluded, finally 100 responses are used for the analysis. The distribution of our respondents in terms of whether their projects involve industry is 50:50. The distributions of the characteristics of our respondents are illustrated in Table 1. Although the number of respondents (100) does not seem to be high, the data we collected were sufficient for longitudinal analysis in that our data are event history data. It means that every single respondent provided us with 7-10 years job history (definition of a job see Appendix 1). That is to say, 630-900 set of year – job history data have been achieved.

Table 1: Distribution of respondents in terms of year of graduation, gender, and current working sectors

Year of graduation		Gender		Industry involvement in project		2008 working sector	
1998	22%	Male	75%	Yes	50%	Industry	49%
1999	22%	Female	25%	No	50%	Government/public/non-profit organisation	14%
2000	30%					University	25%
2001	26%					Company owner/self-employed	6%
						Unemployed/looking after family	6%

For each year, information about whether the respondent got promoted was given. Questions about each respondent's PhD project and training (how close to application, objective of PhD project, number of journal publications and patents, industrial placement and meetings with/presentations to industry, etc.) were asked. Demographic information such as gender, age, and PhD subject area was also included in the questionnaire.

The impact of industrial involvement on academic research is assessed by using the chi-square tests for independence. The impact of industrial involvement on career of our respondents is evaluated by using event-history analysis. Models assessed are multinomial logistic models and Cox models with latent survivor time approach (Box-Steffensmeier and Jones, 2004). The analysing tool is STATA® 10.

6 Findings

6.1 Industrial involvement leads to projects with higher industrial relevance

Descriptive data analysis shows that three-fifth of projects with industrial involvement focus on activities in either "seeking a solution to a specific technical problem identified within a firm's or a group of firms' operations" or in "developing design specifications or prototypes for new or improved industrial products or processes". On the other hand, traditional projects mainly involve "generating knowledge on topics of broad interest to PhD subject area". Projects with the goal of "exploring a high-risk concept identified by a firm or a group of firms – outside the firms' mainstream activities" are very rare (only three cases) (Figure 1). The first two categories (“seeking a solution….” and “developing design…”) can be regarded as objectives with direct industrial relevance, while the latter two categories (“exploring a high-risk concept…” and “generating knowledge…”) are more distant from the market and have low industrial relevance. After the first two and the latter two categories are collapsed into two categories, a chi-square test for independence shows that projects with industrial involvement are significantly associated with seeking solutions within firms’ operation or developing designs/prototypes for new/existing products/processes (direct industrial relevance). On the other hand, (traditional) projects without industrial involvement are significantly associated with generating knowledge in general (low industrial relevance) (Table 2).

Figure 1: Distribution of types of objectives of PhD projects by industrial involvement

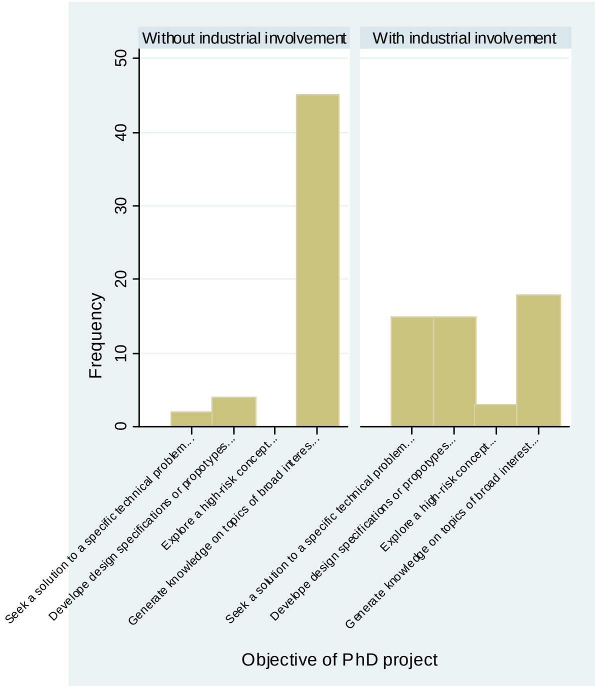


Table 2: Chi-square test for independence: "industrial involvement in project" and "industrial relevance" – after collapsing "objective of PhD project" into two categories

			Industrial involvement in project		Total
			No	Yes	
Industrial relevance	Seeking a solution to a specific technical problem identified within a firm's or a group of firms' operations Developing design specifications or prototypes for new or improved industrial products or processes	Direct	6	30	36
	Exploring a high-risk concept identified by a firm or a group of firms – outside the firms' mainstream activities Generating knowledge on topics of broad interest to PhD subject area	Low	44	20	64
Total			50	50	100

Pearson chi-Square Test p=0.000

6.2 Industrial involvement leads to projects with higher degree of applicability

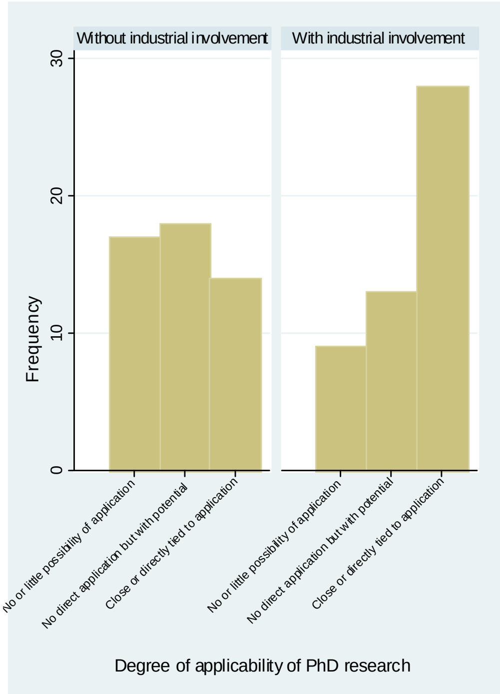
In order to address the degree of applicability of PhD projects, we ask respondents: "In the context of your subject area, how would you rate your PhD research? Please give a score from 1 to 5 (1 = the least close to application; 5 = the most close to application)". Answers given are: 1) not at all linked to application, 2) small possibility of application, 3) not directly tied to but with potential, 4) close to application and 5) directly tied to application. A chi-square test for independence indicates that industrial projects are positively associated with the degree of applicability (Table 3; Figure 2).

Table 3: Chi-square test for independence: "industrial involvement in project" and "degree of applicability of project"

		Industrial involvement in project		Total
		No	Yes	
Degree of applicability of project	None or little possibility of application	17	9	27
	Not directly tied to but with potential for application	18	13	31
	Close or directly tied to application	14	28	42
Total		49	50	99

Pearson chi-square test p=0.019

Figure 2: Distribution of degree of applicability of PhD projects by industrial involvement



6.3 Industrial involvement has no effect on scientific productivity at the aggregate level, but different types of industrial involvement result in different levels of scientific productivity

Comparing the mean number of publications, our figures suggest that projects without industrial involvement and projects with industrial involvement have the same scientific productivity (Table 4). The standard deviation for projects with industrial involvement is greater. This indicates that such projects are more likely to be either very productive or very unproductive (Figure 3); in particular, there is one respondent who worked on a project with industrial involvement exploring a high-risk concept that reports 10 journal publications resulting from the project. Statically, a chi-square test for independence indicates that the number of journal publications is not correlated with whether a project has industry involvement or not (Table 5). That is, projects with industrial involvement are as productive as projects without industrial involvement.

Table 4: The mean of the number of journal publications resulting from PhD by industrial involvement

	Mean	N	Std. Dev.
Project without industrial involvement	2.388	49	1.777
Project with industrial involvement	2.280	50	2.348
Total	2.333	99	2.075

Figure 3: Distribution of the number of journal publications resulting from PhD projects by industrial involvement

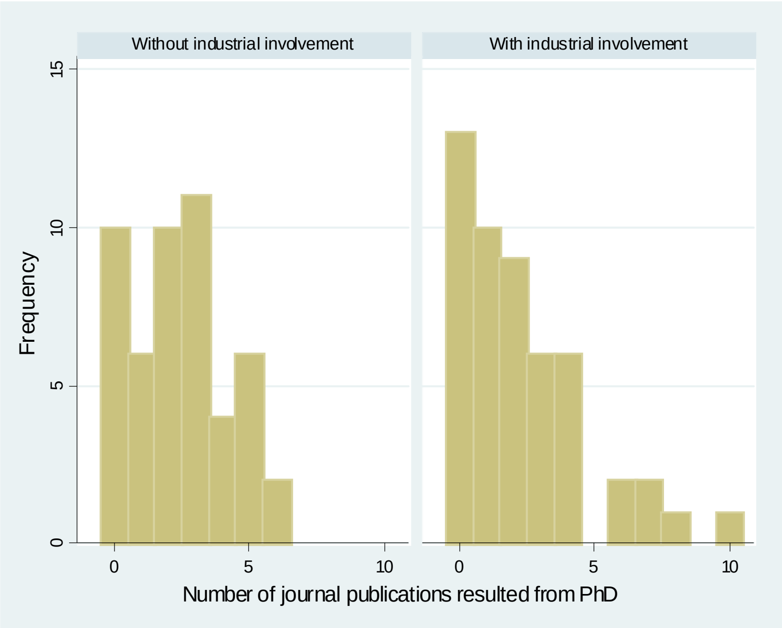


Table 5: Chi-square test for independence assessing the impact of industrial involvement on scientific productivity

		Industrial involvement in project		
		No	Yes	Total
The number of journal publications	0	10	13	23
	1~3	27	25	16
	>= 4	12	12	24
Total		49	50	99

Pearson chi-square test p=0.795

However, following Perkmann and Walsh's (2008) argument that different types of university-industry collaborations are likely to have different impact on scientific productivity, we assess the impact of different types of projects with industrial involvement in terms of degree of industrial relevance (defined by objective of research project) and degree of applicability. The analysis focuses only on projects with industrial involvement, but tries to identify the impact of different types of industrial involvement. Results show that for projects with industrial involvement, it seems that whether they are close to or directly tied to application or not has little effect on scientific productivity (however, for variable "degree of applicability", the two categories other than "close or directly tied to application" have to be collapsed together, as the cases in the category "none or little possibility of application" are too few to conduct a valid chi-square test for independence), but the objective of research indeed results in different levels of scientific productivity. It seems that the types of problem-solving required for specific technical problems or of developing particular specifications for firms result in fewer publications (Table 6).

6.4 Industrial involvement leads to earlier industrial contact

We ask respondents whether they had any industrial placement in industry, presentation to industry or meeting with industry. We also ask whether their labs had any connections with industry and whether they used such contacts to get their first jobs. 71% of our respondents reported that their labs had some sort of connection with industry; it implies that half of the PhDs with projects without industrial involvement worked in the labs where their supervisors conducted other work with industry. 6 cases from projects with industrial involvement and 3 from projects without industrial involvement reported that they used the connection that their labs had to obtain their first jobs. This indicates that as long as the labs have industrial contacts, it does not matter whether the PhDs' projects have industrial involvement or not; the possibility for them to obtain their jobs through those contacts is roughly the same. Indirect factors that contribute to the social network dimension of academic training that involves industry are the intensity of industrial placement and meetings with/presentations to industry. Although these factors are indirect to securing first jobs, they provide the opportunity for them to familiarise themselves with the industrial environment and working mechanisms. They might benefit not only someone who wishes to enter the private sector, but also someone wishing to obtain an academic position given that collaboration with industry is encouraged and thus familiarity with industrial environment and working mechanisms could be an advantage. Our data show that PhDs with projects with industrial involvement obviously involve more industrial contact (meetings, presentations and placement) during their study (Figure 4; Figure 5; Table 7), and here industrial contact refers to familiarity with industrial working environment and understanding of industrially-relevant skills such as presentation and communication, rather than securing first jobs through personal contact with PhDs' industrial partners.

Table 6: Chi-square tests for independence assessing the impact of different types of industrial involvement on scientific productivity

Assessing the impact of degree of industrial relevance				
		Degree of industrial relevance		
		Direct Seeking a solution to a specific technical problem identified within a firm's or a group of firms' operations Developing design specifications or prototypes for new or improved industrial products or processes	Low Exploring a high-risk concept identified by a firm or a group of firms – outside the firms' mainstream activities Generating knowledge on topics of broad interest to PhD subject area	Total
The number of journal publications	0	7	6	13
	1~3	19	6	25
	>= 4	4	8	12
Total		30	20	50
Pearson chi-square test *p*=0.040				

Assessing the impact of degree of applicability					
		Degree of industrial relevance			
		None or little possibility of application	Not directly tied to but with potential for application	Close or directly tied to application	Total
The number of journal publications	0	6		7	13
	1~3	12		13	25
	>= 4	4		8	12
Total		22		28	50
Pearson chi-square test *p*=0.690					

Figure 4: Months spent in industrial placement by industrial involvement

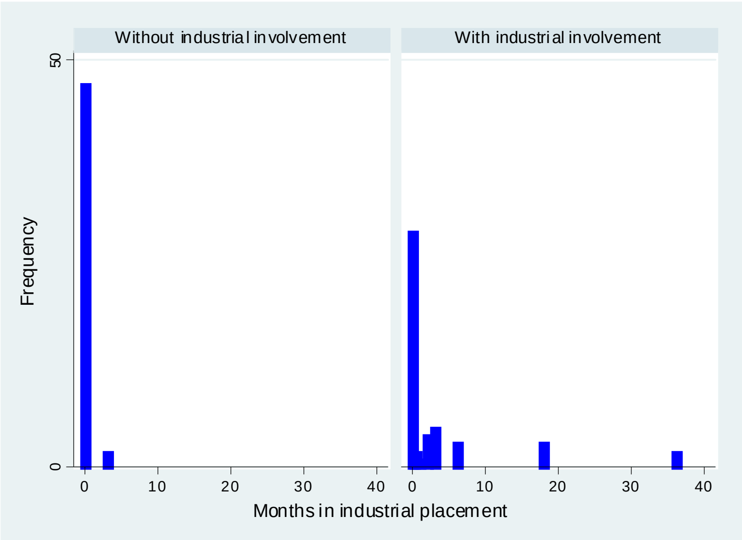


Figure 5: The number of meetings with/presentations to industry by industrial involvement

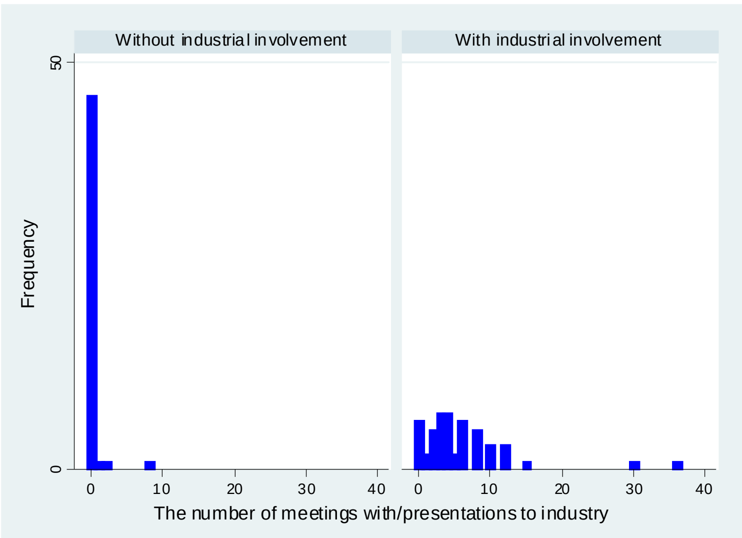


Table 7: Chi-square test for independence: "industrial involvement in project" and "industrial contact"

		Industrial involvement in project		Total
		No	Yes	
Industrial contact	Yes	46	5	51
	No	3	44	47
Total		49	49	98

Pearson chi-square test p=0.000

6.5 The importance of industrial contact in the private sector and continuing value attached to scientific productivity in the public sector

Previously we identified the potential impact of industrial involvement on academic research training. In this section we introduce an indicator, the propensity for promotion, as a proxy for career outcome and determinants (derived from dimensions that are related to industrial involvement) that might affect career outcome, assessed by using two types of competing risks models, multinomial logistic models (model 1-4) and Cox models with latent survivor time approach (models 5-12), within the framework of event-history analysis.[16] The analysis is limited to the cases in paid jobs. Job histories are coded year by year (it is suitable in that it is unlikely for an individual to have more than one promotion in one year). For the multinomial logistic models, the dependent variable is type of promotion in a given year. The independent variables are the four dimensions related to industrial involvement discussed earlier: objective of PhD project, degree of applicability of PhD project, the number of journal publications and industrial contact; control variables used include female (as opposite to male), engineering disciplines (as opposite to physical science) and UK addresses (as opposite to other EU addresses). For the Cox models, censoring variable is type of promotion in a given year. The models measure the relative propensity for reoccurrence of promotion within the observed period. The coding scheme for variables used is shown in Table 8.

[16] The assumption made in this analysing approach is that all events are independent from each other

The correlation matrix for the data is shown in Appendix 3.1. The final result of the tested models is shown in Table 9.

The result indicates that with regard to the relevance of doctoral training with or without industrial involvement, in the private sector, the dimension that affects the propensity for promotion is industrial contact built during PhD training; industrial contact built during PhD training increase the propensity for promotion in the private sector. On the other hand, in the public sector, the number of publications enhances promotion. Whether academic training is close to application or highly industrially relevant does not seem to affect promotion both in the private sector and in the public sector. However, although the number of publications is not directly affected by projects with or without industrial involvement, for projects with industrial involvement, different levels of industrial relevance result in different levels of scientific productivity. Projects with direct industrial relevance that aims at solving specific technical problems or developing specifications for firms produce fewer scientific publications. Therefore, there is a hint that points to the possibility that industrially related academic training that is highly industrially relevant might result in lower scientific productivity and consequently affect career outcome in the public sector. This problem is expected to be marginal for traditional projects where there is no industrial involvement at all, as only 12% (6 out of 50 cases) are identified to be directly relevant to industry, compared to 60% (30 out of 50 cases) for projects with industrial involvement (Table 2). The different success factors in the private and the public sectors indicate that the career reward system held in the private sector and the public sector are distinctly different and the traditional norms are still held in both sectors – social networking for the private sector and scientific productivity for the public sector.

Control variables show that there is no difference in promotion propensity in terms of whether the respondents were from engineering or physical science disciplines, or with UK or other EU addresses. However, it seems that the "glass ceiling" problem exists for female participants in the private sector, as documented in literature (Elliott and Parcel, 1996; Loprest, 1992).

Table 8: The coding scheme for variables

Dependent/Censoring variable	**Initial category**	**Final category**	**Coding**
Type of promotion in a given year	No promotion		0
	Promotion in the public sector		1
	Promotion in the private sector		2
Independent variable	**Initial category**	**Final category**	**Coding**
Industrial relevance	Seeking a solution to a specific technical problem identified within a firm's or a group of firms' operations	With direct industrial relevance	1
	Developing design specifications or prototypes for new or improved industrial products or processes		
	Exploring a high-risk concept identified by a firm or a group of firms – outside the firms' mainstream activities	With low industrial relevance	0
	Generating knowledge on topics of broad interest to PhD subject area		
Degree of applicability	Not at all linked to application	Little or no application	0
	Small possibility of application		
	Not directly tied to but with potential	No direct application but with potential	1
	Close to application	Close or directly tied to application	2
	Directly tied to application		
Paper	The number of journal publications; interval variable		
Industrial contact	With any presentation to/meeting with industry or industrial placement during PhD		1
	Without any presentation to/meeting with industry or industrial placement during PhD		0
Control variable	**Initial category**	**Final category**	**Coding**
Female	Female		1
	Male		0
Engineering	Engineering disciplines		1
	Physical science		0
UK	UK addresses		1
	Other EU addresses		0

Table 9: Models of recurrence of promotions of former PhDs (1998-2001) in science and engineering disciplines from the University of Manchester, from first year in employment after PhD award to 2008

	Multinomial logistic				Cox models with latent survivor time approach			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 7**	**Model 9**	**Model 11**
Promotion in the public sector								
Industrial relevance				1.208 (0.805)				1.077 (0.713)
Degree of applicability								
No direct application but with potential			1.126 (0.668)	1.128 (0.666)			1.188 (0.664)	1.188 (0.664)
Close or direct tired to application			2.188 (1.131)	2.101 (1.413)			2.597* (1.450)	2.555 (1.616)
Paper		1.213* (0.126)	1.277** (0.137)	1.287** (0.147)		1.231** (0.127)	1.299** (0.133)	1.302** (0.139)
Industrial contact	0.637 (0.285)	0.501 (0.237)	0.295** (0.155)	0.272** (0.137)	0.626 (0.273)	0.476 (0.223)	0.252*** (0.133)	0.243*** (0.121)
Female	2.851** (1.351)	2.738** (1.283)	2.209* (1.057)	2.187 (1.076)	2.951** (1.356)	2.698** (1.234)	2.111* (0.930)	2.099 (0.967)
Engineering	0.678 (0.308)	0.692 (0.287)	0.611 (0.249)	0.585 (0.247)	0.702 (0.302)	0.721 (0.277)	0.583 (0.226)	0.572 (0.239)
UK	0.416 (0.282)	0.464 (0.326)	0.417 (0.292)	0.410 (0.283)	0.368* (0.218)	0.407 (0.247)	0.349* (0.214)	0.346* (0.208)
N					805	796	787	787
Log-likelihood					-233.556	-229.102	-206.627	-206.615
					Model 6	**Model 8**	**Model 10**	**Model 12**
Promotion in the private sector								
Industrial relevance				1.062 (0.317)				0.872 (0.271)
Degree of applicability								
No direct application but with potential			1.202 (0.517)	1.195 (0.516)			1.190 (0.515)	1.202 (0.520)
Close or direct tired to application			1.343 (0.535)	1.335 (0.534)			1.728 (0.740)	1.744 (0.730)
Paper		0.880* (0.065)	0.882* (0.067)	0.883 (0.068)		0.865** (0.060)		
$Paper^2$							0.974* (0.013)	0.973** (0.013)
Industrial contact	2.081** (0.659)	2.069** (0.635)	1.918** (0.599)	1.868* (0.611)	2.115** (0.679)	2.164** (0.698)	1.854** (0.574)	1.988** (0.674)
Female	0.311*** (0.132)	0.319*** (0.137)	0.338** (0.143)	0.337*** (0.141)	0.342*** (0.141)	0.373** (0.156)	0.388** (0.160)	0.389** (0.162)
Engineering	0.899 (0.297)	0.860 (0.275)	0.824 (0.270)	0.813 (0.261)	1.015 (0.325)	0.967 (0.305)	0.818 (0.279)	0.842 (0.283)
UK	1.636 (1.090)	1.534 (0.991)	1.570 (1.024)	1.552 (1.024)	1.313 (0.743)	1.304 (0.749)	1.317 (0.713)	1.346 (0.751)
N	800	791	782	782	805	796	787	787
Log-likelihood	-358.398	-351.971	-339.719	-339.625	-325.894	-323.333	-321.670	-321.575

Note: (1) * *p*<0.10; ** *p*<0.05; *** *p*<0.01; Robust standard errors are given in parentheses. (2) The reference category of the dependent variable in the multinomial logistic model is "no promotion". (3) Individual and global tests of the Schoenfeld residuals indicate that the proportional hazard assumption for all individual variables and for the Cox models is held (threshold=0.05). (4) Cox-Snell residual plots to test goodness of fit for the Cox models are shown in Appendix Figure 3.2 to 3.9.

7 Discussion and conclusions

This paper has examined the impact of industrial involvement on academic research projects and the effect of such impact on career of PhDs. The results show firstly that academic research projects with industrial involvement are positively associated with projects with higher level of industrial relevance, higher degree of applicability and earlier industrial contact for PhDs. Although industrial involvement has no effect on scientific productivity, as shown in the existing literature, however, there is a hint that scientific productivity might be affected by the objectives or by the types of university-industry collaborations.

Second, in line with the existing studies for the French cases, we find that doing projects with industrial involvement indeed helps career progression in the private sector. Furthermore, the specific dimension that eventually contributes to PhDs' later career outcome in terms of promotion in the private sector is industrial contact. Although the result is also in line with Lam's (2007) observation that firms recruit talent strategically through interaction with universities, however we find that the interface that firms use to recruit the talent is not directly through sponsored projects. Rather, they keep contact with labs and academic supervisors, and the young bright candidates then are recommended to the firms through such contact regardless of whether the students conducted projects for them or not. A more direct contribution to career outcome in the private sector through projects with industrial involvement is earlier familiarity with the industrial environment (industrial placement, meetings and presentations). Students with such experience enjoy almost double the chance for promotion. Nevertheless, this advantage does not work in the public sector.

Third, interestingly, the dimensions that are central to the debate about the shifting context of research towards application and industrial relevance do not seem to be directly relevant to PhDs' career progression, whether regarding employment in firms, public/non-profit organisations or universities. It appears that it does not really matter whether a PhD student did a project with a high level of industrial relevance with great potential for industrial application or one with low level of industrial relevance and no foreseeable industrial application; the person's promotion opportunity is not affected. It seems that the PhD qualification warrantees a certain level of capability and such capability is unrelated to the content of projects. Only when strict research capability is required for jobs such as academic positions, the selection criterion based on a more objective indicator - the number of scientific journal publications - matters. Indeed, a unit increase in the number of journal publications increases by almost 30% the chance of promotion in the public sector. The reward system in the public sector thus is still in line with the universalistic norms of Merton (1973), which emphasises that professional recognition and rewards are given to those who are the most able or productive or demonstrate the most significant contribution to their fields. A crucial possibility derived from the research is that scientific productivity might be hindered by industrial involvement that aims at solving specific technical problems or developing technical specifications for firms. This implies that PhD students who wish to pursue academic careers but choose such types of projects might be disadvantaged.

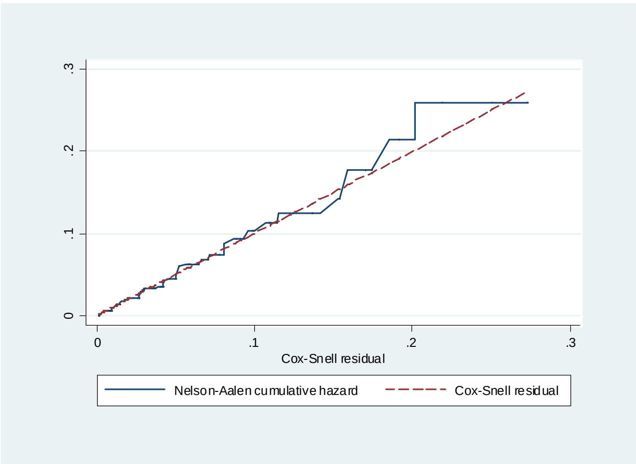
Hence, as industrial placement and meetings with or presentations to industry during PhD academic training are mainly provided by projects with industrial involvement and since it affects promotion in the private sector, and as scientific productivity might be affected by the types of university-industry collaborations and since it is a major indicator for progress in the public sector, particularly in academia, PhD students who intend to pursue a career in the private sector or in the public sector need to pay special attention of the choice of projects that will provide them with different sets of competences for their career.

Finally, the inferences and implications in this research are drawn from the case of the University of Manchester only. A further larger scale investigation is welcome. Besides, we investigate only students from engineering and physical sciences; it is possible that a study of students in biomedicine or life sciences might result in different patterns. Furthermore, the proxy used for career outcome considers only the propensity for promotion. Subjective considerations such as job expectations and satisfaction are not captured in this paper.

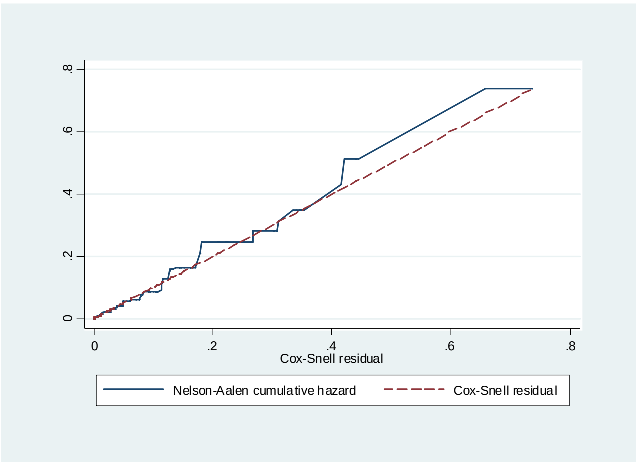
Appendix Table 3.1: The correlation matrix for the data

	Industrial relevance	Degree of applicability	Paper	Industrial contact	Female	Engineering	UK
Industrial relevance	1.000						
Degree of applicability	0.341	1.000					
Paper	-0.115	0.040	1.000				
Industrial contact	0.490	0.371	0.115	1.000			
Female	-0.013	-0.011	0.085	-0.017	1.000		
Engineering	0.231	0.227	-0.039	0.093	-0.206	1.000	
UK	0.080	-0.057	-0.041	-0.002	0.173	-0.173	1.000

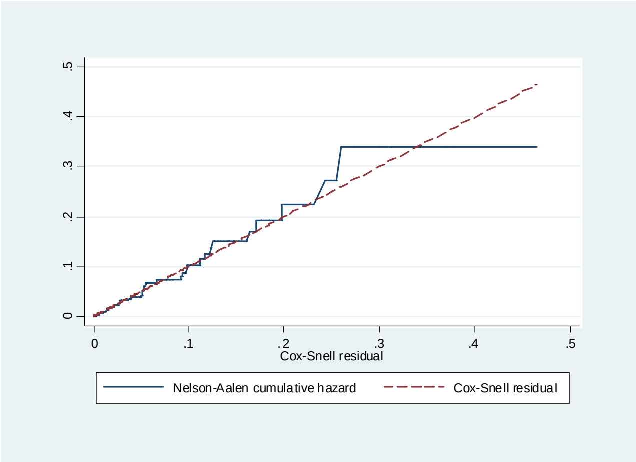
Appendix Figure 3.2: Cox-Snell residual plot for Model 5



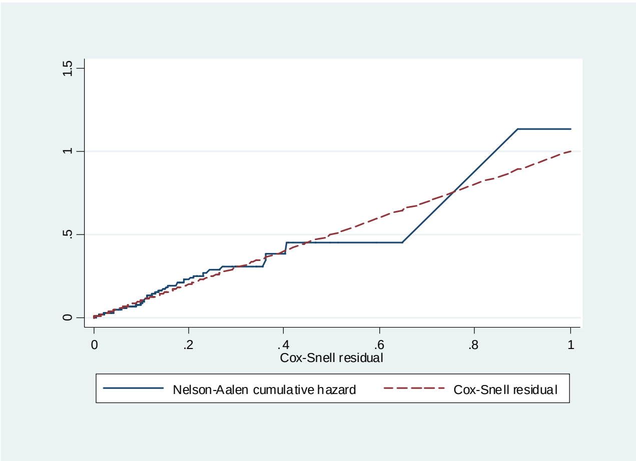
Appendix Figure 3.3: Cox-Snell residual plot for Model 6



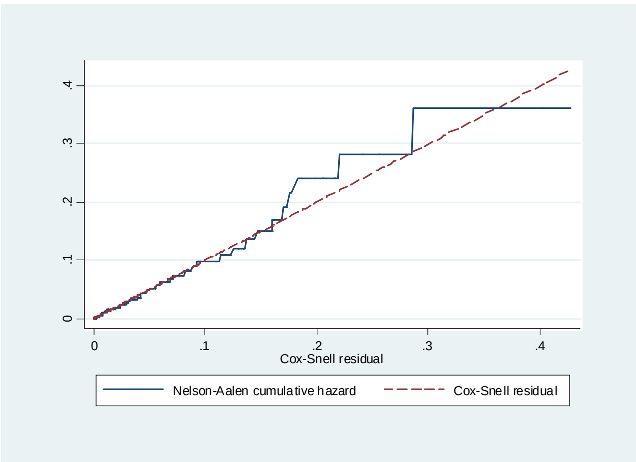
Appendix Figure 3.4: Cox-Snell residual plot for Model 7



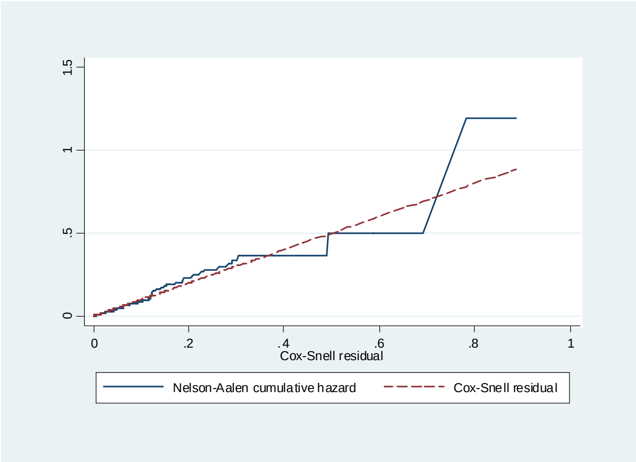
Appendix Figure 3.5: Cox-Snell residual plot for Model 8



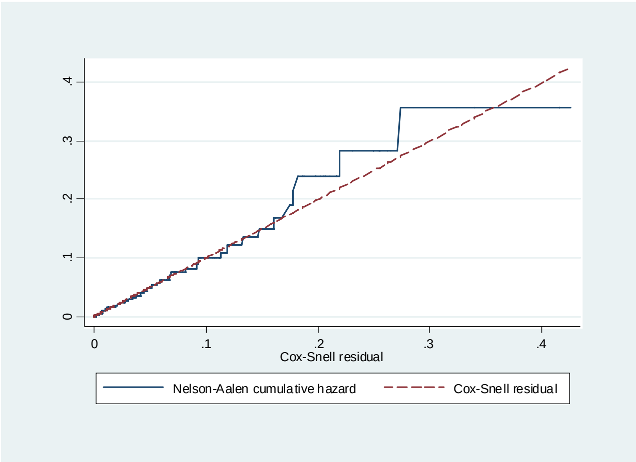
Appendix Figure 3.6: Cox-Snell residual plot for Model 9



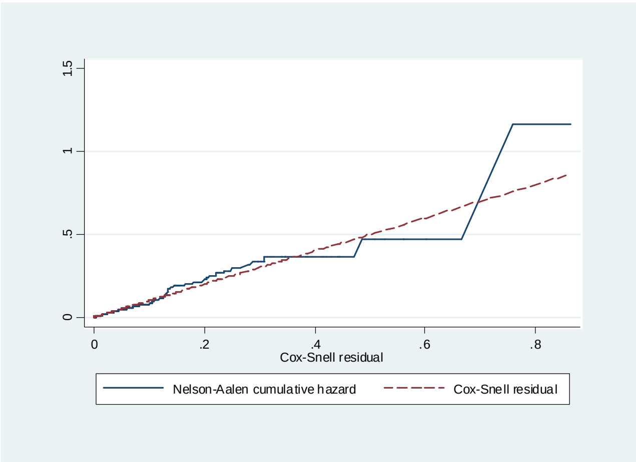
Appendix Figure 3.7: Cox-Snell residual plot for Model 10



Appendix Figure 3.8: Cox-Snell residual plot for Model 11



Appendix Figure 3.9: Cox-Snell residual plot for Model 12



Appendix Table 4: Relative perceived usefulness of "general knowledge in PhD subject areas" between technical positions in private sector manufacturing and employment outside the conventional technical occupations.

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

N observations: 185

Notes:

(a) Comparison uses technical positions in private sector manufacturing as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as "among the three most valuable types of PhD knowledge/skills in a job" rather than not been selected at all by the two labour market segments using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Appendix Table 5: Relative perceived usefulness of PhD competences between stayers [(a)] and movers [(b)] in academic/public research

		The linearised method	
		Odds ratio[(d)]	90% CI
Specialist knowledge in PhD topic	Movers	1.201	0.300-4.811
	Engineering	1.064	0.341-3.321
General knowledge in PhD subject area	Movers	0.841	0.236-2.995
	Engineering	0.845	0.254-2.811
Application of information technology and data processing	Movers	0.447	0.062-3.235
	Engineering	0.669	0.163-2.744
General analytical skills	Movers	5.080	1.198-21.545
	Engineering	0.741	0.207-2.655
Report writing and presentation skills	Movers	0.261	0.067-1.014
	Engineering	3.092*	1.077-8.874
Project management skills	Movers	-- (c)	--
	Engineering	0.564	0.114-2.782
Problem solving capability	Movers	2.394	0.607-9.448
	Engineering	0.990	0.292-3.357
N observations: 73			

Notes:

(a) Stayers refer to those who have always been in academic/public research; (b) Movers refer to those who moved out of academic/public research to employment outside the conventional technical occupations; (c) Not a single mover perceived project management skills from doctoral training to be useful in a job; (d) Comparison uses stayers as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as "among the three most valuable types of PhD knowledge/skills in a job" rather than not been selected at all by stayers and movers using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Appendix Table 6: Relative perceived usefulness of PhD competences between stayers [(a)] and movers [(b)] in technical positions in private sector manufacturing

		The linearised method	
		Odds ratio[(c)]	90% CI
Specialist knowledge in PhD topic	Movers	1.292	0.209-7.961
	Engineering	2.330	1.842-5.802
General knowledge in PhD subject area	Movers	1.033	0.184-5.802
	Engineering	2.568**	0.613-10.766
Application of information technology and data processing	Movers	0.689	0.082-5.803
	Engineering	6.460**	1.801-23.179
General analytical skills	Movers	1.112	0.205-6.033
	Engineering	1.068	0.240-4.750
Report writing and presentation skills	Movers	1.868	0.367-9.518
	Engineering	0.341	0.068-1.712
Project management skills	Movers	0.206	0.032-1.324
	Engineering	0.137*	0.030-0.652
Problem solving capability	Movers	1.969	0.324-11.957
	Engineering	0.567	0.104-3.083
N observations: 38			

Notes:

(a) Stayers refer to those who have always been in technical positions in private sector manufacturing; (b) Movers refer to those who moved out of technical positions in private sector manufacturing to employment outside the conventional technical occupations; (c) Comparison uses stayers as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as "among the three most valuable types of PhD knowledge/skills in a job" rather than not been selected at all by stayers and movers using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Appendix Table 7: Relative perceived usefulness of PhD competences between stayers [(a)] and movers [(b)] in employment outside the conventional technical occupations

		The linearised method	
		Odds ratio[(c)]	90% CI
Specialist knowledge in PhD topic	Movers	0.542	0.117-2.503
	Engineering	1.231	0.181-8.390
General knowledge in PhD subject area	Movers	2.805	0.951-8.272
	Engineering	2.113	0.544-8.212
Application of information technology and data processing	Movers	0.794	0.244-2.588
	Engineering	1.117	0.359-3.477
General analytical skills	Movers	0.435	0.166-1.140
	Engineering	1.585	0.576-4.345
Report writing and presentation skills	Movers	1.157	0.436-3.071
	Engineering	0.248**	0.093-0.664
Project management skills	Movers	2.185	0.859-5.558
	Engineering	1.169	0.475-2.880
Problem solving capability	Movers	0.605	0.231-1.588
	Engineering	0.977	0.196-4.874
N observations: 124			

Notes:

(a) Stayers refer to those who have always been in employment outside the conventional technical occupations; (b) Movers refer to those who moved into employment outside the conventional technical occupations; (c) Comparison uses stayers as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as “among the three most valuable types of PhD knowledge/skills in a job” rather than not been selected at all by stayers and movers using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester’s 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Appendix Table 8: Relative perceived usefulness of PhD competences between dedicated managers and academic/public research

		The linearised method	
		Odds ratio[(a)]	90% CI
Specialist knowledge in PhD topic	Career type		
	Dedicated managers	0.030***	0.007-0.124
	Engineering	3.466*	1.087-11.045
General knowledge in PhD subject area	Career type		
	Dedicated managers	0.104***	0.408-0.263
	Engineering	1.176	0.435-3.174
General analytical skills	Career type		
	Dedicated managers	2.589*	1.007-7.081
	Engineering	1.142	0.450-2.898
Project management skills	Career type		
	Dedicated managers	43.276***	12.734-147.072
	Engineering	0.294	0.082-1.058
Problem solving capability	Career type		
	Dedicated managers	3.438**	1.367-8.649
	Engineering	0.622	0.242-1.597

Notes:

(a) Comparison uses academic/public research as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as “among the three most valuable types of PhD knowledge/skills in a job” rather than not been selected at all by labour market segments using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester’s 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Appendix Table 9: Relative perceived usefulness of PhD competences between technical positions in services and consultants and academic/public research

		The linearised method	
		Odds ratio[(a)]	90% CI
Specialist knowledge in PhD topic	Career type		
	Technical positions in services and consultants	0.109***	0.040-0.298
	Engineering	2.143	0.784-5.862
General knowledge in PhD subject area	Career type		
	Technical positions in services and consultants	0.200***	0.083-0.483
	Engineering	2.000	0.848-4.718
General analytical skills	Career type		
	Technical positions in services and consultants	2.381*	1.063-5.333
	Engineering	0.927	0.380-2.257
Project management skills	Career type		
	Technical positions in services and consultants	2.068	0.824-5.190
	Engineering	0.129*	0.021-0.815
Problem solving capability	Career type		
	Technical positions in services and consultants	2.353*	1.034-5.353
	Engineering	0.732	0.307-1.745

Notes:

(a) Comparison uses academic/public research as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as "among the three most valuable types of PhD knowledge/skills in a job" rather than not been selected at all by labour market segments using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Appendix Table 10: Relative perceived usefulness of PhD competences between dedicated managers and technical positions in private sector manufacturing

		The linearised method	
		Odds ratio[(a)]	90% CI
Specialist knowledge in PhD topic	Career type		
	Dedicated managers	0.226*	0.059-0.863
	Engineering	2.367	0.508-11.024
General knowledge in PhD subject area	Career type		
	Dedicated managers	0.200***	0.075-0.532
	Engineering	1.245	0.322-4.807
General analytical skills	Career type		
	Dedicated managers	1.915	0.707-5.185
	Engineering	2.340	0.585-9.355
Project management skills	Career type		
	Dedicated managers	10.881***	3.333-35.516
	Engineering	0.957	0.198-4.620
Problem solving capability	Career type		
	Dedicated managers	1.688	0.552-5.164
	Engineering	0.799	0.220-2.898

Notes:

(a) Comparison uses technical positions in private sector manufacturing as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as "among the three most valuable types of PhD knowledge/skills in a job" rather than not been selected at all by labour market segments using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Appendix Table 11: Relative perceived usefulness of PhD competences between technical positions in private sector manufacturing and in services (including consultants)

		The linearised method	
		Odds ratio[(a)]	90% CI
Specialist knowledge in PhD topic	Career type		
	Technical positions in services and consultants	0.761	0.239-2.427
	Engineering	1.579	0.495-5.038
General knowledge in PhD subject area			
	Technical positions in services and consultants	0.355*	0.128-0.985
	Engineering	1.913	0.646-5.663
General analytical skills	Career type		
	Technical positions in services and consultants	1.775	0.651-4.840
	Engineering	1.444	0.469-4.439
Project management skills	Career type		
	Technical positions in services and consultants	0.493	0.190-1.276
	Engineering	0.664	1.668-2.641
Problem solving capability	Career type		
	Technical positions in services and consultants	1.181	0.482-2.891
	Engineering	0.972	0.316-2.990

Notes:

(a) Comparison uses technical positions in private sector manufacturing as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as "among the three most valuable types of PhD knowledge/skills in a job" rather than not been selected at all by labour market segments using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Appendix Table 12: Relative perceived usefulness of PhD competences between dedicated managers and technical positions in services and consultants

		The linearised method	
		Odds ratio[(a)]	90% CI
Specialist knowledge in PhD topic	Career type		
	Dedicated managers	0.305	0.068-1.359
	Engineering	1.512	0.363-6.230
General knowledge in PhD subject area	Career type		
	Dedicated managers	0.530	1.169-1.655
	Engineering	2.049	0.717-5.852
General analytical skills	Career type		
	Dedicated managers	1.074	0.373-3.092
	Engineering	3.273	0.873-12.261
Project management skills	Career type		
	Dedicated managers	24.913***	6.423-96.627
	Engineering	0.146**	0.043-0.494
Problem solving capability	Career type		
	Dedicated managers	1.478	0.552-3.961
	Engineering	0.877	0.309-2.485

Notes:

(a) Comparison uses technical positions in services and consultants as reference category. Odds ratio measures the likelihood of each type of knowledge/skills been selected as "among the three most valuable types of PhD knowledge/skills in a job" rather than not been selected at all by labour market segments using design-based logistic regressions. The analysing unit is the job.

Significance (two tailed): *.1; **.05; ***.01.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 home S&E PhD graduates with 7-10 years job histories.

Appendix Table 13: Perceived usefulness of knowledge by job sequence by segment.

	Job sequence Column percentage[(a)]				
Type of knowledge most useful for a job	**1**	**2**	**3**	**>=4**	
Stayers in academia/public research					
Skills acquired from PhD	76	85	60	51	
Organisation-specific skills acquired from previous position	9	8	20	26	
Sector-specific skills acquired from previous position	15	7	10	0	
General skills	0	0	10	23	
N observations	19	14	10	4	Total: 47
Stayers in technical positions in private sector manufacturing					
Skills acquired from PhD	74	35	28	55	
Organisation-specific skills acquired from previous position	0	17	0	0	
Sector-specific skills acquired from previous position	0	14	20	0	
General skills	26	34	52	45	
N observations	8	6	4	2	Total: 20
Stayers in employment outside the conventional technical occupations					
Skills acquired from PhD	33	13	10	0	
Organisation-specific skills acquired from previous position	4	14	22	0	
Sector-specific skills acquired from previous position	11	34	34	57	
General skills	52	39	34	43	
N observations	26	21	18	7	Total: 72
Movers					
Skills acquired from PhD	80	34	4	7	
Organisation-specific skills acquired from previous position	5	19	23	38	
Sector-specific skills acquired from previous position	3	22	41	35	
General skills	12	25	32	20	
N observations	25	23	22	15	Total: 85
All respondents					
Skills acquired from PhD	62	38	19	13	
Organisation-specific skills acquired from previous position	6	15	20	25	
Sector-specific skills acquired from previous position	8	23	32	37	
General skills	24	24	29	25	
N observations	83	69	56	31	Total: 239

Note: (a) Analysis is based on the design-based descriptive data analysis and the analysing unit is the job.

Source: Survey of this thesis based on the University of Manchester's 1998-2001 UK S&E PhD graduates in paid employment, 7-10 years after graduation.

References

1. Abernathy, W. J. and Rosenbloom, R. S., 1969. Parallel strategies in development projects. Management Science 15(10), 486-505.

2. Allen, T. J. and Katz, R., 1986. The dual ladder: motivational solution or managerial delusion? R&D Management 16(2), 185-197.

3. Allen, T. J. and Katz, R., 1992. Age, education and the technical ladder. IEEE Transactions on Engineering Management 39, 237-245.

4. Allison, P. D. and Long, J. S., 1990. Departmental effects on scientific productivity. American Sociological Review 55, 469-478.

5. Allison, P. D. and Stewart, J. A., 1974. Productivity differences among scientists: evidence for accumulative advantage. American Sociological Review 39, 596-606.

6. Allison, P. D., Long, J. S. and Krauze, T. K., 1982. Cumulative advantage and inequality in science. American Sociological Review 47, 615-625.

7. Almeida, P. and Kogut, B., 1999. The localization of knowledge and the mobility of engineers in regional networks. Management Science 45(7), 905-917.

8. Althauser, R. P. and Kalleberg, A. L., 1981. Firms, occupations and the structure of labour markets: a conceptual analysis. In: Berg, I. (Ed.) In Sociological Perspectives on Labour Markets. Academic Press, New York.

9. Alvesson, M., 2000. Social identity and the problem of loyalty in knowledge-intensive companies. Journal of Management Studies 37(8), 1101-1123.

10. American Statistical Association, 1997. What Is a Survey? More about Mail Surveys. American Statistical Association, Alexandria, VA.

11. Anderson, R., 2006. British Universities: Past and Present. Hambledon Continuum, London.

12. Archer, K. J, Lemeshow, S. and Hosmer, D. W., 2007. Goodness-of-fit tests for logistic regression models when data are collected using a complex sampling design. Computational Statistics & Data Analysis 51, 4450-4464.

13. Armstrong, J. S. and Overton, T. S., 1977. Estimating nonresponse bias in mail surveys. Journal of Marketing Research 14(3), 396-402.

14. Arthur, M. B. and Rousseau, D. M, 1996. Introduction: the boundaryless career as a new employment principle. In: Arthur, M. B. and Rousseau, D. M. (Eds.), The Boundaryless Career. Oxford University Press, New York.

15. Arthur, M. B., 2008. Examining contemporary careers: a call for interdisciplinary inquiry. Human Relations 61(2), 163-186.

16. Arthur, M. B., Hall, D. T. and Lawrence, B. S., 1989. Handbook of Career Theory. Cambridge University Press, New York.

17. Arvanitis, S., Kubli, U. and Woerter, M., 2008. University-industry knowledge and technology transfer in Switzerland: What university scientists think about co-operation with private enterprise. Research Policy 37, 1865-1883.

18. Atkinson, J. and Meager, N., 1986. Is flexibility just a flash in the pen? Personnel Management, September, 26-29.

19. Atkinson, J., 1984. Manpower strategies for flexible organisations. Personnel Management, August, 24-31.

20. Autor, D. H. and Handel, M. J., 2009. Putting Tasks to the Test: Human Capital, Job Tasks and Wages. NBER Working Paper 15116. National Bureau of Economic Research, Cambridge, MA.

21. Baba, Y., Shichijo, N. and Sedita, S. R., 2009. How do collaborations with universities affect firms' innovative performance? The role of "Pasteur scientists" in the advanced material field. Research Policy 38, 756-764.

22. Bagdadli, S., Solari, L., Usai, A. and Grandori, A., 2003. The emergence of boundaries in unbounded industries: career odysseys in Italian New Economy. International Journal of Human Resource Management 14, 788-808.

23. Baldry, C., Bain, P., Taylor, P., Hyman, J., Scholarios, D., Marks, A., Watson, A., Gilbert, K., Gall, G. and Bunzel, D., 2007. The Meaning of Work in the New Economy. Palgrave, Basingstoke.

24. Barley, S. R. and Kunda, G., 2004. Gurus, Hired Guns, and Warm Bodies: Itinerant Experts in a Knowledge Economy. Princeton University Press, Princeton, New Jersey.

25. Barley, S. R. and Tolbert, P. S., 1997. Institutionalization and structuration: studying the links between actions and institution. Organization Studies 18(1), 93-117.

26. Barley, S. R., 1989. Careers, identities, and institutions: the legacy of the Chicago School of Sociology. In: Arthur, M. B., Hall, D. T. and Lawrence, B. S. (Eds.) Handbook of Career Theory. Cambridge University Press, New York.

27. Baron, J. N., Davis-Blake, A. and Bielby, W. T., 1986. The structure of opportunity: how promotion ladders vary within and among organizations. Administrative Science Quarterly 31, 248-273.

28. Bauer, M. and Kogan, M., 2006. Higher education policies: Historical overview. In Kogan, M., Bauer, M., Blelklie, I. and Henkel, M. (Eds.), Transforming Higher Education: A Comparative Study. Springer, Dordrecht.

29. Becker, G. S., 1962. Investment in human capital: a theoretical analysis. The Journal of Political Economy 70(5), 9-49.

30. Becker, G. S., 1964. Human capital: a theory and empirical analysis, with special reference to education. Columbia University Press, New York.

31. Becker, H. S. and Strauss, A. L., 1956. Careers, personality, and adult socialization. American Journal of Sociology 62, 253-263.

32. Beechler, S. and Woodward, I. C., 2009. The global "war for talent". Journal of International Management 15, 273-285.

33. Behrens, T. R. and Gray, D. O., 2001. Unintended consequences of cooperative research: impact of industry sponsorship on climate for academic freedom and other graduate student outcome. Research Policy 30, 179-199.

34. Bekkers, R. and Freitas, I. M. B., 2008. Analysing knowledge transfer channels between universities and industry: To what degree do sectors also matter? Research Policy 37, 1837-1853.

35. Biddle, J. and Roberts, K., 1994. Private sector scientists and engineers and the transition to management. The Journal of Human Resources 29(1), 82-107.

36. Bird, A., 1996. Careers as repositories of knowledge: considerations for boundaryless careers. In: Arthur, M. B. and Rousseau, D. M. (Eds.), The Boundaryless Career. Oxford University Press, New York.

37. Blackler, F., 1995. Knowledge, knowledge work and organizations: an overview and interpretation. Organization Studies 16(6), 1021-1046.

38. Blossfeld, H-P. and Mayer, K. U., 1988. Labour market segmentation in the Federal Republic of Germany: an empirical study of segmentation theories from a life course perspective. European Sociological Review 4(2), 123-140.

39. Blumenthal, D., Campbell, E., Anderson, M., Causino, N. and Seashore-Louis, K., 1997. Witholding research results in academic life science: evidence from a national survey of faculty. Journal of the American Medical Association, 227, 1224-1228.

40. Boden, R., Cox, D., Georghiou, L. and Barker, K., 1999. Administrative reform of United Kingdom government research establishments: case studies of new organisational forms. In Cox, D., Gummett, P. and Barker, K. (Eds.), Government Laboratories: Transition and Transformation. ISO Press, Amsterdam.

41. Boden, R., Cox, D., Nedeva, M. and Barker, K., 2004. Scrutinising Science: The Changing UK Government of Science. Palgrave Macmillan, Basingstoke.

42. Box-Steffensmeier, J. M and Jones, B. S., 2004. Event History Modelling: A Guide for Social Scientists. Cambridge University Press, New York.

43. Bozeman, B., Dietz, J. S. and Gaughan, M., 2001. Scientific and technical human capital: an alternative model for research evaluation. International Journal of Technology Management 22(7/8), 716-740.

44. Braddock, D. J., 1992. Scientific and Technical Employment, 1990-2005. Monthly Labor Review 115(2), 28-41.

45. Brett, J. M. and Stroh, L. K., 1997. Jumping ship: who benefits from an external labor market strategy? Journal of Applied Psychology 82, 331-341.

46. Briscoe, J. P. and Hall, D. P., 2006. The interplay of boundaryless and protean careers: combinations and implications. Journal of Vocational Behavior 69, 4-18.

47. Bruno, G. S. F. and Orsenigo, L., 2003. Variables influencing industrial funding of academic research in Italy: an empirical analysis. Int. J. Technology Management 26 (2/3/4), 277-302.

48. Buck, N., Ermisch, J. F. and Jenkins, S. P., 1996. Choosing a Longitudinal Survey Design: The Issues. Occasional Paper of the ESRC Research Centre on Micro-Social Change, Paper96-1. University of Essex, Colchester.

49. Burgess, R. G., 1997. The changing context of postgraduate education and training in the UK. In: Burgess, R. G. (Ed.), Beyond the First Degree: Graduate Education Lifelong Learning and Careers. SRHE/Open University Press, Buckingham.

50. Camuffo, A., 2002. The changing nature of internal labour markets. Journal of Management and Governance 6, 281-294.

51. Cappelli, P., 1999. Career jobs are dead. California Management Review 42(1), 146-67.

52. Causer, G. and Jones, C., 1993. Responding to “skill shortages”: recruitment and retention in a high technology labour market. Human Resource Management Journal 3(3), 1-20.

53. Cervantes, M., 2001. Mobilising Human Resource for Innovation. In: OECD Growth Background Papers No. 2. OECD, Paris.

54. Cheng, M. M. and Kalleberg, A. L., 1996. Labour market structures in Japan: an analysis of organisational and occupational mobility patterns. Social Forces 74(4), 1235-1260.

55. Cochran, W. G., 1977. Sampling Techniques (3rd ed.). Wiley, New York.

56. Cohen, M. D. and Bacdayan, P., 1994. Organizational routines are stored as procedural memory: evidence from a laboratory study. Organization Science 5(4), 554-568.

57. Cohen, W. M. and Levinthal, D. A., 1989. Innovation and learning: the two faces of R&D. The Economic Journal 99(397), 569-596.

58. Cohen, W. M., Nelson, R. R. and Walsh, J. P., 2002. Links and impacts: the influence of public research on industrial R&D. Management Science 48 (1), 1-23.

59. Cole, S., 1979. Age and scientific performance. American Journal of Sociology 84, 958-977.

60. Collins, H. M., 1993. The structure of science. Social Research 60(1), 95-116.

61. Committee of Vice-Chancellors and Principles, 1988. The British PhD. CVCP, London.

62. Cooke, P., 2001. Regional innovation systems, clusters and the knowledge economy. Industrial and Corporate Change 10 (4), 945-974.

63. Cox, A., Grimshaw, D., Carroll, M. and McBride, A., 2008. Reshaping internal labour markets in the National Health Services: new prospects for pay and training for lower skilled service workers. Human Resource Management Journal 18(4), 347-365.

64. Crane, D., 1969. Social structure in a group of scientists: a test of the "invisible college hypothesis". American Sociological Review 34, 335-352.

65. Craswell, G., 2007. Deconstructing the skills training debate in doctoral education. Higher Education Research & Development 26(4), 377-391.

66. Creplet, F., Dupouet, O., Kern, F., Mehmanpazir, B. and Munier, F., 2001. Consultants and experts in management consulting firms. Research Policy 30, 1517-1535.

67. Cullen, J., 1978. The Structure of Professionalism. Petrocelli, New York.

68. D'Este, P. and Patel, P., 2007. University-industry linkages in the UK: What are the factors underlying the variety of interactions with industry? Research Policy 36, 1295-1313.

69. Dany, F. and Mangematin, V., 2004. Beyond the dualism between lifelong employment and job insecurity: some new career promises for young scientists. Higher Education Policy 17, 201-219.

70. David, P. A. and Foray, D., 2002. An introduction to the economy of the knowledge society. International Social Science Journal 54 (171), 9-23.

71. Dawis, R. V., Lofquist, L. H., Henly, G. A. and Rounds, J. B., Jr., 1979. Minnesota Occupational Classification System II (MOCS II). Vocational Psychology Research Work Adjustment Report, Minneapolis.

72. de Vaus, D., 2002 (5th ed.). Surveys in Social Research. Poutledge, London.

73. Deaton, A., 1997. The Analysis of Household Surveys: A Microeconometric Approach to Development Policy. Johns Hopkins University Press for the World Bank, Baltimore, Maryland.

74. Debackere, K., Buyens, D. and Vandenbossche, T., 1997. Strategic career development for R&D professionals: lessons from field research. Technovation 17(2), 53-62.

75. DeFillippi, R. J. and Arthur, M. B., 1994. The boundaryless career: a competency-based perspective. The Journal of Organizational Behavior 15(4), 307-324.

76. DeFillippi, R. J. and Arthur, M. B., 1996. Boundaryless contexts and careers: a competency-based perspective. In: Arthur, M. B. and Rousseau, D. M. (Eds.), The Boundaryless Career. Oxford University Press, New York.

77. DeFillippi, R. J. and Arthur, M. B., 1998. Paradox in project-based enterprise: the case of film making. California Management Review 40(2), 125-139.

78. DeFillippi, R. J., 2002. Organisational modes for collaboration in the new economy. Human Resource Planning 25(4), 7-18.

79. DeFillippi, R. J., Arthur, M. B. and Lindsay, V. J., 2006. Knowledge at Work: Creative Collaboration in the Global Economy. Blackwell, Malden, MA.

80. Delamont, S. and Atkinson, P., 2001. Doctoral uncertainty: mastering craft knowledge. Social Studies of Science 31(1), 87-107.

81. Department for Innovation, Universities & Skills, 2008. Innovation Nation. HMSO, London. Online available at: http://www.dius.gov.uk/innovation/innovation_nation. (Accessed on 20 October 2009)

82. Department of Education and Science (DES), 1987. Higher Education: Meeting the Challenge. HMSO, London.

83. Department of Education and Science White Paper, 1987. Higher Education: Meeting the Challenge. HMSO, London.

84. Dietz, J. S. and Bozeman, B., 2005. Academic careers, patents, and productivity: industry experience as scientific and technical human capital. Research Policy 34, 349-367.

85. DiPrete, T. A. and McManus, P. A., 1993. Tenure, mobility, and incumbency: comparing observed patterns of earnings with predictions from an elaborated theory of occupational and firm labour markets. Research in Social Stratification and Mobility 12, 45-82.

86. DiPrete, T. A., De Graaf, P. M., Luijkx, R., Tahlin, M. and Blossfeld, H., 1997. Collective versus individualistic mobility regimes? Structure change and job mobility in four countries. American Journal of Sociology 103, 318-358.

87. Doeringer, P. B. and Piore, M. J., 1971. Internal Labour Markets and Manpower Analysis. DC Heath, Lexington.

88. Donnelly, R., 2009. Career behavior in the knowledge economy: experiences and perceptions of career mobility among management and IT consultants in the UK and the USA. Journal of Vocational Behavior 75(3), 319-328.

89. Dosi, G., 1982. Technological paradigms and technological trajectories. Research Policy 11, 147-162.

90. Dosi, G., Freeman, C. and Fabiani, S., 1994. The process of economic development: introducing some stylised facts and theories on technologies, firms and institutions. Industrial and Corporate Change 3(1), 1-45.

91. Droege, R. C. and Padgett, A., 1979. Development of an interest-oriented occupational system. Vocational Guidance Quarterly 27(4), 302-310.

92. DTZ Pieda Consulting, 2003. A Study of the Career Paths of PPARC PhD Students. Online available at: http://www.so.stfc.ac.uk/publications/pdf/PiedaNewCohort.pdf. (Accessed on 17 May 2009).

93. Edquist, C. (Ed.), 1997. Systems of Innovation. Frances Pinter, London.

94. Edwards, R., Reich, M. and Gordon, D., 1975. Labour Market Segmentation. Heath, Lexington, MA.

95. EI-Khawas, E. 1994. Staffing issues in the next decade: complex and challenge. Higher Education Policy 7, 43-44.

96. Elliott, M. and Parcel, T. L., 1996. The determinants of young women's wages: Comparing the effects of individual and occupational labour market characteristics. Social Science Research 25, 240-259.

97. Enders, J., 2002. Serving many masters: the PhD on the labour market, the everlasting need of inequality, and the premature death of Humboldt. Higher Education 44, 493-517.

98. Enders, J., 2005. Broader crossing: research training, knowledge dissemination and the transformation of academic work. Higher Education 49, 119-133.

99. Estabrooks, C. A., Norton, P., Birdsell, J. M., Newton, M. S., Adewale, A. J. and Thornley, R., 2008. Knowledge translation and research careers: Mode I and Mode II activity among health researchers. Research Policy 37, 1066-1078.

100. Estevez-Abe M., Iversen, T. and Soskice, D., 2001. Social protection and the formation of skills: a reinterpretation of the welfare State. In Hall, P. A. and Soskice, D. (Eds.) Varieties of Capitalism. Oxford University Press, Oxford.

101. Etzkowitz, H., 1983. Entrepreneurial scientists and entrepreneurial universities in American academic science. Minerva 21, 198-233.

102. Eyraud, F., Marsden, D. and Silvestre, J. J., 1990. Occupational and internal labour markets in Britain and France. International Labour Review 129(4), 501-517.

103. Farnham, D., 1999. The United Kingdom: end of the donnish dominion? In: Farnham, D. (Ed.), Managing Academic Staff in Changing University Systems – International Trends and Comparisons. Open University Press, Buckingham.

104. Feldman, D. C. and Ng, T. W. H., 2007. Careers: mobility, embeddedness, and success. Journal of Management 33(3), 350-377.

105. Finn, M. G. and Baker, J. G., 1993. Further jobs in natural science and engineering: Shortage or surplus? Monthly Labor Review 116(2), 54-61.

106. Fontana, R., Genua, A. and Matt, M., 2006. Factors affecting university-industry R&D projects: The importance of searching, screening and signalling. Research Policy 35, 309-323.

107. Foray, D. and Landvall, B., 1996. The knowledge-based economy: from the economics of knowledge to the learning economy. In: OECD Employment and Growth in the Knowledge-based Economy. OECD, Paris.

108. Foss, N. J., 2002. Introduction: new organizational forms – critical perspectives. International Journal of the Economics of Business 9(1), 1-8.

109. Foss, N. J., 2003. Selective intervention and internal hybrids: interpreting and learning from the rise and decline of the Oticon Spaghetti organisation. Organization Science 14(3), 331-349.

110. Fox, M. F. and Stephan, P. E., 2001. Careers of young scientists: preferences, prospects and realities by gender and field. Social Studies of Science 31(1), 109-122.

111. Freeman, C., 1987. Technology policy and Economic Performance: Lessons from Japan. Frances Pinter, London.

112. Freeman, C., 1992. Formal Scientific and Technical Institutions in the National Systems of Innovation. In: Lundvall, B. Å. (Ed.), National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. Pinter, London.

113. Fujiwara-Greve, T. and Greve, H. R., 2000. Organizational ecology and job mobility. Social Force 79. 547-585.

114. Funtowicz, S.O. and Ravetz, J. R., 1993. The emergence of post-normal science. In: Schomberg, R. van (Ed.), Science, Politics, and Mobility. Scientific Uncertainty and Decision-Making. Kluwer, Dordrecht.

115. Garud, R. and Rappa, M. A., 1994. A social-cognitive model of technology evolution: the case of cochlear implants. Organization Science 5(3), 344-362.

116. George, K. D. and Shorey, J., 1985. Manual workers, good jobs, and structured internal labour markets. British Journal of Industrial Relations 23(3), 425-447.

117. Georghiou, L., 2001. The United Kingdom national system of research, technology and innovation. In Laredo, P. and Mustar, P. (Eds.), Research and Innovation Policies in the New Global Economy. Edward Elgar, Cheltenham.

118. Geuna, A. and Nesta, L. J. J., 2006. University patenting and its effects on academic research: The emerging European evidence. Research Policy 35, 790-807.

119. Geuna, A., 2001. The changing rationale for European university research funding: Are there negative unintended consequences? Journal of Economic Issues 35 (3), 607-632.

120. Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M., 1994. The New Production of Knowledge. Sage, London.

121. Gilliot, D, Overleat, B. and Verdin, P., 2002. Managing academic personnel flow at universities. Tertiary Education and Management 8, 277-295.

122. Giret, J. and Recotillet, I., 2004. The impact of CIFRE programme into early careers of PhD graduates in France. Paper presented to the 16th Annual Conference of the European Association of Labour Economics, Lisbon.

123. Giuliani, E and Arza, V., 2009. What drives the formation of "valuable" university-industry linkages? Insights from the wine industry. Research Policy 38, 906-921.

124. Gluck, M. E., Blumenthal, D. and Stoto, M. A., 1987. University-industry relationships in the life sciences: Implications for students and post-doctoral fellows. Research Policy 16, 327-336.

125. Godin, B., 1996. Research and the practice of publication in industries. Research Policy 25, 587-606.

126. Goldstein, H. A. and Renault, C. S., 2004. Contributions of universities to regional economic development; a quasi-experimental approach. Regional Studies 38, 733-746.

127. Gregorio, D. D. and Shane, S., 2003. Why do some universities generate more start-ups than others? Research Policy 32, 209-227.

128. Griliches, Z., 1992. The search for R&D spillovers. Scandinavian Journal of Economics 94, 29-47.

129. Grimshaw, D. and Rubery, J., 1998. Integrating the internal and external labour markets. Cambridge Journal of Economics 22, 199-220.

130. Gulbrandsen, M. and Smeby, J., 2005. Industry funding and university professor's research performance. Research Policy 34, 932-950.

131. Gunz, H. P., 1980. Dual ladders in research: a paradoxical organizational fix. R&D Management 10, 113-118.

132. Hall, D. T., 1976. Careers in Organisations. Scott, Foresman, Glenview, IL.

133. Hall, D. T., 1996. Protean careers of the 21st century. Academy of Management Executive 10(4), 8-16.

134. Hall, D. T., 2002. Protean career in and out of organizations. Sage, Thousand Oaks, CA.

135. Hamori, M and Kakarika, M., 2009. External labour market strategy and career success: CEO careers in Europe and the United States. Human Resource Management 48(3), 355-378.

136. Hargadon, A. and Sutton, R. I., 1997. Technology brokering and innovation in a product development firm. Administrative Science Quarterly 42(4), 716-749.

137. Harris Report, 1996. Review of Postgraduate Education. HEFEC, CVCP and SCOP. Online available at: http://www.hefce.ac.uk/pubs/hefce/1996/m14_96.htm. (Accessed on 8 March 2009).

138. Haveman, H. A. and Cohen, L. E., 1994. The ecological dynamics of careers: the impact of organizational funding, dissolution, and merger on job mobility. American Journal of Sociology 100, 104-152.

139. Herr, E. L. and Cramer, S. H., 1984. Career Guidance and Counselling through the Lifespan: Systematic Approaches. HarperCollins, New York.

140. Hessels, L. K. and Van Lente, H., 2008. Re-thinking new knowledge production: A literature review and a research agenda. Research Policy 37, 740-760.

141. Hobday, M., 2000. The project-based organisation: an ideal form for managing complex products and systems? Research Policy 29, 871-893.

142. Hosmer, D. W. and Lemeshow, S., 1980. Goodness-of-fit tests for the multiple logistic regression model. Communications in Statistics A9(10), 1043-1069.

143. Høstaker, R., 2006. Policy change and the academic profession. In Kogan, M., Bauer, M., Blelklie, I. and Henkel, M. (Eds.), Transforming Higher Education: A Comparative Study. Springer, Dordrecht.

144. Hudson, K., 2007. The new labour market segmentation: labour market dualism in the new economy. Social Science Research 36, 286-312.

145. Hutchins, E., 1996. Cognition in the Wild. MIT Press, Cambridge, MA.

146. Jacoby, S. M, 1999. Are career jobs headed for extinction? California Management Review 42(1), 123-145.

147. Jain, S., George, G. and Maltarich, M., 2009. Academics or entrepreneurs? Investigating role identity modification of university scientists involved in commercialization activity. Research Policy 38, 922-935.

148. Johnson, D. and Sargeant, A., 1998. Motives for transition: an exploratory study of engineering managers. Human Resource Management Journal 8(3), 41-53.

149. Jones, C. and DeFillippi, R. J., 1996. Back in the future in film: combining industry and self-knowledge to meet the career challenges of the 21st century. Academy of Management Executive 10(4), 89-104.

150. Jones, C., 1996. Career in project networks: the case of the film industry. In: Arthur, M. B. and Rousseau, D. M. (Eds.), The Boundaryless Career. Oxford University Press, New York.

151. Jones, O., 1992. Postgraduate scientists and R&D: the role of reputation in organisational choice. R&D Management 22(4), 349-358.

152. Kalleberg, A. L. and Sørenson, A. B., 1979. The sociology of labour markets. Annual Review of Sociology 5, 351-379.

153. Kalleberg, A. L., 2001. Organizing flexibility: the flexible firm in a new century. British Journal of Industrial Relations 39(4). 479-504.

154. Kalleberg, A. L., 2003. Flexible firms and labour market segmentation. Work and Occupations 30. 154-175.

155. Kenney, M., 1987. The ethical dilemmas of university-industry collaborations. Journal of Business Ethics 6, 127-135.

156. Kline, S.J. and Rosenberg, N., 1986. An overview of innovation. In National Academy of Engineering (Ed.), The Positive Sum Strategy: Harnessing Technology for Economic Growth. National Academy Press, Washington D.C..

157. Kogut, B. and Zander, U., 1992. Knowledge of the firm, combination capability, and the replication of technology. Organization Science 3, 383-397.

158. Kogut, B. and Zander, U., 1996. What firms do: coordination, identity, and learning. Organization Science 7, 502-518.

159. Kogut, B., 2008. Knowledge, Options and Institutions. Oxford University Press, New York.

160. Köhler, C., Götzelt, I. and Schröder, T., 2006. Firm-employment systems and labour market segmentation – an old approach to a new debate? In: Köhler, C., Junge, K., Struck, O. and Schröder, T. (Eds.) Trends in Employment Stability and Labour Market Segmentation. The Collaborative Research Centre 580 at the Friedrich-Schiller-University Jena, Jena.

161. Kornhauser, W., 1962. Scientists in Industry: Conflict and Accommodation. University of California Press, Berkeley and Los Angeles.

162. Krabel S. and Mueller, P., 2009. What drive scientists to start their own company? An empirical investigation of Max Plank Society scientists. Research Policy 38, 947-956.

163. Lam, A., 2004. Social institutions, learning organisations and innovation. Research on Technological Innovation and Management Policy 8, 43-67.

164. Lam, A., 2005. Work roles and careers of R&D scientists in network organisations. Industrial Relations 44(2), 242-275.

165. Lam, A., 2007. Knowledge networks and careers: academic scientists in industry-university links. Journal of Management Studies 44 (6), 993-1016.

166. Lam, A., 2010. From “ivory tower traditionalists” to “entrepreneurial scientists”? Academic scientists in fuzzy university-industry boundaries. Social Studies of Science 40(2), 307-340.

167. Lambert, D. M. and Harrington, T. C., 1990. Measuring nonresponse bias in costumer service mail surveys. Journal of Business Logistics 11(2), 5-25.

168. Larédo, P. and Mustar, P., 2004. Public sector research: A growing role in innovation systems. Minerva 42, 11-27.

169. Larédo, P., 2007. Revisiting the third mission of universities: Toward a renewed categorization of university activities? Higher Education Policy 20, 441-456.

170. Laudan, R., 1984. The Nature of Technological Knowledge. Reidel, Dordrecht.

171. Lavoie, M. and Finnie, R., 1998. The occupational dynamics of recent Canadian engineering graduates inside and outside the bounds of technology. Research Policy 27, 143-158.

172. Lavoie, M., Roy, R. and Therrien, P., 2003. A growing trend toward knowledge work in Canada. Research Policy 32, 827-844.

173. Lawton Smith, H., 2006. Universities, Innovation and the Economy, Routledge, Oxon.

174. Lawton, L. and Parasuraman, A., 1980. The impact of the marketing concept on new product planning. The Journal of Marketing 44(1), 19-25.

175. Layton, E., 1984. Technology as knowledge. Technology and Culture 15, 31-41.

176. Lazear, E. and Shaw, K., 2007. Personnel economics: the economist’s view of human resources. Journal of Economic Perspectives 21, 91-114.

177. Ledwith, S. and Colgan, F., 1996. Women in Organisations: Challenging Gender Politics. Macmillan, London.

178. Lehtonen, R. and Pahkinen, E. J., 2003. Practical Methods for Design and Analysis of Complex Surveys (2nd ed.). John Wiley & Sons, Chichester.

179. Lemeshow, S., Letenneur, L., Dartigues, J. -F., Lafont, S., Orgogozo, J. -M. and Commenges, D, 1998. Illustration of analysis taking into account complex survey

considerations: the association between wine consumption and Dementia in the PAQUID study. American Journal of Epidemiology 148(3), 298-306.

180. Leonard, D., 2000. Transforming doctoral studies: competencies and artistry. Higher Education in Europe XXV(2), 181-192.

181. Levin, S. G. and Stephan, P. E., 1989. Age and research productivity of academic scientists. Research in Higher Education 30, 531-549.

182. Levin, S. G. and Stephan, P. E., 1991. Research productivity over the life-cycle – evidence for academic scientists. American Economic Review 81, 114-132.

183. LFS User Guide Volume 5, 2009. Online available at: http://www.statistics.gov.uk/downloads/theme_labour/Vol5_2009.pdf (Accessed on 14 January 2011)

184. Lindley, R. M., 2002. Knowledge-based economies: the European employment debate in a new context. In: Rodrigues, M. J. (Ed.) The New Knowledge Economy in Europe. Edward Elgar, Cheltenham.

185. Long, J. S. and McGinnis, R., 1985. The effects of the mentor on the academic career. Scientometrics 7, 255-280.

186. Long, J., S., Allison, P. D. and McGinnis, R., 1993. Rank advancement in academic careers: sex differences and the effects of productivity. American Sociological Review 58, 703-722.

187. Loprest, P. J., 1992. Gender differences in wage growth and job mobility. American Economics Review 82, 526-532.

188. Louis, K. A., Jones, L. M., Anderson, M. S., Blumenthal, D. and Campbell, E. G., 2001. Entrepreneurship, secrecy and productivity: A comparison of clinical and non-clinical life science faculty. Journal of Technology Transfer 26 (3), 233-245.

189. Lowe, R. A. and Gonzalez-Brambila, C., 2007. Faculty entrepreneurs and research productivity. Journal of Technology Transfer 32, 173-194.

190. Lundvall, B. -Å., 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. Pinter, London.

191. Mace, J., 1979. Internal labour markets for engineers in British industry. British Journal of Industrial Relations 17(1), 50-63.

192. Madsen, T. L., Mosakowski, E. and Zaheer, S., 2003. Knowledge retention and personnel mobility: the nondistructive effects of inflows of experience. Organization Science 14(2), 173-191.

193. Malerba, F. and Orsenigo, L., 2000. Knowledge, innovative activities and industry evolution. Industrial and Corporate Change 9, 289-314.

194. Malerba, F., 2002. Sectoral systems of innovation and production. Research Policy 31, 247-264.

195. Malhotra, N. and Morris, T., 2009. Heterogeneity in professional service firms. Journal of Management Studies 46(6), 895-922.

196. Mangematin, V., 2000. PhD job market: professional trajectories and incentives during the PhD. Research Policy 29, 741-756.

197. Mangematin, V., 2001. Individual careers and collective research: is there a paradox? Int. J. Technology Management 22(7/8), 670-675.

198. Mansfield, E. and Lee, J. Y., 1996. The modern university: contributor to industrial innovation and recipient of industrial R&D support. Research Policy 25, 1047-1058.

199. Marsden, D., 1986. The end of economic man? John Spiers, Brighton.

200. Marsden, D., 2010. The growth of extended “entry tournaments” and the decline of institutionalised occupational labour markets in Britain. CEP Discussion Paper No 989. LSE.

201. Martin, B. and Irvine, J., 1981. Spin-off from basic science: the case of radioastronomy. Physics in Technology 12(5), 204-212.

202. Martin, B. R., 2003. The changing social contract for science and the evolution of the university. In Geuna, A., Salter, A. J. and Steinmueller, W. E. (Eds.), Science and Innovation: Rethinking the Rationales for Funding and Governance. Edward Elgar, Cheltenham.

203. Martin, J. and Roberts, C., 1984. Women and Employment: Technical Report. HMSO, London.

204. Martinelli, D., 1999. Labour market performance of French PhDs: A statistical analysis. In: OECD Mobilising Human Resources for Innovation. OECD, Paris.

205. Mason, G. and Wagner, K., 1994. High-level skills and industrial competitiveness: post-graduate engineers and scientists in Britain and Germany. National Institute of Economic and Social Research Report Series Number 6, London.

206. May, T. Y., Korczynski, M. and Frenkel, S. J., 2002. Organisational and occupational commitment: knowledge workers in large corporations. Journal of Management Studies 39(6), 775-801.

207. Mayrhofer, W., Meyer, M. and Steyrer, J., 2007. Contextual issues in the study of careers. In: Gunz, H. and Peiperl, M. (Eds.) Handbook of Career Studies. Sage, Los Angeles, CA.

208. McGee, R. M., 1971. Academic Janus. Jossey-Bass, San Francisco.

209. McGovern, P., 1995. To retain or not to retain? Multinational firms and technical labour. Human Resource Management Journal 5(4), 7-23.

210. McGovern, P., Hill, S., Mills, C. and White, M., 2007. Market, Class and Employment. Oxford University Press, New York.

211. McMillam, G. S. and Deeds, D. L., 1998. The role of reputation in the recruitment of scientists. R&D Management 28(4), 349-358.

212. Merton, R. K., 1968. The Matthew effect in science. Science 159, 56-63.

213. Merton, R. K., 1973. The Sociology of Science, University of Chicago Press, Chicago.

214. Merton, R. K., 1988. The Matthew effect in science, II cumulative advantage and the symbolism of intellectual property. ISIS 79, 606-623.

215. Meyer-Krahmer, F. and Schmoch, U., 1998. Science-based technologies: university-industry interactions in four fields. Research Policy 27, 835-851.

216. Michaels, E., Handfield-Jones, H. and Axelrod, B., 2001. The War for Talent. Harvard Business School Press, Boston.

217. Miles, I., 2003. Services and the knowledge-based economy. In: Tidd., J. and Hull, F. M. (Eds.), Service Innovation: Organizational Responses to Technological Opportunities & Market Imperatives. Imperial College Press, London.

218. Miles, I. and Boden, M., 2000. Introduction: are services special? In: Boden, M. and Miles, I. (Eds.), Services and the Knowledge-Based Economy. Continuum, London.

219. Mincer, J., 1958. Investment in human capital and personal income distribution. The Journal of Political Economy 66(4), 281-302.

220. Miozzo, M. and Grimshaw, D., (Eds.), 2006. Knowledge Intensive Business Services: Organizational Forms and National Institutions, Edward Elgar, Cheltenham.

221. Mirvis, P. H. and Hall, D. T., 1996. Psychological Success and the Boundaryless Career. In: Arthur, M. B and Rousseau, D. M. (Eds.) The Boundaryless Career, Oxford University Press, New York.

222. Moonesinghe, R., Yesupriya, A., Chang, M. –h, Dowling, N. F., Khoury, M. J. and Scott, A. J., 2010. A Hardy-Weinberg equilibrium test for analyzing population genetic surveys with complex sample designs. American Journal of Epidemiology 171(8), 932-941.

223. Moser, C. A. and Kalton, G., 1971 (2nd ed.). Survey Methods in Social Investigation. Gower, Aldershot.

224. Mowery, D. C. and Sampat, B. N., 2005. Universities in the national innovation systems. In: Fagerberg, J., Mowery, D. C. and Nelson, R. R., (Eds.) The Oxford Handbook of Innovation. Oxford University Press, New York.

225. Mowery, D. C., Nelson, R. R., Sampat, B. N. and Ziedonis, A. A. (2004), Ivory Tower and Industrial Innovation: University-Industry Technology Transfer Before and After the Bayh-Dole Act. Stanford Business Books, Stanford, California.

226. Murray, F., 2002. Innovation as co-evolution of scientific and technological networks: exploring tissue engineering. Research Policy 31, 1389-1403.

227. Murray, F., 2004. The role of academic inventors in entrepreneurial firms: sharing the laboratory life. Research Policy 33, 643-659.

228. Musselin, C., 2005. "European academic labour market in transition", *Higher Education* 49, 135-154.

229. Nelson, K. and Nelson, R. R., 2002. On the nature and evolution of human know-how. Research Policy 31, 719-733.

230. Nelson, R. and Winter, S., 1977. In search of a useful theory of innovation. Research Policy 5, 36-76.

231. Nelson, R. R. and Winter, S. G., 1982. An Evolutionary Theory of Economic Change. Harvard University Press, Cambridge, MA.

232. Nelson, R. R., 1993. National Innovation Systems. Oxford University Press, Oxford.

233. Nonaka, I., 1994. A dynamic theory of organizational knowledge creation. Organization Science 5, 14-37.

234. Nordhaug, O., 1993. Human Capital in Organizations: Competence, Training, and Learning. Scandinavian University Press, Oslo.

235. Nowotny, H., Scott, P. and Gibbons, M., 2001. Re-Thinking Science: Knowledge and the Public in an Age of Uncertainity. Polity Press, Cambridge.

236. O'Connor, J., 1973. Fiscal Crisis of the State. St. Martin's, New York.

237. O'Reilly, C. A. and Pfeffer, J. A., 2000. Hidden Value. How Great Companies Achieve Extraordinary Results with Ordinary People. Harvard Business School Press, Boston, MA.

238. OECD, 1991. Science and Technology Policy: Review and Outlook. OECD, Paris.

239. OECD, 1992. Technology-Economy Programme. Technology and the Economy: the Key Relationship. OECD, Paris.

240. OECD, 2000. A New Economy? The Changing Role of Innovation and Information Technology in Growth. OECD, Paris.

241. Osterman, P., 1975. An empirical study of labour market segmentation. Industrial and Labor Relations Review 28(4), 508-523.

242. Osterman, P., 1988. Employment Futures. Reorganization, Dislocation and Public policy. Oxford University Press, New York.

243. Osterman, P., 2009. The contours of institutional labour economics: notes towards a revived discipline. Socio-Economic Review 7. 695-726.

244. Park, C., 2005. New Variant PhD: The changing nature of the doctorate in the UK. Journal of Higher Education Policy and Management 27(2), 189-207.

245. Pavitt, K., 1984. Sectoral patterns of technical change: towards a taxonomy and a theory. Research Policy 13, 343-373.

246. Pavitt, K., 1991. What makes basic research economically useful? Research Policy 20, 109-119.

247. Pavitt, K., 2001. Public policies to support basic research: What can the rest of the world lean from US theory and practice? (And what they should not learn). Industrial and Corporate Change 10 (3), 761-779.

248. Pavitt, K., 2003. Commentary. In Geuna, A., Salter, A. J. and Steinmueller, W. E. (Eds.), Science and Innovation: Rethinking the Rationales for Funding and Governance. Edward Elgar, Cheltenham.

249. Pelz, D. C. and Andrews, F. M., 1966. Scientists in Organizations. John Wiley and Sons, New York.

250. Perkmann, M. and Walsh, K., 2008. Engaging the scholar: the types of academic consulting and their impact on universities and industry. Research Policy 37, 1884-1891.

251. Perkmann, M., 2008. Intellectual arbitrage across institutional domains: Effects on innovation, unpublished manuscript, Loughborough University.

252. Pfeffer, J. and Sutton, R. I., 2006. Evidence-based management. Harvard Business Review 84(1), 62-74.

253. Pink, M., 2001. Free Agent Nation. Warner Business, New York.

254. Piore, M. J., 1971. The dual labour market. In: Gordon, D. (Ed.) Problems in Political Economy. D. C. Health and Co., Lexington, MA.

255. Piore, M. J., 2002. Thirty years later: internal labour markets, flexibility and the new economy. Management and Governance 6, 271-279.

256. Pole, C., 2000. Technicians and scholars in pursuit of the PhD: some reflections on doctoral study. Research Papers in Education 15(1), 95-111.

257. Pratt, J., 1992. Unification of higher education in the United Kingdom. European Journal of Education 27, 29-43.

258. Price, D. J. de Solla, 1963. Little Science, Big Science. Columbia University Press, New York.

259. Reed, M. I., 1996. Expert power and control in late modernity: an empirical review and theoretical synthesis. Organization Studies 17(4), 573-597.

260. Reich, M., Gordon, D. M. and Edwards, R. C., 1973. A theory of labour market segmentation. The American Economic Review 63(2), 359-365.

261. Reponen, T., 1994. Recruitment and career development in competition with the private sector. Higher Education Policy 7(2), 30-32.

262. Robin, S. and Cahuzac, E., 2003. Knocking on academia's doors: an inquiry into the early careers of doctors in life science. Labour 17(1), 1-23.

263. Rogers, E. M., 1995 (4th ed.). Diffusion of Innovations. The Free Press, New York.

264. Rosenberg, N., 1990. Why do firms do basic research (with their own money)? Research Policy 19(2), 165-174.

265. Rosenberg, N., 1982. Inside the Black Box. Cambridge University Press, Cambridge.

266. Rosenkopf, L. and Almeida, P., 2003. Overcoming local search through alliances and mobility. Management Science 49(6), 751-766.

267. Rutherford, T. D., 2006. Requiem or rebirth? Internal labour markets and labour market restructuring in the Kitechener and Sault Ste. Marie regions. The Canadian Geographer 50(2), 197-216.

268. Ryle, G., 1949. The Concept of Mind. Hutchinson, San Francisco, CA.

269. Rynes, S. L., 1987. Career transitions from engineering to management: are they predictable among students? Journal of Vocational Behavior 30, 138-154.

270. Sammarra, A. and Biggiero, L., 2008. Heterogeneity and specificity of inter-firm knowledge flows in innovation networks. Journal of Management Studies 45(4), 800-829.

271. Saxenian, A., 1990. Regional networks and the resurgence of Silicon Valley. Caliifornia Management Review 33(1), 89-112.

272. Saxenian, A., 1996. Beyond boundaries: open labour market and learning in Silicon Valley. In: Arthur, M. B. and Rousseau, D. M. (Eds.), The Boundaryless Career. Oxford University Press, New York.

273. Schein, E. H., 1975. How career anchors hold executives to career paths. Personnel 52(3), 11-24.

274. Schein, E. H., 2007. Careers research: some issues and dilemmas. In Gunz, H. and Peiperl, M. (Eds.) Handbook of Career Studies. Sage, Los Angeles, CA.

275. Schultz, T. W., 1961. Investment in human capital. The American Economic Review 51(1), 1-17.

276. Schuster, J. H. and Finkelstein, M. J., 2006. The American Faculty: Restructuring Academic Work and Careers. John Hopkins University Press, Baltimore.

277. Shane, S. and Stuart, T., 2002. Organisational endowments and the performance of university start-ups. Management Science 48 (1), 154-170.

278. Shattock, M. L. and Berdahl, R. O., 1984. The British University Grants Committee 1919-1983: Changing relationships with government and the universities. Higher Education 13 (5), 471-499.

279. Shaw, A., Walker, R., Ashworth, K., Jenkins, S. and Middleton, S., 1995. Moving off Income Support? Obstacles, Opportunities, Choices. Report to the UK Department of Social Security, Paper CRSP246. Centre for Research in Social Policy, Loughborough University.

280. Simon, H. A., 1957. Models of Man. John Wiley, New York.

281. Simon, H. A., 1978. Rationality as process and as product of thought. The American Economic Review 68(2), 1-16.

282. Skinner, C. J., Holt, D. and Smith, T. M. F., 1989. Analysis of Complex Surveys. Wiley, New York.

283. Slaughter, S. and Leslie, L. L., 1997. Academic Capitalism. The Johns Hopkins University Press, Baltimore.

284. Slaughter, S., Campbell, T., Holleman, M. and Morgan, E., 2002. The “traffic” in graduates students: graduate students as tokens of exchange between academe and industry. Science, Technology & Human Values 27 (2), 282-312.

285. Smith, K., 2000. Human resource, mobility and the systems approach to innovation. In: OECD Innovative People: Mobility of Skilled Personnel in National Innovation Systems. OECD, Paris.

286. Soete, L., 2002. The challenge and the potential of the knowledge-based economy in a globalised world. In: Rodrigues, M. J. (Ed.) The New Knowledge Economy in Europe. Edward Elgar, Cheltenham.

287. Squire, L. R. and Kandel, E. R., 1999. Memory: From Mind to Molecules. Scientific American Library, New York.

288. Squire, L., 1987. Memory and Brain. Oxford University Press, New York.

289. Stephan, P. A., 1996. The economics of science. Journal of Economic Literature 34, 1199-1235.

290. Stephan, P. E. and Levin, S. G., 1992. Striking the Mother Lode in Science: The Importance of Age, Place and Time. Oxford University Press, New York.

291. Stephan, P. E., Gurmu, S., Sumell, A. J. and Black, G., 2007. Who’s patenting in the university? Evidence from the survey of doctorate recipients. Economics of Innovation and New Technology 16, 71-99.

292. Stephan, P. E., Sumell, A. J., Black, G. C. and Adams, J. D., 2004. Doctoral education and economic development: the flow of new Ph.D.s to industry. Economic Development Quarterly 18, 151-167.

293. Stinchcombe, A. L., 1979. Social mobility in industrial labour markets. Acta Sociologica 22(3), 217-245.

294. Stoke, D. E., 1997. Pasteur’s Quadrant: Basic Science and Technological Innovation. The Brookings Institution, Washington, D. C.

295. Super, D. E., 1957. The Psychology of Careers. Harper and Row, New York.

296. Teece, D. J., 2003. Expert talent and the design of (professional services) firms. Industrial Corporate Change 12(4), 895-916.

297. The Dearing Report, 1997. Higher Education in the Learning Society: The National Committee of Inquiry into Higher Education. HMSO, London.

298. The Robert Report, 2002. SET for Success. HM Treasury. Online available at: http://www.hm-treasury.gov.uk/ent_res_roberts.htm (accessed on 24 January 2010)

299. Tolbert, P. S., 1996. Occupations, organizations, and boundaryless careers. In: Arthur, M. B and Rousseau, D. M. (Eds.) The Boundaryless Career. Oxford University Press, New York.

300. Tornquist, K. M. and Kallsen, L. A., 1994. Out of Ivory Tower: characteristics of institutions meeting the research needs of industry. The Journal of Higher Education 65 (5), 523-539.

301. Van Looy, B., Ranga, M., Callaert, J., Debackere, K. and Zimmermann, E., 2004. Combining entrepreneurial and scientific performance in academia: towards a compounded and reciprocal Matthew-effects? Research Policy 33, 425-441.

302. Vinodrai, T., 2006. Reproducing Toronto's design ecology: career paths, intermediaries, and local labour markets. Economic Geography 82(3), 237-263.

303. Walton, R. E., Cutcher-Gerschenfeld, J. E. and McKersie, R. B., 1994. Strategic Negotiation: A Theory of Change in Labour-Management Relations. Harvard Business School Press, Boston, MA.

304. Williamson, O. E., 1981. The economics of organizations: the transaction-cost approach. American Journal of Sociology 83, 548-577.

305. Williamson, O. E., 1996. The Mechanisms of Governance. Oxford University Press, Oxford.

306. Wolter, K. M., 1985. Introduction to Variance Estimation. Springer, New York.

307. Zellner, C., 2003. The economic effects of basic research: evidence for embodied knowledge transfer via scientists' migration. Research Policy 32, 1881-1895.

308. Zenger, T., 2002. Crafting internal hybrids: complementarities, common change initiatives, and the team-based organization. International Journal of the Economics of Business 9(1), 79-95.

309. Ziman, J., 1996. Postacademic science: constructing knowledge with networks and norms. Science Studies 9(1), 67-80.

310. Zucker, L. G., Darby, M. R. and Armstrong, J. S., 2002a. Commercializing knowledge: university science, knowledge capture, and firm performance in biotechnology. Management Science 48(10), 138-153.

311. Zucker, L. G., Darby, M. R. and Torero, M., 2002b. Labor mobility from academe to commerce. Journal of Labor Economics 20(3), 629-660.