'Knowledge Networks and Careers: Academic Scientists in Industry-University Links'*

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Abstract

Careers are central to our understanding of the knowledge creation dynamics of network organizations. Based on the example of R&D project collaboration between firms and universities, this paper examines the emerging forms of career models that support knowledge flows between organizations. It explores how some large firms in the high-technology sectors have sought to break away from the limitations of internal R&D and firm-based careers for scientists by engaging in external collaborative projects to gain access to the open knowledge networks of university researchers. It examines how the firms seek to forge close institutional ties with their university partners and develop network career structures in order to engage academic scientists in joint knowledge production. It argues that firms have sought to extend their human resource and knowledge boundaries into the established internal labour markets of the universities with which they collaborate leading to the formation of a pool of joint human resources with work experiences and career patterns straddling the two sectors. The paper develops the concept of an 'extended internal labour market' ('EILM') to provide a conceptual bridge between internal labour markets and network organizations.

Keywords: knowledge, network organizations, scientists, careers, university-industry links, extended internal labour markets.

INTRODUCTION

The 'knowledge economy' has been characterised in recent years by the search for new models of organizations and employment in order to cope with rapid technological innovation and change (Arthur and Rousseau 1996; DeFillipi 2002). Many organizations have to balance the need for retaining a strong in-house competence in their core business area, while at the same time, building external networks in order to remain open to new knowledge and scientific developments. In the field of innovation, and research and development (R&D), large organizations offering well-established firm-based careers embedded in strong internal labour markets find themselves at a disadvantage. This is because of the fast-moving nature of scientific knowledge, the increased importance of open-networks for knowledge exchange, and the frequent trans-disciplinary nature of discoveries (Jones 2000; Howells et al 2003). With the accelerated pace of technological advance, a profitable line of R&D may cease to be so in five years, and the scientists hired for current R&D needs may have inappropriate expertise for later needs. In addition, too much employment stability in the R&D teams can lead to 'group think', and therefore miss the potential for important new scientific developments taking place outside. Therefore, many large high-technology firms have sought to break away from the knowledge creation constraints of internal R&D by developing various forms of external collaborative arrangements and network ties, for example, by means of collaborative projects with university scientists (Powell and Owen-Smith 1998; Murray 2002; Lam 2003). This helps them to keep abreast of the latest scientific advances in their areas and ensures that they integrate them into their innovative routines. However, the frameworks for cooperation and career structures needed to motivate scientists to engage in collaborative projects and support knowledge transfer across organisational boundaries remain poorly understood. Despite the voluminous literature on the network organization as a new mode of innovation, we know surprisingly little about how the flow of knowledge across organizational boundaries is intertwined with careers and employment relationships.

The development of network organizations characterised by less sticky employment relationships calls for re-conceptualisation of the traditional career models based on either 'internalisation' or 'externalisation'. This dichotomy is too simplistic, and fails to capture the complexity of career models emerging in the knowledge-intensive sectors of the economy (Lepak and Snell 1999; Marsden 2004). Piore (2002), in reviewing the relevance of the concept of Internal Labour Market (ILM) thirty years on argues that the narrow concept of ILM associated with large bureaucratic organizations will need to be redefined to take into account the growth of more flexible forms of organization and project work. He argues that these changes justify a broader definition of ILM to include its socially defined boundaries spanning organisational boundaries. In a similar vein, Camuffo (2002) notes that the rise of network organizations, marked by more flexible and open relations between firms and employees, has eroded the interpretive power of ILMs. In some of the fast-moving high-technology sectors, value-added arises increasingly from novel combinations of knowledge and skills, and workers who have acquired external project experience become valuable to firms. Nevertheless, for many organizations, the type of knowledge and competences needed for innovative projects will retain a contextual dimension and their formation takes time. In this context, Camuffo (2002) argues that firms continue to have incentives to capitalise on knowledge investments by adopting a variety of hybrid employment models that may blur the traditional distinction between the ILM and external labour market. He asks researchers to develop new concepts to bridge ILMs and network organizations.

In this paper, I develop the notion of an 'extended internal labour market' (EILM) to interpret the network career models that are emerging to support inter-organizational collaboration and knowledge production in some of the most dynamic, fast-moving industries. The idea that internal labour markets may extend their roots beyond the boundaries of an organization has a long heritage, from the studies by Rees (1966) and Granovetter (1974) of informal networks in recruitment, and that of Manwaring (1984) who coined the term, EILM, to describe how firms recruit through their existing employees and seek to extend their internal labour markets through the social networks into their local community. In the present paper, I use the concept in a broader sense to stress the active role of firms in developing social networks for skills and knowledge sourcing through external project links. It also highlights the critical role of such network ties in providing stable frameworks for career development, and supporting mobility of people and knowledge flows across organizational boundaries. While Manwaring used the term 'EILM' to refer to the extension of firms' ILMs into their local communities, I use the term to refer to how the boundaries of ILMs could be extended into new types of relationships cutting across two sets of organisations. Several authors stress the importance of careers and human resource linkages to collaboration and knowledge sharing between the scientific and business communities (Murray 2002; 2004; Powell and Owen Smith 1998). Zucker et al (2002 a&b) draw attention to the growth of a common scientific and technological labour market spanning university and industry, and the career moves of focal scientists as an important structural mechanism in facilitating the transfer of knowledge between the two sectors. The literature on 'boundary-spanning roles' in innovation and 'brokers' in social networks (Tushman 1977; Burt 2000) suggests that career experiences are central to developing individuals' abilities to provide social capital bridging between their organizations with other domains. Building on these insights, I argue that careers are of utmost importance in understanding the motivation of scientists in developing project links with firms, and in supporting collaborative arrangements underpinning knowledge flows in project networks.

The empirical research is based on a number of case studies carried out in the high-technology sectors in which R&D and scientific collaboration are crucial drivers of innovative success. The study explores how some large firms in these sectors have sought to remedy the limitations of corporate in-house R&D by engaging in various forms of collaborative arrangements to gain access to the open knowledge networks of university researchers. It examines how the firms use collaborative projects to engage academic scientists in joint knowledge production and develop network career models that span the two sectors.

The paper is structured as follows. Section one reviews changes in models of R&D organisation and careers of scientists in order to provide a context for the study. Section two discusses the problem of joint knowledge production between firms and universities, focusing on two inter-related human resource problems: that of cognition and competences, and that of careers and incentives. Section three examines how the firms have sought to resolve these problems by developing special organizational arrangements and career structures to support the development of joint human resources and close collaborative relationships with their university partners. Section four applies an interpretative framework, arguing that in these cases the firms have not abandoned internal labour markets as such, but have sought to transform the way they operate. Indeed, they have sought to develop hybrid arrangements with one kind of large organization which has acted as a host to a variety of knowledge networks, namely universities. In this context, the large private firms have sought to construct what might be called 'extended internal labour markets' (EILMs) by extending their scientific human resource boundaries into academia, and making use of the career systems provided by universities with which they collaborate. This has enabled them to shape the knowledge and competencies they need, and to provide a suitable career framework for the scientists engaged in short-duration projects.

THE CHANGING CONTEXT: R&D ORGANIZATION AND CAREERS OF SCIENTISTS

Over the past four decades, large industrial firms have developed different models of R&D organization and human resource strategies to integrate academically trained scientists into the innovation process. The network organization is the latest of three distinct phases in the structural transformation of industrial R&D. The dominant model has evolved from that of 'technology-push' of the 1950s and 1960s to the 'market-pull' model of the 1970s until the late 1980s, and the emerging 'network' model of today (Rothwell 1992). These three models reflect the changes in the relationship between 'science' and 'business' both within the firm, and also between industrial R&D and academia. The careers of scientists have also co-evolved with these different models of R&D.

The early technology-push model assumed a linear flow of knowledge from basic research to applied industrial R&D. The university was the main supplier of fundamental knowledge and qualified scientific personnel, and the industrial laboratory socialized academic scientists into an industrial environment (Abrahamson 1964). Under this model, industry and university operated as two separate institutional spheres and the central linking mechanism between them was the recruitment of scientists. Within the firm, management sought to elicit the commitment of R&D staff by adopting high-trust career strategies through the provision of long-term job security and careers (Causer and Jones 1996).

The market-pull model gained currency during the 1980s when increased product market competition prompted many firms to decentralize their R&D in order to speed up product innovation, and to pursue more market-focused R&D strategies through greater use of external subcontractors (Whittington 1991). Within the firm, R&D ceased to be the exclusive responsibility of the R&D function and became more closely linked to other business activities. The downsizing and commercialization of corporate R&D diminished the traditional technical career path, and generated career insecurity among R&D personnel

(Lam 1994; Causer and Jones 1993). A more fundamental dilemma facing the market-pull firms is the potential difficulty of attracting and retaining the necessary core scientific personnel. The long-term weakness of this model has become more apparent since the early 1990s when the accelerated pace of technological progress makes firms vulnerable to the destruction of their knowledge base.

A solution adopted by many R&D intensive large firms has been to move towards the network model and use network of scientists across organizational boundaries to augment their internal knowledge base. The recent scientific and technological revolution has also provided a spur to external R&D collaboration. This has blurred the boundaries between basic research and applied and development work, and eroded traditional barriers between scientific and technological disciplines. Especially in the sectors where basic science is a key source of innovation and economic advantage, many large firms seek to collaborate with research universities (Kaufmann and Todtling 2001). The move towards the network model of R&D involves a significant shift in the relationship between industry and university from the older linear model of one-way knowledge flow to an interactive model of two-way knowledge exchange between the two sectors. This increased interchange also takes place within a potent change in the government's public science policy seeking to promote closer science and business links in a knowledge-driven economy (HMSO 1992; DTI 1998). For many high-technology firms, the university becomes a key actor in their innovation strategies and hence a major challenge for them is the development of collaborative structures to engage academic scientists in joint knowledge production.

PROBLEMS OF COOPERATION AND KNOWLEDGE CREATION IN INDUSTRY-UNIVERSITY COLLABORATION

University-industry collaboration has long been shown to be problematic because of the difficulties in reconciling the divergent work norms and reward structures governing the two different knowledge production systems (David et al 1999). One might consider the problems as rooted in two inter-related human resource issues: that of cognition and competencies, and that of careers and incentives. The first relates to the nature of the activity itself, the joint production of new knowledge with commercial application, and the development of the necessary joint human capital. The second relates to the patterns of careers and organizational frameworks necessary to encourage positive cooperation between academic scientists and firms.

Joint production of new knowledge and competencies

To understand the nature of the joint human capital needed for collaboration between companies and open scientific knowledge networks, it is helpful to consider the contrasted ways in which knowledge is held and developed in the academic and industrial environments. Academic knowledge networks tend to be based on what Gibbons et al (1994) describe as 'mode 1' knowledge. This is discipline-based. The reasons for this are easy to see. These knowledge networks depend upon a collective effort of scientific advance within specialist fields in which peer criticism provides a major stimulus. Hagstrom (1970: 93) characterised specialties as the 'micro environments of research' that provide the 'building blocks of science' because scientists will communicate most intensively and frequently with others in their specialities and form their own tightly knit communication networks. As such, not only are the cognitive and intellectual interests of academic scientists built around specialist disciplines; but the priority-based reward system also provides incentives for scientists to expand effort on the formulation and testing of discipline-specific theories (Merton 1957; Dasgupta and David 1994). In the university environment, specialisation of knowledge production is legitimated by the organization of intellectual provinces into disciplines supported by academic departments responsible for the training and certification of new scientists (Chubin 1976). Thus both cognitively and sociologically, academic science cannot do without disciplines and this explains why mode-1 knowledge production remains the dominant form.

In contrast, what Gibbons et al. (1994) characterise as 'mode 2' knowledge has become predominant in the business environment and much commercial R&D. Such knowledge is problem-based and it lies often at the boundary between existing disciplines. Mode 2 knowledge is contextual and its development often reflects the influence of other practical constraints, notably those of customer demands and cost. Whereas mode 1 knowledge networks may be very effective in promoting scientific development within open disciplinary structures, there is no reason why the social demand for new products and new processes should coincide with disciplinary boundaries (Nowotny et al 2001). The dominance of 'mode 1' knowledge in academic knowledge networks poses problems especially for commercial collaboration. The methods of intellectual discovery and development differ between the two environments; and the knowledge imparted through education tends to conform to ‘mode 1’ rather than ‘mode 2’. If companies are therefore to seek to anchor their R&D activities in academic knowledge networks, which brings the advantages of being at the cutting edge of new research, then they have to find a way of getting scientists to draw on their mode 1 knowledge and apply it in a mode-2 environment and they have to help shape the competencies acquired by scientists so that they can function easily in this manner.

Career incentives and knowledge flows

At the start of the paper, it was argued that established modes of scientific research in a business environment have reached their limits for many firms as the speed of knowledge advancement and the variety of applications militate against firms hiring large number of scientists as long-term career employees. However, hiring scientists short-term for projects is not a viable solution because scientific research projects are of an inherently long-term nature and they require inputs from different disciplines and occupational groups. Building cooperative scientific teams takes time and depends on experiences in particular contexts. The scientists engaged in such work also need a pattern of career development that will motivate them to work conscientiously at their scientific tasks to produce high quality outputs.

Although careers and long-term employment are a source of inertia, they are also an important incentive device, and they provide a platform enabling firms to develop skills and knowledge which are tailored to their own needs. As an incentive device, careers can be thought of as a form of deferred reward. They are particularly suited to cases in which it is difficult for management to assess true quality of current performance until after some quite long time delay as often arises in scientific work. They also provide a basis for ‘promotion tournaments’ whereby competition with one’s peers for prestige and promotion can act as an incentive to achieve high quality performance (Lazear 1995). For the individual scientists, careers and organizational attachment are all the more important because of the time, research resources and teams needed for the production of scientific knowledge (Goldberg and Kirschenbaum 1988; Stephen 1996).

The need to motivate creative staff, to encourage knowledge creation and to foster cooperative team work is as present as ever, but when firms seek to move away from career employment they have to consider how to achieve the same ends but with different means. Lepak and Snell (1999: 41) argue that in this situation firms will seek to develop a hybrid mode of employment relationship that blends internalisation and externalisation by developing partnerships with external organizations to create joint human capital. In the cases examined in this paper, the firms chose to collaborate with research universities. As will become apparent in the analysis of the case study material, the joint project between the company and the university resolves a number of the above problems. First and foremost, universities are embedded in open knowledge networks and they are non-rival partners. Second, universities have the resources to serve as ‘brokering organizations’, certifying and signalling the competencies and reputation of individual scientists, and have their own internal incentive mechanisms to ensure performance. And third, more critically, universities provide independent career structures and employment systems for those engaged in collaborative research projects. The existence of such an organizational anchor is of particular importance in scientific R&D projects because most scientific collaborations are not just on a one-off basis. If they are successful, they may be repeated over time. However, scientists must also remain in contact with their own knowledge networks while they engage on such collaboration. To do otherwise would simply mean that the value of the knowledge they bring to the relationship would gradually decline as it became out-of-date. The scientists therefore need to remain well-integrated into their scientific networks to continue to create new knowledge and engage in competitive science. They are not selling a stock of knowledge, but rather they are providing the firms with access to a continuous and often rapid flow of new knowledge. This is critical for the scientist from a career perspective and also for the company as the best competitive returns it can gain from investment in R&D arise from being ahead of the field.

Thus, a key hypothesis of this research is that in these circumstances firms will support their collaborative relationships with universities by developing special organizational and career arrangements to support close network ties in order to engage academic scientists in joint knowledge production.

THE EMPIRICAL STUDY

The field research is based on three in-depth company case studies from two sectors: two in information and communication technology (ICT1 and ICT2) and one in pharmaceuticals (Pharma). These are all large companies operating in dynamic and innovation-intensive industries. All the three companies selected for the study have, or have had in the recent past, well-established in-house central R&D facilities that conduct long-term or advanced research and offer long-term stable careers for their scientists. Both sectors are 'science-based', and in the past 'technology-push' innovation was important. These two sectors are chosen to illustrate the new innovation challenge facing firms arising from the recent scientific and technological revolution. Firms operating in these industries are under intense pressure, on the one hand, to speed up innovation through the adoption of market-induced innovation strategies, and on the other, to maintain their core technological base and develop capabilities in the newly emerging scientific fields.

Data were collected by semi-structured interviews with technical managers and scientists in R&D laboratories, managers in human resource groups and with technical staff directly engaged in collaborative projects with universities. I carried out a total of thirty individual interviews with the company scientists and managers. The investigation focused on the companies' R&D and knowledge sourcing strategies, the organisation of links with universities and the mechanisms used to gain access to the knowledge and expertise of academic scientists. I also conducted a total of twenty-seven interviews with university scientists engaged in collaborative links with firms. The interviews explored in detail their work roles and career experiences. Fifteen of the university scientists interviewed were directly engaged in project links with the companies studied, and twelve were in similar roles but not directly linked to the companies. Most of the interviews were conducted between 2000 and 2001. Each interview lasted for about 60-75 minutes. All the interviews were recorded and transcribed. The interview sample is shown in Table 1.

TABLE 1 ABOUT HERE

The case study companies

All the three companies examined in the study introduced major structural changes in their R&D organizations from the latter half of the 1990s. They sought greater decentralization of R&D, and a closer alignment of R&D programmes with business objectives. These have led to increased business influence over the R&D agenda and narrowed the knowledge bases of the companies. However, the firms have made serious attempts at the corporate level to counter-balance the pull towards short-term, market-driven R&D objectives by developing closer ties to the external academic knowledge base through long-term strategic relationships with universities.

ICT1

ICT1 is a multinational corporation in the computation and communications business. The research and development conducted by the company is distributed between the corporate laboratories and R&D groups at the divisional level. Its central research organization is globally distributed employing 800 people, and its headquarters are located in the USA and UK. The UK lab employs around 200 R&D staff. In the late 1990s, the company re-organised its businesses into four autonomous business divisions aiming at developing a sharper market focus. At the same time, the central laboratories re-organized their research programmes into four areas seeking closer alignment with the four business areas. These changes have led to greater business influence over the laboratories' research agenda, and increased pressures on the laboratories to be accountable to the businesses. However, at the corporate level, there have also been systematic policies to counter balance 'market-pull' and prevent the focus of R&D from becoming too short-term oriented. A key aspect of this has been to develop closer links with major research universities in order to maintain and leverage its basic research capability. The company introduced a ‘Basic Research Initiative’ in 1994 to set up basic research programmes with major research universities in the U.K. and U.S. In 1995, it developed its Strategic University Relations Programme on a global scale. Its mission was to develop long-term partnerships with a small number of key universities. These academic links constitute the foci of the companies’ external knowledge networks and provide important channels for gaining access to top academic researchers. ICT 1’s vision of its corporate labs, according to the director of corporate R&D, is that they will become the ‘integrating centre for a network of relationships outside’ with their key researchers located within universities.

ICT2

ICT2 is a multinational telecommunications equipment manufacturer and a supplier of networking solutions and services. The company had developed a strong technology-oriented culture with a centralised R&D organization operated through a wholly owned research company. In 1998, this was dissolved and the R&D function was distributed amongst the different business lines, with only a small central R&D group called *Advanced Technology* remaining at the headquarters. The European R&D headquarters in the U.K. served as advanced development centres, employing around 1500 staff. The distribution of the R&D function has meant that there is no longer a central budget. R&D is regarded as one of the activities, amongst others, developed by the businesses. As a result, the company's technology base has become much narrower than it was ten years ago. In recent years, the company has placed an increased emphasis on establishing collaborative links with universities which are now seen as critical for sustaining the company’s long-term innovative capability. It has recently introduced a global university relationship programme, managed by an External Research Group, which reports to the Vice-President of Disruptive Technologies at the corporate level. The group has a strategic role in searching for new directions of research and ensuring that the relationships with universities generate disruptive ideas that will shape the company’s future businesses.

Pharma

Pharma is a global pharmaceutical company which has been experiencing rapid growth and expansion in recent years. The company’s Global Research and Development division employed approximately 12,000 people at six discovery sites in 2001. It has formed alliances with more than 250 partners in the academia and industry that strengthen its position in science and biotechnology. R&D has been one of the pillars on which the company has supported its rapid growth over the past decade. The Discovery Group in the UK employed 640 staff at the time of the study. Like other firms in the pharmaceutical industry, links with the academia have always been important for Pharma, but the recent growth in the scientific intensity and complexity of drug research has further strengthened its propensity to enter into collaborative relationships with external research organizations and universities. The world-wide budget for external research had more than tripled between 1995 and 2000. Moreover, the recruitment of PhD scientists was reported as being critical for maintaining the company’s academic networks. In the face of growing competition for qualified scientific personnel, Pharma has sought to develop a more focused and targeted approach to the ways it relates to higher education institutions. Forging closer academic links has become so important that the company has recently created ‘strategic recruitment specialists', staffed by senior PhD scientists, to liaise and develop strategic relationships with selected universities.

BUILDING COLLABORATIVE KNOWLEDGE NETWORKS AND HUMAN RESOURCE LINKS

Developing 'strategic university partnerships' for joint knowledge production

Although all the three companies studied have always had links with universities in one form or another in the past, a significant recent development has been the tendency to form closer ties with a small number of key institutions in a more systemic and strategic manner. The main objective has been to focus attention and concentrate resources on a small number of key universities from which they are most likely to acquire their people and knowledge. The term 'strategic partnership' is often used to denote an intention to forge long-term, multi-dimensional ties and trusting relationships with what the companies refer to as their 'preferred institutions'. The relationships are usually sustained by a wide range of linking mechanisms including research collaboration, industrial inputs to curriculum development, student sponsorships and placements, and exchange of scientific staff. While in the past the companies would tactically manage their university links to gain a leading edge in hiring scientific staff, the new strategic focus has been to view the university as a critical partner in the knowledge production chain and to use the long-term relationship to build deep inter-organisational linkages in order to transfer new ideas and knowledge, and to shape the human resources needed for joint projects. A senior manager responsible for university links in ICT1, for example, talked about the importance of building 'deep and trusting relationships' with their university partners so that ' you have early access to the best ideas and trusted access to the best people…'. ICT2 stressed the importance of acquiring 'disruptive ideas' from their university partners by using collaborative projects as main linking mechanisms and key scientists as 'interactors' to connect their internal R&D with the external academic knowledge base (interview with Research Manager). Pharma wanted to use the 'deep relationships with key universities and lecturers' to 'influence what those PhDs do…' and to get them to 'work on particular research areas of interest to the company' (interview with R&D Director).

In short, the firms are developing a new model of collaborative relationships to engage academic scientists in the knowledge production process. A main thrust of this has been to use joint projects and hybrid research units to breakdown the cognitive and institutional barriers between the two sectors and to stimulate active collaboration with university scientists at the bench working level. On the basis of this, the firms seek to develop a pool of human resources, the 'linked scientists', whose work roles and careers span the two sectors and are capable of linking Mode 1 scientific knowledge to Mode 2 industrial problem-solving. As will be discussed below, these collaborative arrangements enable the firms to extend their human resource and knowledge boundaries into the academic career system, and to contextualise the knowledge produced through joint projects.

Creating permeable boundaries through hybrid research organizations

An important mechanism used by the firms to gain close access to the academic scientists has been to set up university-based research units. These are usually partly or fully funded by the firms, comprising academic and industrial research staff engaged in collaborative projects. Indeed, collaborative university research centres have been one of the fastest growing academic structures in recent years (Jennings 2003; Lambert 2003). Many large companies are using these centres to consolidate their relationships with university partners and to provide strategic foci for developing long-term collaborative projects and close human resource ties. These centres constitute a form of hybrid organization at the interface between the two sectors where two-way exchanges of people and knowledge take place within fluid and permeable boundaries. The blurred boundaries enable the collaborating partners to organise projects and mix research teams flexibly outside the established disciplinary boundaries and organisational structures. They create what Galison (1997) describes as 'trading zones' in which the different research goals and interests between scientists and firms are subject to negotiation. The existence of such overlapping spaces makes it possible for firms to contextualise the research carried out in the academic environment, and to connect Mode 1 knowledge production with Mode 2 industrial problem solving.

ICT1, for example, set up a basic research institute in mathematics in the mid-1990s as part of the company's basic research initiative to widen its research base. The hybrid research unit sits at the interface between ICT1 Lab and its partner university in West England. It provides a forum for joint recruitment, collaborative activities and personnel exchanges. The core research staff comprises a mix of ICT1 researchers, academic scientists jointly appointed by the company and university, and a continuous flow of sponsored post-doctoral researchers and PhD students working on projects jointly supervised by academic and industrial scientists. The initial decision to create the unit was prompted by the difficulties encountered by the company in attracting leading research scientists because it was no longer seen as offering stable careers for long-term research. In the face of growing competition for scientific talent, the company decided to collaborate with its partner university in making joint appointments based at the university. A longer-term objective of ICT1 is to use the hybrid arrangements to construct a new space in which joint knowledge production could be managed through subtle alignment of academic research goals with the strategic interests of the company. This is achieved ‘through the people we now share’ and by getting the university scientists ‘to enter into the discussion and seeing the context in which the company works’, according to the research director interviewed. In doing so, ICT1 seeks to develop a core group of researchers who would understand the industrial context and ‘develop interests in areas of strategic importance to the company’. In other words, ICT1 is using the interface to manage Mode 2 knowledge production where new ideas and knowledge are generated through contextualisation of academic research in a subtle manner. For example, the director of the unit talked about how to get the researchers to ‘absorb some of the things’ that are of interest to the company while at the same time allowing them ‘to operate in an academic environment’. The hybrid organisation provides a forum for developing ‘Mode 2’ capacities among the core academics involved and it also serves as a training ground for the younger scientists, the post-docs and doctoral students, who provide a potential source of new recruits for the company: ‘Because some of the postdocs have actually come here and they’ve so much liked what they found, they’ve stayed, they’ve joined. It’s become a recruiting porthole for ICT1’ (research director).

ICT2 has also recently established a university-based laboratory aiming at developing a novel area of expertise in mathematics that lies outside the company's core competence. The company has traditionally recruited the majority of its researchers with expertise in electronics engineering and computer science. However, the internet revolution has prompted increased awareness among top management of the growing potential that mathematics could offer to the telecoms industry, especially in internet traffic control. The initial idea of recruiting a small number of mathematicians to work in its in-house laboratories was rejected for fear that these people might find themselves isolated and 'unable to obtain the kind of support that they could get in an academic environment' (interview, ICT2 project manager). A solution adopted by ICT2 was to part-fund a research unit, based at a university where it had already established collaborative relationships with a professor in Mathematics. The unit brought together a team of researchers from two different sub-disciplines in Mathematics, led by the professor. The idea is to combine their expertise, together with industrial inputs, to develop new approaches for solving data processing problems.

ICT2 has two main objectives in this collaboration. The short-term, immediate one is to acquire new techniques to control internet traffic which is core to its current activities. The long-term objective, according to the academic relations manager interviewed, is to create an extended pool of human resources with 'continuity of experience and knowledge' that the company can draw upon when needed:

> 'Well what we expect, of course, is that they will have a nucleus of bright young people with experience of telecom networks and may be other things that ICT2 introduces…So we want this pool of information and resource so if we get a problem with data management or software or production process they have people here who have contacts with the company and quite possibly a lot of experience actually with the problem'.

An immediate challenge for ICT2 was to bridge the large cognitive gap between the abstract world of the Mode 1 mathematicians and the concrete reality of Mode 2 problem solving in industrial data processing. A professor commented that 'most people [academics] wouldn't deal with industrial statistics' because 'It's a mess and you don't get nice clear results'. A central concern of ICT2 was to find a way to encourage good mathematicians to work on industrial problems. The creation of the research unit has enabled the company closely to engage a core group of academics to define a cluster of projects aimed at developing mathematical techniques that could be commercially important for the company but also academically interesting for the researchers. These negotiated projects play a crucial role in contextualising knowledge production through gradual fusion of ideas and interests between the scientists and company over time. The ICT2 project manager responsible for the collaboration commented on the effort and time that both partners had spent on 'defining the problem in a way that would be understood by people in ICT2 and completely by people in the mathematics world'. An academic engaged in the projects noted how 'the attitude of Maths department to getting their hands dirty has changed' because 'there's been a realisation one way but there has also been a reciprocal movement the other way'. The direct knowledge output of these projects has been the development of new techniques and patents for the company, and new research ideas and publications for the academics. More crucially, the collaboration has created a core group of 'pretty good workers who know their stuff' and 'work in an academic environment for ICT2', as noted by the professor heading the research unit.

It is apparent from the above two cases that the hybrid organization serves to resolve a human resource dilemma for the firms. The collaborative structure enables the firms to engage academic scientists in industrial projects while at the same time ensuring that they remain firmly integrated into wider scientific communities. It also creates a 'transaction space' for the firms to foster a zone of shared interests between themselves and the scientists, and to manage Mode 2 knowledge production through contextualisation of Mode 1 research.

The 'linked scientists': hybrid work roles and careers

At the core of the firms' collaborative links with their university partners is the creation of a pool of human resources, the 'linked scientists' (Zucker et al 2002a), whose work roles and careers straddle the two sectors. There are three categories of researchers who perform the role of 'linked scientists'. The first concerns the 'entrepreneurial' professors who have on-going collaborative links with firms but retain their full university positions. The term 'entrepreneurial', following the notion of the 'entrepreneurial university' (Clark 1998; Etzkowitz 2003), is used here to denote those scientists who make connections to business firms in their research, and who combine academic goals with knowledge application by building organizational ties between academic research groups and firms.[1] The second category of 'linked scientists' concerns those in joint appointments, or post-docs, who are formally affiliated to the university but work on collaborative projects with firms. And the third concerns the doctoral students who are selected and funded on the basis of criteria negotiated between the firm and its academic partners, some of whom may subsequently be employed by the firm. Together they constitute the knowledge network nodes in firms' university partnerships, and provide key human resource links enabling firms to connect their internal R&D with the external academic knowledge base.

The 'entrepreneurial' professors as focal links

The ‘entrepreneurial’ professors are the focal points of firms’ links to the universities. They are academic scientists who participate in both the scientific and business communities, and are active in building inter-institutional ties through collaborative research, student placements, consulting and company advisory board membership. The majority of these professors have maintained long-term relationships with their key industrial partners and have developed, through their career experiences, a ‘dual cognitive mode’ (Etzkowitz 1998) in their research, focusing both on scientific advances and application of their knowledge. A chemistry professor, for example, talked about his fascination with ‘business problems’:

> “Let’s take the problem that they set. Problems which they set which are their business problems are fascinating because they have challenges such as, 'we have a 90% yield in this process, let’s make it 95%' and the constraints are enormous ‘but you cannot sell this material for more than £5 for a kilo’, so the limitations and the constraints imposed by the economics channel your thinking into finding cheap solutions. But at the same time Company X can produce exotic fragrances with very beautiful organic molecules which may take, let's say, ten steps to make and which may be very sophisticated state of the art organic synthesis …And that’s at the forefront, cutting edge of academic research at the same time”.

Many of these professors are cognizant of the value of combining ‘mode 1’ fundamental research with ‘mode 2’ industrial problem-solving, and saw the multi-disciplinary nature of industrial problems as a source of intellectual challenge and creativity:

> ‘I’m an academic so I must make a fundamental academic contribution…but at the same time if you inter-twine your academic thread with fundamental curiosity with your industrial thread of tackling important problems to solve then, I think, then you come up with the best combination of research to do…So there are engineering problems, there are chemistry problems and always there are fundamental chemistry problems to be solved and you have to come up with creative, ingenious solutions’ (Professor of Chemistry).

> ‘The challenges of questions, scientific problems that they [industry] put to you which just need solutions and they may be very practical but they can often draw on quite challenging, theoretical, scientific, pure scientific methods.’ (Professor of Physical Chemistry).

As a result of their long-standing links with their industrial partners, the professors become what Etzkowitz (1998) refers to as ‘knowledgeable participants’: they are aware of the industrial contexts of their scientific work and willing to play an active role in arranging knowledge transfer to their industrial partners. Thus both cognitively and organizationally, these entrepreneurial professors play a critical role in bridging the interface between science and business. They contribute not only their deep scientific expertise to industrial projects, but more critically, their ‘brokering’ role enables the firms to embed themselves within the wider scientific networks, including their local laboratory networks of researchers and doctoral students.

All the firms looked at in this study have developed their university partnerships through the deep engagement of such entrepreneurial professors in the collaborative relationships. Pharma, for instance, has recently engaged in a 5-year large-scale consortium research project with a university in Scotland. The engine behind the creation of the project was a 'star' bio-scientist who had developed strong personal links with Pharma through informal consultancy activities starting around the mid-90s. The relationship subsequently expanded and developed into a formal collaborative link with the university, culminating in the creation of the new laboratory led by the professor. While maintaining his full university status, the professor has become a vital source of intellectual capital for the company through collaborative projects, his leading role in promoting wider links between his department and the company, and more critically, his key role in transferring early discovery results via frequent contacts with Pharma scientists. He also acts as a magnet for attracting other top scientists to his laboratory, providing a source of reliable researchers for the collaborative projects.

ICT1’s strategic partnership with a university in the west of England also revolves around an entrepreneurial scientist who had been an industrial researcher in computer science for fifteen years before joining academia. His relationship with ICT1 dated back to his years in industry where he had built a strong reputation in both the business and academic communities. His arrival at the university gave a strong impetus to the partnership through funding of research projects and drawing up a broad framework agreement to facilitate long-term relationships based on personnel exchanges and participation of ICT1 scientists in curriculum development and project supervision. Thus, this professor not only represents a centre of expertise for ICT1, he is also the main conduit through which ICT1 gains early access to students and influences their training: 'They want to be able to get access to students and to try and target and persuade the best one, the ones that fit their profile…' (interview with the professor).

Likewise, the relationship between ICT2 and a university based in London builds on the work of a prominent academic in opto-electronics whose long-standing relationship with the firm spans over twenty years throughout his entire academic career. It started in the 1970s when he was completing his doctorate. ICT2 subsequently funded his appointment at the university with a contractual obligation to work on areas of interest to the company, defined in broad terms. While maintaining his formal position as a full-time university employee, this professor has a dual employment relationship in practice and his work is governed by contractual arrangements with ICT2. His relationship with the company has been a deep and extensive one covering a wide range of activities including collaborative research, funding and joint supervision of doctoral students and student placements in ICT2 laboratories. Through the long-standing relationship with this professor, ICT2 has also been able to develop multiple links with the university in both research and educational programmes. At the time of the study, there were at least ten other academics in the department who had developed close ties with the company.

The post-doctoral researchers as joint human capital

The post-doctoral researchers are a growing category of 'linked scientists' situated at the interface between industry and academia. These are usually young scientists located half-way between training and scientific employment who are employed for a fixed duration on industrial collaborative projects. For the firms, these researchers constitute a pool of flexible scientific labour and a repository of new knowledge that they can draw upon but without having to commit themselves to a period of employment of more than two to three years. All the companies looked at in the study use post-doctoral researchers as a main mechanism for funding collaborative projects with the professors. Pharma, for example, spends over half of its academic collaboration budget on the post-doctoral scheme and believes that it is 'good value for money' because 'you've got somebody who is already well-trained and who has a PhD… and are usually very productive' (interview, head of strategic resouring, Pharma). For the universities, these funded positions enable them to expand their research activities and offer temporary employment to their new PhDs while they build up their research record and wait for permanent positions in either academia or industry. Some of these researchers may eventually be recruited by the sponsored firms, which seek direct transfer of project experience into their R&D laboratories. A professor engaged in a major collaborative project with a consortium of pharmaceutical companies talked about how the companies were trying to pick some of his 'star' post-docs. Another senior academic saw the post-doctoral positions as opportunities for some of his younger colleagues to 'get their faces known in the companies' and as vehicles for career moves from academia to industry. The post-doctoral researchers represent a kind of joint human capital shared between firms and universities within a transitional labour market.

The doctoral students as a new breed of 'hybrid' scientists

Another category of 'linked scientists' is provided by the doctoral students whose competences are jointly produced by universities and firms either through full industrial sponsorships or some kind of private-public collaborative education and training programmes.[2] All the network firms use such programmes to strengthen links with their academic partners, and influence postgraduate training in order to develop a new breed of hybrid scientists capable of operating in a 'mode 2' problem-solving context. Pharma, for example, sponsors about 30 doctoral students each year, and ICT2 has been a key sponsor of the Engineering Doctorates[3] in telecommunications at one of its partner universities. This involves regular teaching inputs, joint supervision of projects and advisory board memberships. The most important aspect of the sponsorship, according to the professors interviewed, is not so much the funding itself, but the supervision inputs from the industrial partners, and provision of opportunities for the research students to 'learn in context' through solving mode-2 type of industrial problems. This resembles a kind of informal apprenticeship, which allows industrial practice to penetrate academic training, and facilitates the reverse-flow of knowledge from industry to universities by shaping the skills and competences of the new generation of scientists. Several of the professors pointed out how their industrial partners used the relationships with them to get the students they need and to 'match' their competencies to the roles in the companies.

THE CAREERS OF 'LINKED SCIENTISTS' AND EXTENDED INTERNAL LABOUR MAKRETS (EILMs)

The 'linked scientists' in the academic career system

A notable feature of the above three types of position is that they reconcile the needs of mode-2 knowledge production with the career needs of the individual scientists. Such needs are partly economic: scientists need an income flow to reward them for their investments in training. They are also partly scientific because individual scientists need to remain a part of the research community in their chosen area while engaging in short-duration industrial projects, if they are to function as practising scientists and to keep abreast of new developments in their disciplines.

For the tenured professors, universities provide a stable career structure with a clear set of rewards which has considerable advantages over those of the private firm, and as consultants. Evidence based on the interviews, and also elsewhere (Murray 2004; Catherine et al 2004), suggests that renowned scientists typically retain their academic positions, while engaging in industrial ventures. The rank of professor brings both stable income and it signals scientific prestige within an occupational community. A key question, then, is: what motivates them to build links with firms and engage in dual work roles? The interviews suggest that it is primarily career-related motives that drive the majority of academic scientists to build links with industry. For physical scientists, the resource requirements for doing research are extensive, involving access to substantial equipment, materials and the assistance of numerous postdoctoral researchers and graduate students (Slaugher et al 2002). Thus funding becomes a necessary condition for doing research, and scientists working in these fields tend to take on many of the characteristics of 'entrepreneurs' (Stephen 1996). Many of the professors interviewed use their reputation and expertise to acquire funding and other resources from industry to support and expand their core research activities. They also regard the firms as 'knowledge trading' partners, providing additional cognitive resources that helped to improve the scientific capabilities of their research teams and stimulated new areas of research. Some professors talked about how they 'used' the companies' expertise and technology, and others mentioned the benefit of a ‘multiplication effect’. Collaborative arrangements with firms also provide career opportunities for students and post-doctoral researchers. This could further enhance the reputation of the professors, resulting in a ‘virtuous circle’ of attracting promising young researchers into their laboratories.

For the pre-tenured researchers, universities provide a type of ‘apprenticeship’ position in the form of PhD research training. Unlike on-the-job training in a firm, this brings a recognised qualification, and opens up research career paths into either academia or industry. In exchange for three or four years on low income, the students have the opportunity to develop their scientific expertise in context and other transferable skills which could enhance future career options. Some recent research suggests that the engagement of younger scientists in industrial ventures provides opportunities for developing their ability to apply mode-1 expertise in mode-2 problem-solving and helps to open up career opportunities in industry (Mangematin 2000; Enders and Egbert de Weert 2004) . My own interviews with a small number of doctoral students engaged in industrial projects shows that the majority of them saw the experience beneficial in career terms because it gives them an opportunity to discover the operation of work communites in industry, and more critically, it enables them to acquire a wide range of skills and competences beyond scientific bench work. Similar observations can also be made about the post-doctoral researchers who are situated somewhere in between the PhD students and the linked professors. They occupy an intermediate career position between, on the one hand, the ‘apprenticeship’ and the research-and-teaching career and, on the other, business careers as their exposure to the company on joint projects ‘get their faces known in companies’, as noted by a professor collaborating with Pharma. In the past, the post-doctoral position was seen as a bridge to a tenured position in academia and the majority of those in this transitional position could expect to obtain permanent positions after one or two temporary contracts. However, with the growing competition for tenured posts in recent years, an increasing number of post-doctoral researchers are finding it difficult to make a smooth transition to permanent academic employment (Lipsett 2005). In this context, an alternative career in industry could serve to sustain the professors’ ‘career promises’ to these young researchers and provides an incentive for them to continue to work hard and cooperate in collective scientific work (Arthur and Rousseau 1996; Dany and Mangematin 2004). Some of the post-doctoral researchers interviewed believed that collaborating on industrial projects could enhance their career prospects, in either academia or industry, because of the additional skills they acquired and the opportunities for building networks of business contacts.

In sum, a distinctive feature of the academic career system is that it combines stable employment with more transient positions that offer considerable flexibility for project collaboration. The institutionalised temporary positions structurally encourage the reassembling of teams over time and span organizational boundaries. At the same time, the career system offers a stable basis for the accumulation of a core body of expertise and for regulating quality and performance. It offers the prospect of progression to stable employment for those who are currently in more transient positions, and so provides incentives for them to deliver good performance. Freeman et al (2001) argue that the tournament model of career in universities provides a powerful incentive for scientists to work hard to produce high effort and output. This applies to the tenured professors who must continue to do good research to sustain their reputation in the scientific community and also, the pre-tenured researchers, who must compete to obtain tenured positions (Li and Ou-Yang 2003; Stephen and Levin 2001).

Thus, by establishing close ties with selected universities, firms are able to tap into these dynamic knowledge networks and maintain a continuous flow of reliable new knowledge and high quality scientific labour. The collaborative arrangements with universities help to resolve a major knowledge production and human resource dilemma for firms. They enable firms to use collaborative projects to engage with the open knowledge networks of academic science so as to increase their knowledge options, while at the same time ensuring that the scientists involved in short-duration projects have an independent career structure that provides long-term incentives for delivering good performance. Figure 1 illustrates the career positions of the linked scientists in the overlapping knowledge networks and patterns of knowledge flows between the two sectors.

FIGURE 1 ABOUT HERE

EILMs as frameworks for cooperation and joint knowledge production

One might consider the collaborative arrangements as an extension of firms' scientific human resources into the academia career system. The development and utilisation of a pool of ‘linked scientists’ through affiliation and sponsorship enables the firms to tap into the established internal labour markets of their university partners so as to maintain a cooperative framework for joint knowledge production. This amounts to the formation of what might be called an ‘extended internal labour market’ (EILM). The original idea behind this concept builds on that of a firm’s internal labour market, and how it may be extended beyond the boundary of the firm following established recruitment channels and social networks. Two complementary strands of theory support this interpretation of internal labour markets. The first, from Doeringer and Piore (1971), stresses the importance of skill formation and knowledge development, and particularly that of firm-specific skills and knowledge, whereas the second, from Williamson (1975), stresses the need for suitable career incentives to support cooperative behaviour. Albeit to differing degrees, both lines of reasoning stress how long-term jobs in stable organizations can provide a platform for shaping skills and knowledge to the firm’s requirements. They also identify a set of incentives for both firms and employees to take a cooperative view of their relationship. Earlier research on social networks in labour markets illustrates how internal labour markets may extend their roots beyond the administrative boundaries of the firm (Rees 1966; Granovetter 1974; Manwaring 1984). These roots follow the same logic as those of internal labour market formation.

Here, I apply the concept of the ‘EILM’ to interpret how these traditional benefits of ILMs are extended into new types of relationships in network organisations. The cooperative arrangements set up between the firms and universities support career and knowledge flows across organizational boundaries. It might be thought that the term ‘overlapping’, rather than ‘extended’, ILMs would be a more appropriate description of the arrangements as the joint human resources operate in the overlapping space between the two sets of organizations. However, I use the established concept of an ‘EILM’ to stress how the roots of ILMs may extend beyond organizational boundaries, and the ways in which firms ‘extend’ their human resource and knowledge boundaries into the ILMs of their partner universities in order to retain the traditional benefits of ILMs for themselves. More specifically, I argue that these arrangements perform four important functions associated with EILMs. First, they provide an effective platform for blending mode-2 industrial problem-solving with mode-1 academic knowledge production, and thus facilitating the co-production of new knowledge that has commercial applications. Second, they serve as informal apprenticeship systems for developing joint human capital, enabling firms to shape unique human resources for connecting their internal knowledge with new knowledge generated through collaborative projects. Third, they serve as a selection and screening mechanism as the entrepreneurial professors filter those whom they choose as post-doctoral collaborators, and recommend graduate students as potential recruits for firms. Being ‘rigorously honest, absolutely honest’ in recommending the best students to the companies, according to a professor interviewed, is absolutely vital for long-term trust and the future careers of your students: “ If I sell company X one duff person, I could have five or six good ones after who would never even get looked at’. EILMs thus enable firms to have an established channel and trusted information source to recruit a core of reliable researchers. And fourth, more critically, EILMs enable firms to retain stable jobs and scientific careers for members of the extended core based at their partner universities. As firms seek to break away from the constraints of their internal R&D system and firm-based careers, the relationship with universities provides an effective solution for them to gain access to the top researchers whom ‘they would never be able to get unless they were to offer them the security of life time jobs’, to put it in the words of a professor collaborating with one of the ICT firms. Thus, EILMs provide career structures and incentives to ensure that academic scientists are willing to engage in short-duration industrial projects while maintaining their positions at universities and remaining integrated into the academic scientific community. In this context, one can argue that despite what might seem to be ‘externalisation’ of their human resources, the large innovative firms have not entirely abandoned internal labour markets as such. Instead, they have sought to transform the way they operate by making use of the career systems provided by universities through project networks.

CONCLUSIONS

This paper has sought to contribute to our understanding of the emerging forms of career models that support knowledge flows across organizational boundaries, based on the example of R&D project collaboration between firms and universities. Industry-university collaboration can take a variety forms. This study has examined one particular type of collaborative relationship, namely the career and labour market nexus that has emerged to support knowledge flows between the two sectors. The EILM arrangements described in this paper reflect not only a shift in the innovation and human resource strategies of firms towards an open model but they also underline a broader transformation in the nature of knowledge production system in the contemporary economy from ‘Mode 1’ to ‘Mode 2’ in which greater collaboration through network organization is a key feature. Although recent research draws attention to the development of a hybrid scientific labour market against the backdrop of these changes (Murray 2002; Powell and Owen-Smith 1998), there has been little analysis of the careers of scientists within these shifting and dynamic contexts. This study examines closely the career structures embedded in the network ties between firms and universities.

The concept of the ‘EILM’ gives new insights into our understanding of the intertwining relationships between careers and knowledge flows in network organizations. The value of introducing this concept into the analysis is fourfold. First, it highlights the career arrangements that enable knowledge and competences to be shared and jointly produced at the interface between two sets of organizations. It draws our attention to the emergence of a hybrid space structured around the linked mobility of human resources that facilitates the interconnection of two different knowledge communities. Second, the concept carries a connotation that an element of flexibility (‘extended’) is injected into the more stable structure (‘ILM’) which provides a space for negotiation and for fostering a zone of shared interests between the different actors. This flexible component in the career structures underlines the dynamic character of knowledge networks. Third, the concept also illustrates the interdependent relationship between transient projects, and the more enduring organizational arrangements and career structures. Flexible projects often need a stable institutional basis particularly if they are to exclude unreliable elements and to function as loci of knowledge creation. Grabher (2002) argues that ‘cool projects require boring institutions’ because the temporary nature of the former requires the stability of the latter to provide a stable context for trust building and effective learning. The EILM arrangement constitutes one particular form of institutional mechanism supporting knowledge creation in flexible project networks. And finally, more crucially, the concept provides a conceptual bridge between ILMs and network forms of organizations. While the traditional model of ILMs appears to come under challenge with the rise of project networks in many sectors of the new economy, this study suggests that the essence of ILMs remains important in some of the most dynamic, fast-moving industries in which learning and knowledge creation are crucial drivers of innovative success. Long-term relationships are important for the generation of trust which is a precondition for successful learning and innovation. Given the apparent importance of firm-specific knowledge in competition, firms will continue to seek unique combinations of knowledge and expertise with product or problem-solving domains specific to them. In their attempts to enhance their innovative potential by breaking away from the administrative boundaries of ILMs, the firms studied appear to have re-invented ILMs albeit the borders of which span organizational boundaries. The notion of an EILM suggests that the traditional dichotomous distinction between 'internalisation' or 'externalisation' may be inadequate for understanding the subtle variations in modes of employment relationships and careers in network forms of organizations.

Although the general theoretical insights gained from the study have wider relevance, a number of qualifications should be noted. First, the EILM arrangements appear to be most developed in those sectors where there are increased overlaps in research goals between academia and industry, as the pharmaceutical and ICT case studies illustrate. In other sectors where the link between basic science and industrial application is less direct, the human resource links between firms and universities are likely to be more distant than those described in the paper. Second, the incentives for scientists to engage in industrial ventures to support research are most salient in the Anglo-American context with its pluralistic forms of research competition and funding structure. The conception of the roles of university scientists in this paper is thus placed implicitly within the Anglo-American context and may not hold true in countries with more hierarchical research systems (e.g. Germany and Japan).[4] And third, it is also worthy of note that those interviewed might be considered as 'insiders' and therefore may have exaggerated the appeal and stability of the overlapping ILM arrangement. Some recent studies draw attention to the possible losers in the system – the 'trapped' post-doctorates employed on 'soft' money and graduate students used as cheap scientific labourer in industry-university exchanges (Stephan and Levin 1997; Slaughter et al 2002). Future research should examine more closely how universities' increased diversification of research funding towards the private sector and the associated EILM arrangements may alter the nature of their internal labour markets, and the relationships between the tenured faculty and pre-tenured researchers.

NOTES

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[1] Recent literature tends to use the term 'entrepreneurial scientists' narrowly to refer to a small sub-set of academic scientists who have formed their own companies (e.g. Shane 2004; Renault 2006). This definition differs from the initial conceptualisation of Ben David (1971: 159) who used the term 'scientific entrepreneurship' to refer to academic scientists, who conduct professional large-scale research with graduate students, including research 'paid for' by industry. Louis et al (1989) also use the term to describe academic scientists engaged in a broad range of industrial links activities ranging from the traditional modes of consulting, student sponsorship and collaborative research to the newer forms of patenting and firm formation. In the context of the present paper, I use a broad definition of the term and focus on those who have developed ties with large companies.

[2] The most common ones are Industrial Case studentship and Engineering Doctorate programmes, coordinated by the Engineering and Physical Sciences Research Council of the UK government Industrial Case are three and a half year postgraduate awards allocated to companies. Their aim is to enable companies to take the lead in defining, and arranging projects with an academic partner of their choice. The Engineering Doctorate Scheme is a four-year postgraduate training that takes the traditional approach to academic research and merges it with industrial needs. The Research Engineers are expected to spend around three-quarters of their time working directly with their collaborating company. Projects are designed jointly by the academics and the cooperating company and each student has a unversity supervisor as well as an industrial supervisor. (see, *http:www.epsrc.ac.uk/Postgraduate Training*).

[3] See note 2.

[4] I am grateful to one of the reviewers for drawing my attention to this.

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Table 1 The Interview Sample

	ICT1	ICT2	Pharma
No. of company interviews Total= 30	10 interviews at corporate labs	5 interviews at Advanced Development Labs	15 interviews at corporate lab (Discovery)
No. of interviews with academic scientists directly linked to the companies Total= 15	- 1 professor in computer science - 1 professor in mathematics - 1 post-doctoral researcher	- 2 professors in electronic engineering - 3 professors in mathematics -1 post-doctoral researcher	-2 professors in biosciences -2 professors in chemistry - Head of industrial liaison office
No. of interviews with other academic scientists in similar roles = 12		- 2 professors - 8 post-doctoral researchers - 2 Phd students	

Figure 1 Career and knowledge flows across academic-industry boundary