Work Roles and Careers of R&D Scientists in Network Organizations

ALICE LAM*

Despite the burgeoning literature on the network organization as a new mode of innovation, we know little about how the flow of knowledge across organizational boundaries is intertwined with careers. This study explores the implications of the network model of R&D organization for the work roles and careers of R&D scientists within the changing relationship between industry and the academia. It examines how firms seek to resolve the tension between science and business by developing closer human resource ties with universities. It argues that firms have sought to construct "extended" internal labour markets (EILMs) between themselves and the universities with which they collaborate, leading to the formation of a hybrid scientific community straddling the two sectors.

Introduction

A central problem in the management of industrial research & development (R&D) lies in the difficulty of resolving the inherent tension between scientific objectives and industrial goals (Shepard 1956; Kornhauser 1963; La Porte 1965; Debackere, Clarysse, and Rappa 1996; Randle and Rainnie 1997). Over the past four decades, large industrial firms have developed different models of R&D organization and career strategies to manage that tension, and integrate academically trained scientists into the innovation process. The dominant model of R&D organization has evolved from the technology-push model of the 1950s and 1960s to the market-pull model of the 1970s until the late 1980s, and an emerging network model of today in which firms use collaborative links and networks of scientists across organizational boundaries to support their innovation activities (Rothwell 1992; Liyanage, Greenfield, and Don 1999). These three models reflect the

---

* School of Business and Management, Brunel University, Uxbridge, West London, UB8 3PH, U.K. Tel.: +44 (0)1895 265251, E-mail: *alice.lam@brunel.ac.uk*. The research was funded by the European Commission, DGXII, Targeted Socio-Economic Research Programme, SOE1-CT97-1054. I should like to thank Professor David Levine, editor of *Industrial Relations*, and the two anonymous referees for their valuable comments on earlier drafts of the paper.

Industrial Relations, Vol. 44, No. 2 (April 2005).
Published by Blackwell Publishing, Inc., 350 Main Street, Malden, MA 02148, USA, and 9600 Garsington Road, Oxford, OX4 2DQ, UK.

changes in the relationship between science and business both within the firm, and between industrial R&D and the academia (Niosi 1999; Kaufmann and Todtling 2001). The nature of scientific and technical work, and the careers of R&D scientists have coevolved with the different models of R&D organization.

The recent growth of the network model of R&D represents an attempt by firms to remedy the limitations of the traditional linear technology-push and market-pull approaches in an environment of rapid change. Instead of relying on corporate in-house R&D and a cadre of career scientists, firms have increasingly engaged in various forms of external collaborative arrangements to gain access to the expertise and open knowledge networks of university researchers (Powell, Koput, and Smith-Doerr 1996; Howells et al. 2003). The increased interchange between industry and university has been particularly notable in the science-based high-technology sectors where basic science is increasingly a key source of innovation and economic advantage (Murray 2002; Meyer-Krahmer and Schmoch 1998; Kaufmann and Todtling 2001). Several authors have observed a significant shift in the nature of the relationship between the two sectors from the traditional one-way flow of knowledge from universities to industry to closer network ties characterised by reciprocal flows of people and knowledge (Etzkowitz and Leydesdorff 2000; Owen-Smith 2003; Powell and Owen-Smith 1998). Ties that involve the direct engagement of industrial and academic scientists in collaborative R&D, and the movement of academic scientists from universities to firms are becoming more commonplace (Murray 2002; Zucker, Darby, and Torero 2002; Zucker, Darby, and Armstrong 2002). Thus, the network approach to R&D is not only transforming the relationship between science and business, it is also reshaping the occupational roles and careers of R&D scientists in the knowledge-driven economy.

Despite the burgeoning literature on the rise of the network organization as new mode of knowledge production and innovation (Powell, Koput, and Smith-Doerr 1996; David, Foray, and Steinmueller 1999), we know surprisingly little about how the coproduction and flow of knowledge across organizational boundaries are intertwined with careers and employment relationships. Accordingly, the aim of this article is to explore the implications of the network model of R&D for the work roles and careers of R&D scientists within the changing relationship between industry and the academia. It argues that many of the traditional tensions and dilemmas in managing the relationship between science and business manifest themselves in a much more complex manner under the network model. The study examines how firms seek to resolve these tensions by developing closer institutional ties and human resource links with their academic partners. It argues that firms have sought to construct "extended" internal labour markets (EILMs) between themselves and the universities with which they collaborate, leading to the emergence of a hybrid scientific community straddling industry and the academia. The empirical evidence is based on five in-depth company case studies carried out in the science-based high technology sectors in the United Kingdom.

The article is structured as follows. Section one reviews changes in models of R&D organization and provides the context for the empirical investigation. Section two describes the research methods and the characteristics of the case companies. This is followed by an analysis of the case studies in section three, focusing on the changing nature of R&D work as the companies have sought to move towards the network model of R&D. The analysis is based on contrasting the work roles of scientists in two categories of firms: the market-pull vs. the network model firms. Section four looks at the new organizational routines and career models that the network firms are developing to support collaborative knowledge sharing networks between industry and the academia. Section five discusses the career and institutional challenges emerging from the closer ties between industry and university.

Models of R&D Organization: Implications for the Roles and Careers of the R&D Scientist

The Technology-push Model: Corporate Centralization of R&D and the Professional Scientist. The early incorporation of R&D laboratories into large industrial firms was an attempt to apply linear thinking to the innovation process through in-house accumulation and exploitation of scientific knowledge. The technology-push model was the dominant approach to R&D during the 1950s until early 1970s, and it 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 provided resocialization experience to integrate academic scientists into an industrial environment (Abrahamson 1964). Within the corporation, R&D was the main driving force behind product innovation. This period was marked by corporate expansion in R&D investment, and R&D was centralized and concentrated at the corporate level.

Under this model, the R&D organization resembled that of a professional bureaucracy characterized by the dominance of the scientific and technical specialists underpinned by a professional ideology (Child et al. 1983; Gerpott and Domsch 1985). It stressed occupational specialization and autonomy of the R&D experts. There was a clear connection between their formal disciplinary expertise and work activities. In other words, the R&D experts were primarily "Mode-1" (Gibbons et al. 1994) technical experts whose formal qualification and training defined their work goals and task boundaries within the corporations.

The scientific autonomy of the R&D personnel, however, gave rise to the classic conflict between professional and managerial goals and values within the corporation (Kornhauser 1963; Marcson 1960; Badaway 1988). These tensions were partially resolved by allowing R&D staff a high degree of strategic autonomy while management maintained control over operational issues (La Porte 1965). Management also 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 (Fox 1974; Causer and Jones 1996). The provision of parallel technical and managerial career tracks was introduced to balance professional and managerial commitments (Allen and Katz 1986; 1992; Debackere, Clarysse, and Rappa 1996). The technical ladder attempted to emulate academic working conditions in an industrial R&D environment.

The Market-pull Model: Decentralization of R&D and the Corporate Scientist. 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 (Twiss 1986; Whittingdon 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. R&D was decentralized to business units, and a market relationship was established between R&D (as suppliers) and business divisions (as customers), and project management was used to break the isolation of R&D department. Scientific and technical works were reorganized through strategic planning based on corporate expectations of relevance and accountability. These changes significantly altered the work roles and career structures of R&D scientists. The scientist was expected to become more of a corporate scientist operating at the boundaries between science and business management, and increasingly engaged in a variety of techno-commercial roles. The trend towards downsizing and commercialization of corporate R&D diminished the traditional technical career path. In its place, there has emerged a range of what Bailyn (1991) described as "hybrid" career options, for example, cross-functional, project-to-project and mixed technical and managerial roles. These changes have generated a strong sense of role ambiguity and career insecurity among R&D personnel, and caused perceptions of career blockage and under-utilization (Lam 1994; Causer and Jones 1993; Whittingdon 1991).

A more fundamental dilemma facing firms is the potential difficulty of attracting and retaining the necessary core scientific personnel. Firms may choose to delegate and subcontract basic R&D to external research organizations, but the lack of scientific expertise and established research capability inside the firm could lead to organizational resistance to external knowledge (Cohen, Wesley, and Levinthal 1990). The long-term weakness of the market-pull model of R&D has become more apparent since the mid-1990s as the accelerated pace of technological progress makes firms vulnerable to the destruction of their technological base.

The Network Model: External R&D Collaboration and the Role of the Scientist in Boundary-crossing Knowledge Networks. During the 1990s, many firms attempted to develop new knowledge-sourcing strategies in order to remedy the weaknesses of the market-pull approach so as to sustain a long-term vision and maintain the ability to generate new knowledge. An emerging trend has been the growth in R&D collaboration with other firms, government research institutes and universities (Howells 1999; Howells, James, and Malik 2003).

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. Radical product and process innovation in the science-based sectors increasingly requires a greater variety of knowledge in different scientific disciplines and functional areas (Gambardella 1995; Hage and Hollingsworth 2000). Gibbons et al. (1994) argue that the nature of knowledge production in the knowledge-based economy is shifting from “Mode 1” to “Mode 2”, that is from knowledge production within single disciplines to that within broader, trans-disciplinary and multiple organizational contexts.

Within the network approach to R&D, firms attempt to enhance their capacity for knowledge sourcing by developing flexible and permeable organizational structures to facilitate the creation and flow of knowledge across organizational boundaries (Reger and Wichert-Nick 1997; Liyanage, Greenfield, and Don 1999; Niosi 1999). This involves a significant shift in the relationship between university and industry away from the older linear model of one-way knowledge transfer to an interactive model of two-way knowledge exchange between the two sectors. This increased interchange takes place within a potent and enduring change in public science policy that seeks to promote closer science and business links (OECD 2000;

HMSO 1992; DTI 1998). Some authors argue that these developments have transformed the relationship between university and industry from a once separate system into a "hybrid regime" (Owen-Smith 2003), with "overlapping spheres" and "network interfaces" (Etzkowitz and Leydesdorff 2000) characterized by reciprocal knowledge flows and mobility of scientists across the institutional boundaries (Powell and Owen-Smith 1998; Zucker, Darby, and Armstrong 2002). Others, however, stress the potential for greater conflict as scientists recruited from these two different communities, built around fundamentally antithetical sets of norms and cultural orientations, seek to collaborate in joint projects (Dasgupta and David 1994; David, Mowery, and Steinmueller 1994; David, Foray, and Steinmueller 1999).

The network model of R&D is complex and difficult to manage because it engages more closely a variety of internal and external actors, spanning the private and public domains more closely than the two previous models. The transfer of knowledge between the open science communities and private proprietary industrial R&D is inherently difficult, owing to the divergent norms, incentives and modes of communication characterizing the two communities. Zucker, Darby, and Torero 2002 and Zucker, Darby, and Armstrong 2002 note that in the transfer of knowledge from academia to industry, a large part tends to be tacit and uncodified, requiring the bench-level engagement of firm and academic scientists in cooperative teams, and the movement of discovering (mainly academic) scientists to firms. The successful implementation of the network model of R&D will depend greatly on the development of a new breed of scientists and creation of new career structures to facilitate collaborative links and knowledge sharing between the traditionally separate institutional spheres of industry and university.

The empirical study that will be presented examines how the role of the R&D scientist is being reconstituted within the network form of R&D organization. It also examines the new career models with which the companies are experimenting to support boundary-crossing knowledge networks between industry and university.

Research Methods and the Sample

The research is based on five in-depth company case studies from two sectors: three in information and communication technology (ICT) and two in pharmaceuticals and specialist chemicals. They are all large companies operating in innovation-intensive industries. All five companies selected for the study have, or have had in the recent past, well-established in-house

TABLE 1

THE INTERVIEW SAMPLE

	ICT1	Pharma1	ICT2	ICT3	Pharma2
No. of company interviews Total = 49	8 interviews at corporate labs and operating companies —Managing director, Central Research —3 HR managers, R&D and business divisions —Manager, corporate training —Manager, graduate recruitment —2 project leaders, Network groups	11 interviews Corporate level (3): —External Relations Manager, Group Research and Technology — Manager, Science and Policy and Technology Strategic Unit —Manager, European Recruitment Business level (8): —Fragrance business (4) —Catalysis (2) —Lubricants (1) —Speciality chemicals (1)	10 interviews at corporate labs —Managing director —Academic liaisons manager (twice) —4 project leaders/ tech managers (4 areas) —Principal engineer engaged in collaborative project —Director, hybrid research organization	5 interviews at Advanced Development Labs —Manager, external research group —Manager, HR —3 project leaders (interactors)	15 interviews at corporate lab (Discovery) —HR Director —Learning and development manager —Recruitment and academic liaison manager —VP, Medicinal Discovery —Director, discovery biology —Director, medicinal technologies —Head of external technology acquisition group —Licensing and collaboration manager —Director, project management —5 project leaders (engaged in collaborative projects)
No. of interviews with academic partners Total = 15	3 interviews at one partner university —1 professor in networks research —2 professors in electronic engineering	2 interviews at two partners universities —1 professor in organic chemistry —1 professor in applied catalysis	2 interviews at one partner university —1 professor in computer science —1 professor in mathematics	5 interviews at three partner universities —2 professors in electronic engineering —3 professors in mathematics	3 interviews at one partner university —2 professors in biosciences —Head of industrial liaison office

central R&D facilities that conduct long-term or advanced research. They are, or were, at least until recently, market leaders in their technological fields and characterized by relatively high R&D intensities. Both sectors, ICT and pharmaceuticals, are science-based and technology-push innovation has been historically important. The two sectors were chosen to illustrate the new innovation challenges facing firms arising from the recent scientific and technological revolution. This has resulted in technological convergence and created a new phase of rapid growth in new markets and products. Firms operating in these industries are on the one hand under intense pressure 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 multi-disciplinary scientific fields. The companies selected for the study differ in their ability to balance the opposing forces. Two of the companies (ICT1 and Pharma1) have remained driven by market-pull forces, whereas the other three (ICT2, ICT3 and Pharma2) have sought to move towards the network model by developing knowledge sourcing strategies and closer network ties with universities (see succeeding discussion).

Data were collected by semi-structured interviews with technical managers and scientists in R&D laboratories, managers in human resource groups and technical staff directly engaged in external technology acquisition and collaborative projects with academic institutions. The first points of contact for interviews were the technical director and academic liaison or external technology manager at the corporate laboratories. The aim was to collect background information on the companies' innovation strategies and R&D organization, and recent developments in their external knowledge-sourcing strategies. This provided the necessary contextual information for subsequent interviews with staff in other functions. In the two companies (ICT1 and Pharma1; see Table 1) where the central laboratories have been dramatically run down and most of the R&D activities were carried out at the business division level, the interview samples included a mixture of staff at the corporate and divisional levels. In the other three cases (ICT2, ICT3 and Pharma3) where the corporate laboratories remain important, the majority of the interviews were carried out at that level. The semi-open questionnaires covered four main areas: organization of R&D and innovation strategies, skills and knowledge sourcing, human resource strategies and recruitment, and links with universities. Interviews were also carried out with the university academics engaged in collaborative projects with the companies. A total of 49 individual interviews were carried out in the companies, and 15 interviews with their academic partners. Each interview lasted for about an average of 75 minutes and all were recorded and

TABLE 2

A PROFILE OF THE R&D ORGANIZATION OF THE FIVE COMPANIES

The company	ICT1 (Industrial and communication electronics)	Pharma1 (Specialist chemical)	ICT2 (Computing and communication)	ICT3 (Telecommunications equipment and network services)	Pharma2 (Pharmaceutical)
Model of R&D organization	"Market-pull"	"Market-pull"	"Network"	"Network"	"Network"
R&D organization	Historical reliance on protected defense market. But this has contracted over the past decade. Shift towards industrial electronics exerted strong pressures to introduce market-orientation in R&D programs.	The R&D function has become totally decentralized and distributed to the business units. There is a core R&D group at the corporate level but it is now very small (about 45 people), performing primarily a networking and coordinating role.	R&D distributed between corporate and divisional labs. Corporate labs globally distributed; employing 800 people in six sites around the world. UK site of corporate labs; employing around 200 staff.	The company had developed a strong technology-oriented culture with a centralized R&D organization. In 1998, this was dissolved and R&D function was distributed amongst the business lines, with an Advanced Technology Group remaining at the corporate level. European R&D headquarters in UK serve as advanced development centres, employing around 1500 staff.	The company boasts the industry's largest pharmaceutical R&D organization: its global R&D division, with approximately 12,000 employees, six discovery sites. Central research organized as a globally distributed network. The Discovery Group at UK site (European headquarters) employs 640 staff.
Recent development	Recent history has been marked by de-merger of less successful business segments. Both number of employees and amount of R&D	Until the early 1990s, the company was a large, vertically integrated chemical-pharmaceutical conglomerate,	Reorganization of company into four autonomous business divisions. Central labs also organized into four research programs seeking closer business	There is no longer a central R&D budget. R&D regarded as one of the activities, amongst others, developed by the businesses. As a result, the company's technology base has	Rapid expansion and growth; increased global coordination in R&D. The company has formed alliances with more than 250 partners in academia and industry that strengthens its position in science and biotechnology.

	have diminished significantly. Sold off to foreign electronics group in 2000.	with a strong in-house R&D. This model was abandoned in 1992 as the company transformed itself into a specialized chemical company. From mid-1990s, the company reorganized itself into autonomous business units, and decentralized its R&D to the business units.	alignment. Increased business influence over research agenda.	become much narrower than it was ten years ago.	
Role of corporate labs	Primarily an internal contracting agent for operating companies, and more recently, external contract research.	Diminished and almost non-existent. Corporate R&D is essentially a distributed network across the different businesses, with a central core of technology leaders acting as champions for key scientific areas important to the company as a whole.	Remain strategically important in searching for radical breakthrough technologies.	Advanced technology group and development centres play strategically important role in internal and external knowledge networking.	Increasingly work in collaboration with external research organizations and biotechnology companies.

TABLE 2 (cont.)

The company	ICT1 (Industrial and communication electronics)	Pharma1 (Specialist chemical)	ICT2 (Computing and communication)	ICT3 (Telecom-munications equipment and network services)	Pharma2 (Pharmaceutical)
Special organization to sustain fundamental search cability	None	Internal networks of senior scientists/ technical managers to identify strategically important scientific areas.	"Basic research initiatives" at corporate level to protect basic research.	External research group coordinates worldwide university links. It has a strategic role in searching for disruptive technologies.	External technology acquisition unit. Significant increase in external technology investments over the last few years.
University links	Diminished resources for establishing close links with universities. University links have become more focused on specific priority technological fields central to current businesses.	Diminished resources for university links. Build fewer relationships with universities, focusing on specific areas of direct relevance to businesses.	Strategic university relations program Hybrid research organizations.	Global university relationships program Hybrid research organizations.	Postdoctoral collaboration; Strategic research collaboration. Strategic recruitment specialists to develop strategic relationships with universities.

transcribed. The interviews were conducted between 1999 and 2001. The interview sample is shown in Table 1.

A Profile of the Case Study Companies

Table 2 gives a summary of the profiles of the R&D organizations of the five companies. Two of the companies, ICT1 and Pharma1, are referred to as "market-pull" firms, while the other three (ICT2, ICT3 and Pharma2) can be classified as "network" firms.

All the companies looked at in the study introduced major structural changes in their R&D organizations and innovation strategies from the latter half of the 1990s. One dominant trend has been towards greater decentralization of R&D, and a closer alignment of R&D programs with business objectives. In most of the companies (with the exception of Pharma2), the corporate R&D function has become smaller than before, and in one case (Pharma1), it performs primarily a coordinating function within the distributed R&D units across different businesses. The greater decentralization of R&D has led to increased business influence over the R&D agenda and narrowed the knowledge bases of the companies. One can argue that the market-pull model of R&D has become deeply entrenched in all the five companies as sources of R&D funding shifted from corporate to business units, and corporate R&D became more directly engaged in product development addressing the needs of specific business units.

However, the companies differ in the extent to which they use external knowledge networks to counter-balance the drift towards market-driven, short-term R&D. The R&D model pursued by ICT1 and Pharma1 remains heavily business-driven. Both companies have drastically downsized their corporate laboratories and decentralized R&D to the autonomous business units. Although ICT1 maintains its corporate research laboratory, it is now primarily an internal contracting R&D agent for the operating companies, and is also increasingly engaged in external contract research to generate income. During the 1990s, ICT1 spun off a number of less successful business segments. Both the number of R&D employees and amount of R&D undertaken diminished significantly. While the company recognizes that external research links are important for sustaining its technological base, its resources for maintaining such links appear to be limited. The situation in Pharma1 is rather similar. From the mid-1990s, the company embarked on a program of decentralizing its R&D functions to the business units. This accelerated in the late 1990s as the company underwent a major portfolio shift from commodity to specialty chemicals. The corporate R&D function in Pharma1 has now almost disappeared. It comprises merely a core group of around 45 research managers operating as a central coordinating unit for the strategic management of the company's technology base—down from 1500 R&D staff in the early 1990s.

Historically, Pharma1 has funded research and educational programs in universities for the recruitment of graduates and post-docs. This has now changed. Over the last few years, the company has sought to build fewer relationships with universities and focus on specific research areas of direct relevance to the business. The recruitment of R&D specialists appears to be less pressing as the company now looks for more generalists to fill the growing number of techno-commercial roles in the business units. As noted by the Academic Relations Manager interviewed, ". . . the out and out scientists—we won't be recruiting as many. And we will be recruiting more generalists. And what you will find is that because of that, in due course, we'll not be recruiting as many PhDs because we won't need the specialization".

In contrast, in the three network model companies (ICT2, ICT3 and Pharma2), the role of corporate R&D remains strategically important. There have been serious attempts at the corporate level to counter-balance the pull towards short-term, market-driven R&D objectives by maintaining their core scientific base and technological capability. This is achieved by the recruitment of core groups of PhD scientists and also by gaining access to the external academic knowledge base through developing long-term strategic relationships with universities. ICT2 introduced a "Basic Research Initiative" in 1994 to set up basic research programs with major research universities in the United Kingdom and United States. In 1995, it developed a "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 recruiting and gaining access to top academic researchers. Likewise, ICT3 has been placing an increased emphasis on establishing collaborative links with universities amidst the drift towards more market-driven R&D. Links with the academic knowledge base are now seen as critical for generating new ideas and sustaining the company's long-term innovative capability. To put this in the words of the company's external research manager: ". . . the chances of us inventing something outside our core business have gone. And in some ways that's what we are looking at universities for." ICT3 has recently introduced a global university relationship program, 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 the academia generate disruptive ideas that will shape the company's future businesses. The company also stresses the importance of using a bottom-up process for initiating collaborative links with external partners. The R&D scientists and engineers are expected to maintain their own academic networks to facilitate the search for external partners and opportunities for collaboration. In the case of Pharma2, links with academia have always been important but the recent growth in the scientific intensity and complexity of drug research has further strengthened the propensity of the company to enter into collaborative relationships with external research organizations and universities. Pharma2 increasingly recognizes that it "doesn't have a monopoly of good ideas" and that "outside collaboration fosters innovation", according to the head of external technology group. There has been a significant increase in the company's external technology investments in recent years. The worldwide budget for external research collaboration more than tripled between 1995 and 2000. Moreover, the recruitment of PhD scientists is seen as critical for maintaining the company's academic networks. In the face of growing competition for qualified scientific personnel, Pharma2 has sought to develop a more focused and targeted approach to the ways it relates to higher education institutions. The Director of Human Resources in Central Discovery described recruitment as a very "tough" area. Forging closer academic links has become so important that the company has recently created "strategic recruitment specialists" to liaise and develop strategic relationships with, what he called, their "preferred institutions". This contrasts with the retrenchment in the two market-pull companies characterized by a reduction in corporate R&D and increased focus of the remainder on immediate product market needs.

The next section explores the impact of the network model of R&D on the work roles and careers of scientists, using the contrast between the previously discussed two categories of companies.

Nature of R&D Work in Network Firms

Conflict in Goals between Science and Business. Evidence from the interviews shows that the tension between science and business has been largely reconciled in the market-pull firms through the recruitment of a new breed of corporate scientists and the creation of a variety of techno-commercial roles. The classical image of the professional scientist engaged in autonomous research is virtually nonexistent in these companies. Hence, balancing opposing demands for individual scientific autonomy with business goals has ceased to be a key tension for the majority of the technical staff in these firms.

In contrast, their counterparts in the network firms are exposed to multi-faceted conflicting demands, and there appears to be considerable anxiety about managing the difficult interface between the scientific and business worlds. This reflects the tension inherent in the innovation strategies adopted by the network firms which seek, on the one hand, close integration and alignment between R&D and businesses, and on the other, maintenance of their scientific and technological base. The scientists in the network firms are expected to be both corporate and professional scientists, having to deal with some of the same business demands as those in the market-pull firms, but also to maintain their place in scientific networks outside the firm. I shall deal with these two aspects in turn.

First, like the corporate scientists in the market-pull firms, they have to engage closely in the business and commercial activities of the corporation:

> ". . . we have to go out and start negotiating building business contracts, business leads with partner companies which are very different to how it used to be. It used to be, we develop technologies, we then go to our divisions, out on the company, if they would got sold on the idea they would put their R&D facilities on it to take it into manufacture, into product . . . we don't do that so much anymore . . ." (R&D scientist, ICT2).

An increasingly important part of their role is to transfer technology and "deliver value" to the company:

> "Transfer is rated extremely high in performance, so if anything, the measures would encourage people not to worry about research but to worry about being relevant to the company . . . I think if we go too far down that business road, we won't have ICT2 labs. It will cease to exist. Because it won't be, no fundamental research will come out of it" (R&D scientist/group leader, ICT2).

> "When I arrived here there was much more of a culture of, there were many different ways in which we can deliver value, we could do fundamental research, we could have visibility in the outside world, we could deliver value to divisions etc. You know you could publish papers . . . and so on. And actually after of a couple of years of that we worked very hard to start to engender the culture that what mattered was that you were delivering value to the company" (R&D scientist, ICT2).

A result of the closer business alignment and emphasis on technology transfer is that many of the scientists saw their discretion and control over selection of R&D projects eroded:

> "So historically what we always invested in was always our decision. The way that this process is operated this time the individual businesses are being asked to bear the cost of the research that ICT2 labs is doing for that business, and some of them will say, 'no I can't afford that' . . . And so suddenly our freedom to take decisions and invest in what we thought, you know, was right will be severely curtailed" (R&D scientist, ICT2).

> "In the past, we had a lot of discretion. This last reorganization—which is just part of life swings and roundabouts—has taken us very closely into being managed by the divisions, by the major business as to what we invest in. We're not quite as free as we were to invest where we like" (R&D scientist/group leader, ICT2).

Others find it difficult to fit their good ideas into the line of business, or maintain their expertise as R&D projects become embroiled in the ups and downs of business contracts:

> "At the moment it's very much 'line of business focus' and I particularly noticed that when I recently came up with a patent idea, an idea to patent, and the problem with it be not being centralized meant that even though it was a good idea it didn't have an obvious home. You know it wasn't one of these lines of business and therefore to try and get somebody to pay to have it patented, it was not obvious. . . . But the thing that makes it important is that's it's a novel idea and that it's going to be worth money. But the problem is fitting it into that structure" (project leader, ICT3).

> "I think people in my group feel more vulnerable . . . They have to deal with the fact that they had to give up on work they have invested in for the last two to three years, customers they have built relationships with, and start from the ground zero, to find what are we gonna do in this new space. Nobody knows what we should be doing, we have to invent it ourselves, what we are gonna do with it, talk with customers . . . There is quite a lot of reinventing and re-structuring . . ." (R&D scienitst/group leader, ICT2).

Even in Pharma2 which maintains a strong corporate laboratory, some of the scientists expressed concerns about the difficulties in maintaining their scientific expertise:

> ". . . we work on very focused research. Everything we do is towards drug discovery. If there ain't drug coming out of it, we don't do it. So we might find interesting things that might be interesting academically that we never pursue . . . So one day I might work on a kinase. Tomorrow that might go down and then I might work on a proteose or I might work on a receptor. And I would only work on it if it were allergy and respiratory-based . . . When I

> started at Pharma2 I was kind of like in between academics and I sort of, I was going to do the same sort of thing only in a different environment. But now, I do completely different things from academics . . . I couldn't go back to university and do academic science because it's too different . . ." (Research scientist, Pharma2).

Turning to the second aspect of the role tensions of scientists in network firms, amidst the drift towards business-driven R&D and the erosion of scientific autonomy, R&D staffs are expected to maintain their professional scientific capability so as to sustain a research culture in the laboratories. Many of the R&D managers interviewed talked about the importance of patenting, publications, and maintaining their "visibility in the wider research community." The following remarks made by a departmental manager in ICT2 is illustrative:

> "I kind of hope that the experienced staff they're actually all in the right forum where things are happening, so they just know every one who is important in the area . . . It's to be part of the wider research community in this place, and we certainly expect that from our staff. So this is attending the right conferences, the right trade shows, you know the standard bodies that are influential, the universities. . . ."

> "I still encourage publications and patenting and all those things . . . To sustain a group you have to be part of the wider research community, in fact to help our products you have to be part of that wider community and be taken seriously, and you can't do that if you don't publish and you don't give papers at conferences. You don't have to do huge amounts but you've got to be there . . . So it's a difficult tension to manage . . ."

Although it is not entirely clear whether these constitute formal performance criteria, several of the managers interviewed stressed the need to maintain ambiguity to avoid what they called "errant behaviour."

In contrast with the market-pull firms which no longer regard the recruitment of PhD specialists as core to their human resource strategy, the network firms continue to stress the critical role of PhD scientists in sustaining their core scientific base and external research networks. For example, for Pharma2, the recruitment of high quality PhD scientists has become so important that the company has recently created "strategic recruitment specialists" staffed by senior PhD scientists to help identify the candidates, using their academic scientific networks, and to show "the best face to the external world," as pointed out by the human resource director. In ICT2 and ICT3, although both companies recognize that they are looking for more scientists with practical business experience, the recruitment of what one manager describes as "out now, pure researchers" with PhD qualifications remains essential.

Multidisciplinary Project Teams: The "Specialization-Flexibility" Dilemma. The general trend observed in all the companies has been increasingly to organize R&D work on a cross-functional and multidisciplinary basis. The classic tension between specialist and project groups has long been discussed in the literature (Shepard 1956; Cordero 1999). While the former facilitates the development of deep expertise and solidarity among members of a discipline, the latter enables the organization to attain greater flexibility in the utilization of expertise in shifting problem contexts.

In the market-pull firms, project groups are used primarily as vehicles for facilitating a greater degree of science and business interaction in order to speed up product development. Thus, a central management focus has been on the development of cross-functional teams aiming at closely integrating R&D into the product development and business cycles. In the network firms, project teams serve the additional purpose of developing cross-disciplinary scientific capability for solving complex problems. The increased multidisciplinary nature of R&D work has meant that the scope for the R&D staff to maintain and develop their core scientific expertise has been reduced. While this may not necessarily be perceived as a problem in the market-pull firms, for the scientists in the network firms where technical excellence and scientific reputation are still regarded as important for career advancement, the difficulty in maintaining their core expertise is causing anxieties.

For example, some of the R&D staffs interviewed are concerned about losing their expertise as they move around different projects. A senior researcher at ICT2, who joined the company from academia several years ago, expressed his anxiety:

> "So one of the main things about working for ICT2 is exactly that. That you have an area of expertise, but then you also have to . . . its product has lots more things in it that are not my area of expertise. Recently, I've had to learn about optics because they were relevant to particular product concepts we were playing with . . . I suppose I had to find out something about sensor technology which, again, is totally outside my area of expertise. So yes, it's very much multidisciplinary. So we have partially multidisciplinary teams. And we have to get off our own areas of expertise. I think a lot of people find that that dilutes their area of expertise"

> "One of the things that worried me about coming here was losing my skills. As projects move about. But once you've made a position, and got yourself 'This

is what I do', as long as the winds of change aren't so great then you can keep on doing it. But eventually, you can't resist the changes that can happen in an organization like this" (R&D scientist, ICT2).

Others talked about problems of isolation in mixed project teams:

"You know, they have to learn a bit about other disciplines, they have to inform people about what they are bringing to the party. The drawback is that if you just got one physicist he feels a bit lonely that he hasn't got a natural group. So what you find in ICT2 labs is that the electrical engineers they tend to group together a little bit, socially and sort of in the background. They help each other out and they form their own sort of community, or guild in a sense . . . We have here only a few physicists and sometimes they feel a bit lonely" (project leader, ICT2).

The tension between disciplinary-based specialist groups and project teams is especially notable in Pharma2, a company which seeks to maintain a deep scientific base and yet the growing complexity of drug discovery increasingly requires inputs from a diverse range of disciplines and cross-disciplinary team working. The company has recently moved away from the traditional disciplinary-based structure (such as biochemistry versus cell biology) and reorganizes project teams around therapeutic areas (such as tissue repair, and allergy and respiratory) that draw on the inputs of different disciplinary groups. As a result, the scientists from disciplinary groups move around different therapeutic areas. This new structure was resisted by some of the scientific teams who sought to revert back to the skills-based structure:

"But we are now thinking of reorganizing around skills base. Because we just feel that within a team environment it's better when you're talking science, for instance, you can have a collection of people who are able to critique that science" (group leader, Pharma2).

A compromise solution adopted by the group was to integrate the disciplinary-based teams into a therapeutic area in order to maintain a degree of scientific stability:

"What we decided was that it would be better for us to merge with their therapeutic area because then we could learn that therapeutic area more intensely and become part of the idea generation etc; whereas before we could get moved around therapeutic areas as needs be so you couldn't become experts in anyone . . . The idea of that was just that it gave us some stability in terms of the science we were exposed to. But in theory if a particular therapeutic area needed a lot of help and others didn't, then you could get moved around" (group leader, Pharma2).

However, Pharma2 is seeking to move further down the path of multidisciplinary team working. A senior executive interviewed stressed the need to develop more "multiskilled" scientists to work in teams. The existence of a strong disciplinary culture is increasingly regarded as problematic by the management:

> ". . . Physicists tend to think physics. Chemists tend to think chemistry, Biology and so on. We have to do something to bring these people together . . ." (human resource director, discovery laboratory, Pharma2).

The experience of Pharma2 illustrates the "specialization-flexibility" dilemma encountered by the research-based firms, and the growing difficulty for industrial scientists to maintain their specialist expertise within fluid project-based organizations.

Networking: The Scientist in Boundary-crossing Knowledge Networks. As firms move away from centralized R&D and increasingly depend on distributed knowledge sources, a growing part of the scientist's role is to engage in a diverse range of internal and external knowledge networking activities. Although external knowledge sourcing is important for all the firms looked at in the study, the nature of knowledge networks and role of scientists differ markedly between the market-pull and network firms.

Simplifying somewhat, one could characterize the market-pull model of knowledge sourcing as running from the customer through the manager to the scientist. Thus, it is the manager, rather than the scientist, who plays the key role in coordinating and monitoring collaborative projects to ensure that they are tightly focused on the strategic objectives of the businesses. For example, Pharma1 created a central technology board around the mid-1990s as it downsized and eventually dismantled the corporate laboratory in the late 1990s. The central technology board consists of the R&D directors from the different business units and is responsible for identifying and integrating the knowledge and skills needed to meet the company's strategic business objectives. Collectively, the R&D directors are responsible for managing the company's external projects to ensure that they generate the necessary knowledge and competence for the chosen fields of business. A result of this business-oriented, top-down approach to knowledge sourcing is that there is relatively little scope for the individual scientists to mobilize and develop their scientific networks independently of the firm's formal collaborative projects and structures. In other words, the scientists in the market-pull firms are not the main players in developing the firms' external knowledge networks.

In contrast, their counterparts in the network firms are the key actors in connecting the internal knowledge base of firms with external knowledge networks. The role of the scientist in the network firms increasingly resembles that of a "strategic broker" (Reich 1992) or "boundary-rider" (Turpin and Deville 1995) whose key task is to network and manage knowledge boundaries across different contexts, both internally within the firm, and externally with scientific colleagues outside.

Internally, the R&D scientists have to manage the boundary relationship between the laboratories and other areas of the business in order to exert their influence over the R&D agenda. Once able to control outcomes of their work through direct control of resources, scientists must now use personal influence and networking to achieve similar ends. For example, the researchers in ICT2 saw networking with a variety of people outside the central laboratory as a means of "selling" their ideas and getting things done:

> ". . . the leader of the business unit here would shape things even more . . . And so we would have good links with the R&D folks, we'd need to work with the R&D manager, the section manager, and technical folks would need to get into good liaison with the leading technical opinion formers in the division, you know and we'd talk to the general manager. And so then if we wanted to sell them a strategy or an idea you could do that" (R&D scientist, ICT2).

> "[This] is a company of networking, of personal networks . . . you are exposed to the whole width of the company . . . I think it's astonishing me joining the company from where I've come from, in this position I had not only the ability but the expectation to go and talk to very senior people in the company . . . You have to network to work . . ." (R&D scientist, ICT2).

Externally, the scientists are encouraged to develop formal and informal personal networks and scientific links to the support firms' external knowledge sourcing and collaborative activities. The manager responsible for coordinating external research at ICT3 pointed out that the majority of the company's collaborative projects were initiated bottom-up from the external personal contacts of their scientists who act as "interactors" on the projects:

> ". . . the majority of projects I think will come bottom-up because interactors [scientists] want the work done, and particularly in a lab like this, which is an advanced technology lab—I don't know how many PhDs we've got here . . . but what I was saying is that because there are so many people who have a research background, and they go to conferences and they keep up-to-date with what's happening, they have their contacts into the university anyway. In most areas, they don't need me to find them for them" (manager, external research, ICT3).

The importance of mobilizing the professional networks of scientists is also stressed by a manager in Pharma2:

> "Much of the seeking for collaborative opportunities is done by the scientists. So they're going out looking for collaborative opportunities and they spoke about that . . . going out and bumping into academics at meetings and so on . . . " (manager, external technology acquisition, Pharma2).

Although large collaborative projects are monitored closely by senior managers, the "broad involvement of scientists" is regarded as critical for the success of such projects in the network firms. Pharma2, for example, places a strong emphasis on "getting the science right" in their collaboration through the close engagement of bench-level scientists. The development of informal personalized networks between the scientists and their external colleagues within formal collaborative projects are encouraged to ensure that new knowledge generated can be rapidly fed into problem-solving teams within the firm. A technical director responsible for coordinating a major academic collaboration commented on the importance of building scientific links to ensure project success:

> ". . . Good links between the scientists. This is a scientific collaboration and so it has to be driven by the science, and I've moved too far away from the lab now to be making quality technical thinking. Science moves too quickly. You have to involve the scientist on both sides . . ."

For the individual scientists, building close links with external academic colleagues not only constitutes an essential part of their work, it could also be an important avenue for claiming expertise and making career advancement. Especially in turbulent and fast developing technological fields where expertise depends not so much on an accumulated stock of knowledge but more on one's ability to gain rapid access to evolving new knowledge, the development of extensive external knowledge networks becomes critical. For example, a young project leader in ICT3 was able to make rapid advance in his career because he had established himself as the "centre of expertise" in an important new technological field through his extensive academic links and close involvement in several collaborative projects. He took pride in pursuing a new "middle" career path situating between the traditional managerial and technical routes:

> ". . . people find it hard to become international experts. I've personally managed it but I still associate myself with the middle path . . . In my case, because we have a technology that I've introduced to the company and built up a team and got involved in many projects . . . Yes, we've got lots of external links" (project leader, ICT3).

His academic collaborator also commented on how the university contacts helped the project leader established his position as a "specialist" in the company:

> ". . . So many of these areas were new to him and then the university contacts, as far as he is concerned, get him up and running as quickly as possible. And internally he is very much in demand because he is known to be the person who is a specialist in this area" (academic collaborator, ICT3).

In sum, scientists in the network firms increasingly operate within the boundary-crossing knowledge networks between industry and the academia. Within the firm, they are "research gatekeepers" (Tushman 1977: 592) who connect firms' R&D projects to state-of-the art knowledge inputs from the outside research communities. Externally, they operate as what Turpin, Garret-Jones, and Rankin (1996) describe as "boundary riders" to protect the firms' proprietary knowledge resources and investment in collaborative projects, while at the same time, engaging in open knowledge exchange with their external colleagues in order to explore and identify new scientific advances. Here, the requirement of industrial secrecy inevitably comes into conflict with the norm of open communication. "Knowing what they can say and what they can't say," according to a Pharma2 manager interviewed, is "often one of the things that scientists have to struggle with." Such conflict in communication norms, however, manifests not only in tension between the scientist and the firm as discussed in much of the literature, but also between the industrial researchers and academic scientists. Differences in research timescale, work norms, and ownership of research results appear to be the key areas of contention. Although industrial and academic scientists are both involved in the research community, their additional participation in different organizational systems governed by divergent goals and careers systems could be a barrier to open knowledge exchange.

Building Industry–University Collaborative Knowledge Networks

Network Model of R&D and Problems for Firms in Skills and Knowledge Sourcing. The evidence presented previously shows that many of the old tensions and dilemmas in managing the relationship between science and business manifest themselves in a much more complex manner within the network model of R&D, spanning industry and the academia. A fundamental challenge for firms is to manage the emerging network interface between the two sectors. The problems that firms will have to deal with are two-fold.

The first is the recruitment of a core group of scientists, especially at the PhD level, who will be able to connect the firms' internal R&D with the external academic community. However, evidence from the interviews suggests that firms are finding it difficult to attract and retain the best scientists—many of whom appear to be reluctant to pursue a career in an industrial environment where there is little scope for conducting long-term research and building specialist expertise within a stable scientific environment. As noted by the human resource director of Pharma2: "increased external knowledge sourcing could take away interesting work from scientists." A research director at ICT3 also pointed out that the company was having difficulties in attracting the best scientific researchers because "ICT3 Laboratories wasn't seen to be thinking sufficiently long-term for them to feel that their talents could be realised in that space." Thus, a key challenge for the network firms is to devise new strategies to tackle what Liebeskind et al. (1996) describe as the "intellectual resource immobility" problem. New organizational arrangements are needed to gain access to the best scientific researchers based at universities.

A second problem arises from the difficulties in transferring knowledge across organizational and institutional boundaries. Knowledge is by nature sticky and has a tacit dimension, its transfer requires social interaction and mobility of people (Polanyi 1962; Lam 2000). The direct transfer of knowledge between industry and the academia is especially difficult because of the divergent goals and career objectives sought by members recruited from the two different communities (David, Foray, and Steinmueller 1999). Firms will need to develop new coordination mechanisms and career structures to support the development of cooperative scientific team to ensure that new knowledge generated through common projects can be effectively transferred and integrated into their innovative competences.

Evidence based on the case analysis suggests that the network firms are devising new structural mechanisms to foster closer ties with their academic partners. The new policy strategy comprises three key components: (1) developing "strategic partnerships" with key universities; (2) creating hybrid organizations located at the interface between firms and universities; and (3) the employment of "linked scientists" at networks nodes to bridge the interface between the two sectors.

Building Strategic University Partnerships for Human Resource and Knowledge Flows. A significant development observed in the three network firms is the tendency to develop closer ties with a smaller number of key universities. The main objective of the firm is to focus attention and concentrate resources on a small number of key institutions 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, multidimensional ties and trusting relationships with their "preferred institutions." The relationships are usually sustained by a range of linking mechanisms including research collaboration, industrial inputs to curriculum development, student placements, and exchange of scientific staff.

A strong focus is placed on long-term relationship-building rather than acquisition of specific expertise or technologies. The intention behind such partnerships, according to a senior manager responsible for university links in ICT2, is to have early access to the best ideas and people:

> "So it's early access to the best ideas and trusted access to the best ideas. And so they know they have a good partner who's not going to rip them off. And that same thing applies, I think, to getting hold of the best talent, people. One of the specific projects that I'm doing is developing strategic university relations program for ICT2 Labs. And the objectives of the program are to develop a network of deep relationships with key institutions—building on that base probably, to recruit the most innovative and entrepreneurial people from the best universities . . ." (university relations manager, ICT2).

By becoming a trusted partner in the academic community, firms are not only in a better position to gain access to the best researchers, but also have an opportunity to influence the education and training of future employees:

> ". . . by having the deep relationship with key universities, then you can spot and encourage people to come to you with the right skill. Because you've got this relationship with the lecturer, you can now influence what those PhDs do: We would like you to be in [this area X] and why don't you go and look at this particular area of X. Come and see what we do, come and see if you can improve it . . ." (R&D director, Pharma2).

Furthermore, developing long-term stable relationships with their academic partners also provides firms with an established channel and trusted information sources to recruit a core group of researchers with the necessary competence profiles:

> "The recruitment side is very important. 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 . . ." (professor, academic partner of ICT2).

Hybrid Organizations as Overlapping Knowledge Networks. The hybrid research organization is another mechanism used by the network firms to create an overlapping social space where scientists from industry and university can interact and work in close proximity. It seeks to establish an organizational infrastructure for recruiting and developing a pool of human resources with competence and careers straddling industry and the academia. ICT2, 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 institute sits at the interface between ICT2 lab and its partner university, providing a forum for joint recruitment, collaborative activities, and personnel exchanges. The core research staff comprises a mixed blend of ICT2 researchers, academic scientists jointly appointed by the company and university, and postdoctoral and PhD students working on projects jointly supervised by academic and industrial scientists. Likewise, ICT3 has also recently established a university-based laboratory supported by joint appointments, aiming at developing a novel area of expertise outside the company's core competence. The intention behind this, 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.

The hybrid organization creates a permeable boundary between firms and universities. It seeks to integrate the business and science systems within a single organization in order to facilitate knowledge exchange.

The "Linked Scientists" and Network Nodes in Knowledge Transfer. At the core of the network firms' strategies for developing closer ties with their academic partners is the creation of a pool of human resources, the "linked scientists," who engage in the practices of both science and business, and work on common projects in collaborative scientific teams. Such collaborative teams constitute vital mechanisms for the capture and transfer of knowledge across organizational boundaries. Zucker, Darby, and Torero (2002) use the term "linked scientist" to refer to academic scientists collaborate on joint research projects with a firm. Here, I use the term more broadly to describe a growing category of scientists whose work and careers straddle industry and the academia. These "linked scientists" play a vital role in shaping the overlapping knowledge networks between firms and universities. Their hybrid career experiences and mobility between the two sectors become key mechanisms for knowledge sharing and transfer.

There are three categories of researchers who perform the role of "linked scientists" in bridging the interface between science and business. The first concerns the "entrepreneurial" professors who have ongoing collaborative links with firms but retain their full university positions. The second concerns the "joint appointments" or postdocs 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 the 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 sponsored research, student placements, consulting, and company advisory board membership. All the network firms have developed their university partnerships through the personal contacts and deep engagement of such entrepreneurial professors in the collaborative relationships. Pharma2, 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 Pharma2 through consultancy activities and advisory board membership. While maintaining his full university status, the professor has become a vital source of intellectual capital for Pharma2 through joint research, and his key role in creating and transferring early discovery results via direct contacts with Pharma2 scientists. He also acts as a magnet for attracting other top scientists to his team, providing a source of reliable researchers for the collaborative project.

ICT2'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 15 years before joining the academia. His relationship with ICT2 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 personnel-based exchanges including student placements, visiting staff arrangements, and participation of firm scientists in curriculum development and project supervision. Thus, this professor not only represents a centre of expertise for ICT2, he is also the main conduit through which ICT2 gains access to students and influences their training early on.

Likewise, the relationship between ICT3 and a university based in London builds on the work of a prominent academic in opto-electronics whose long-standing relationship with the firm started in the 1970s when he was completing his doctorate. ICT3 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 position as a university employee, this professor's work is governed by contractual arrangements with ICT3. Through the long-standing relationship with this professor, ICT3 has been able to develop multiple links with the university in both research and educational programs.

The Postdoctoral Researchers as "Joint" Human Capital. The postdoctoral researchers are a growing category of "linked scientists" situated at the interface between industry and the 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 2 to 3 years. For the universities, these funded positions enable them to offer temporary employment to their new PhDs while they build up their research record and wait for permanent positions in either the 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 are trying to pick some of his "star" postdocs. Another senior academic saw the postdoctoral positions as opportunities for some of his younger colleagues to "get their faces known in the companies" and as vehicles for career moves from the academia to industry.

The postdoctoral researchers represent a kind of joint human capital shared between firms and universities within a temporary and dynamic transitional scientific labour market characterized by mobility and flows of people between the two sectors.

The Doctoral Students as a New Breed of "Hybrid" Scientists. Another category of "linked scientists" is provided by the doctoral students whose competence are jointly produced by universities and firms through some kind of private–public collaborative education and training programs. All the network firms use such programs 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. ICT3, for example, has been a key participant of the engineering doctoral program 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 direct engagement in solving industrial problems. This resembles a kind of "informal apprenticeship" which allows industrial practice to penetrate academic training, and facilities the reverse-flow of knowledge from industry to universities by shaping the skills and competence of the new generation of scientists. Several of the professors pointed out how their industrial partners use the relationships with them to get the students they need and to "match" their competencies to the roles in the companies.

Evidence from the interviews suggests that firms tend to hire those who have interned with them. The employment of these students further strengthens the firms' network ties with their academic partners.

Towards the Formation of "Extended Internal Labour Markets" (EILMs)

The network firms are devising new mechanisms to support skills and knowledge sourcing. A main thrust of this has been the development of human resource linkages and career structures to break down the cognitive and institutional barriers between industry and university, and to incorporate academic scientists into the firms' knowledge networks. As a result, a growing number of scientists operate at the emerging overlapping space between firms and universities, leading to the formation of a common scientific community spanning the two sectors.

For the firms, the extension of their knowledge networks into the academia and the employment of a pool of "linked scientists" through affiliation and sponsorship amounts to the formation of what might be called an "extended internal labour market" (EILM). The basic 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. Manwaring (1984) first used the term "EILM" to describe how firms recruit through their existing employees and seek to extend their internal labour markets through their social networks in the local community (Manwaring 1984). Here, I apply the concept in a broader sense to stress the active role of firms in developing social networks for knowledge and skills resourcing, and also to highlight the critical role of careers and mobility of people in the transmission and sharing of knowledge across organizational boundaries. The arrangements set up between the firms and universities provide stable frameworks for supporting cooperation and knowledge production in flexible project networks. More specifically, they perform four important functions associated with EILMs. First, they provide effective channels for blending industrial problem-solving with academic modes of knowledge production, and thus facilitating the coproduction of new knowledge that has commercial applications. Second, they serve as informal apprenticeship systems for shaping joint human capital. They enable firms to shape unique human resources required for connecting their internal knowledge with new knowledge generated through collaborative projects. They also constitute established avenues for transmitting reliable information about the competence of potential recruits. Third, they serve as a selection and screening mechanism as the entrepreneurial professors filter those whom they choose as postdoctoral collaborators. And fourth, more critically, they 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 enabling 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 lifetime jobs," to put it in the words of a professor collaborating with ICT2. 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 the large innovative firms have not abandoned their internal labour markets but have sought to transform the way they operate by making use of the career systems provided by universities.

However, for the individual academic scientists incorporated into the firms' EILMs, their simultaneous engagement in the science and business systems can cause a great deal of role pressure and tension. Indeed, evidence based on this study and elsewhere (Turpin and Deville 1995; Cohen, Duberley, and McAuley 1999) suggests that academic scientists increasingly experience many of the traditional dilemmas encountered by their industrial colleagues. To start with, balancing the fundamental differences between the academic norm of free communication and the industrial requirements of confidentiality is problematic. Many of the academic scientists interviewed regard confidentiality as a thorny issue in their collaborative relationships with firms as this may deprive them of the opportunities to gain recognition in the scientific community. This can be a serious problem for younger scientists, especially those employed on short-term projects, who are often dependent on the research output of these projects to secure future long-term employment in the academia. A study by Slaughter, Campbell, Holleman, and Morgan (2002) also suggests that "secrecy" and delayed publications can potentially jeopardize the careers of doctoral students engaged in industrial projects. Moreover, for many of the "linked scientists," striking the right balance between academic scientific goals and industrial objectives in their research appears to be a sensitive issue. The following comment by an "entrepreneurial" professor expresses this sentiment:

> ". . . if you sort of do their [the companies'] problems that does not give you credit in your own environment, then you are solving the wrong kind of problems".

The blurring of boundaries between university and industry, and the hybridization of occupational roles and careers within firms' EILMs mean that the same individual scientist can be a "private" industrial researcher as well as "public" academic scientist. While the comingling of ideas and perspectives of the two different systems can be a source of creativity and new knowledge, balancing the divergent, and at times conflicting, demands of these two different systems remains an immensely challenging task for the scientists involved.

Conclusion

By comparing market-pull and network firms, this paper has explored the changing work roles and careers of R&D scientists as the latter types of firms increasingly extend their knowledge networks into the academic scientific community to compensate for the weaknesses of internal R&D. It argues that the increased interchange between industry and the academia is leading to the emergence of a hybrid scientific community with a growing number of scientists in knowledge networks straddling the two sectors. This community consists of a blend of industrial researchers and academic scientists working on common projects in collaborative scientific teams. The interchange and mobility of scientific personnel between the two communities constitutes a key mechanism in supporting the collaborative knowledge networks between industry and university. The paper draws attention to the notion of an "extended internal labour market" as one particular form of institutional mechanism underpinning the network model of R&D organization.

While firms have used their EILMs to support the hybrid community to tap into the open knowledge networks of universities, the resulting incorporation of academic scientists as key actors in firms' innovation process has caused worries about the basic knowledge creation role of universities. Some authors have also raised concerns about the difficulties in containing the conflicts that are likely to arise from the lack of congruence between the goals and careers sought by members from the private proprietary and public open scientific communities (David, Foray, and Steinmueller 1999). For the individual scientists, the increased overlap between industry and the academia creates opportunities for developing new competences, and pursuing alternative career options outside their own research communities.

However, the tension inherent in the nature of the relationship between the science and business systems, and the "temporary" state of many of the collaborative projects mean that the career paths for those engaged in hybrid work roles could be fragile and uncertain. Among the possible losers in this process are the "trapped" postdoctorates employed on "soft" money, and graduate students used as cheap scientific labourer in industry-university exchanges (Stephan and Levin 1997; Slaughter et al. 2002).

This paper has sought to contribute to our understanding of how the evolution of industrial R&D shapes the work roles and careers of scientific personnel by contrasting their nature in two types of firms. Although the in-depth case studies shed light on key aspects of new models of careers and employment underpinning knowledge production in network organizations, the nature of the sample calls for some qualifications. First, the sample is small—a constraint on all case studies. Second, those interviewed might be considered "insiders", who have benefited from the changes and so see the problems in a positive light. This might exaggerate the stability of the EILM arrangements and their ability to appeal to academic scientists. Future research is needed to gain a deeper understanding of the operation of EILMs from the perspectives of a broader cross-section of scientists. The role of the linked scientists and their positions in firms' EILMs deserve particular attention in future investigation.

References

Abrahamson, Mark. 1964. "The Integration of Industrial Scientists." *Administrative Science Quarterly* 9(2):208–18.

Allen, Thomas J., and Ralph Katz. 1986. "The Dual Ladder: Motivational Solution or Managerial Delusion?" *R&D Management* 16(2):185–97.

———. 1992. "Age, Education and the Technical Ladder." *IEEE Transactions of Engineering Management* 39(3):237–45.

Badaway, M. K. 1988. "What We Have Learned: Managing Human Resources." *Research Technology Management* 31(5):19–35.

Bailyn, Lotte. 1991. "The Hybrid Career: An Exploratory Study of Career Routes in R&D." *Journal of Engineering and Technology Management* 8(1):1–14.

Causer, Gordon, and Carol Jones. 1993. "Responding to Skill Shortages: Recruitment and Retention in a High–Technology Labor Market." *Human Resource Management Journal* 3(3):1–20.

———. 1996. "Management and the Control of Technical Labor." *Work, Employment and Society* 10(1):105–23.

Child, John, Michael Fores, Ian Glover, and Peter Lawrence. 1983. "A Price to Pay? Professionalism and Work Organization in Britain and West Germany." *Sociology* 17(1):63–78.

Cohen, Laurie, Joanne Duberley, and John McAuley. 1999. "The Purpose and Process of Science: Contrasting Understandings in the UK Research Establishments." *R&D Management* 29(3):233–247.

———, Wesley M., and Daniel A. Levinthal. 1990. "Absorptive Capacity: a New Perspective on Learning and Innovation." *Administrative Science Quarterly* 35:128–52.

Cordero, Rene. 1999. "Developing the Knowledge and Skills of R&D Professionals to Achieve Process Outcomes in Cross–Functional Teams." *The Journal of High Technology Management Research* 10(1):61–78.

Dasgupta P., Paul A. David. 1994. “Toward a New Economics of Science.” *Research Policy* 23:487–521.
David, Paul A., David C. Mowery, and W. Edward Steinmueller. 1994. “University–Industry Research Collaborations: Managing Missions in Conflict.” Paper presented at the CEPR/AAAS Conference on University Goals, Institutional Mechanisms, and the Industrial Transferability of Research, Stanford University, March, 18–20.
———, Dominique Foray, and W. Edward Steinmueller. 1999. “The Research Network and the New Economics of Science: From Metaphors to Organizational Behaviours.” In *The Organization of Innovation Activities in Europe*, edited by Alfonso Gambardella and Franco Malerba, pp. 303–342, Cambridge: Cambridge University Press.
Debackere, Keonraad, Bart Clarysse, and Michael A. Rappa. 1996. “Autonomy in the Industrial Laboratory: The Dilemma Revisited.” *Journal of High Technology Management Research* 7(1):61–78.
DTI 1998. *Our Competitive Future: Building the Knowledge Driven Economy.* London: Department of Trade and Industry.
Etzkowitz, Henry, and Loet Leydesdorff. 2000. “The Dynamics of Innovation: From National Systems and ‘Mode 2’ to a Triple Helix of University–Industry–Government Relations.” *Research Policy* 29:109–23.
Fox, Alan. 1974. *Beyond Contract: Work, Power and Trust Relations.* London: Faber and Faber.
Gambardella, Alfonso. 1995. Science and Innovation. Cambridge: Cambridge University Press.
Gerpott Torsten J., and Michael Domsch. 1985. “The Concept of Professionalism and the Management of Salaried Professionals: A Cross–National Perspective.” *Human Resource Management* 24(2):207–26.
Gibbons, Michael, Camille Linoges, Helga Nowotny, Simon Schwartzman, Peter Scot, and Martin Trow, eds. 1994. *The New Production of Knowledge.* London: Sage.
Hage, Jerald, and J. Rogers Hollingsworth. 2000. “A Strategy for the Analysis of Idea Innovation Networks and Institutions.” *Organization Studies* 21(5):971–1004.
HMSO. 1992. *Realizing Our Potential—A Strategy for Science, Engineering and Technology.* London: Her Majesty’s Stationery Office.
Howells, Jeremy. 1999. “Research and Technology Outsourcing.” *Technology Analysis and Strategic Management* 11(1):17–29.
———, Andrew James, and Khaleel Malik. 2003. “The Sourcing of Technological Knowledge: Distributed Innovation Process and Dynamic Change.” *R&D Management* 33(4):395–409.
Kaufmann, Alexander, and Franz Todtling. 2001. “Science–Industry Interaction in the Process of Innovation: The Importance of Boundary–Crossing Between Systems.” *Research Policy* 30:791–804.
Kornhauser, William. 1963. *Scientists in Industry: Conflict and Accommodation*. Berkeley and Los Angeles: University of California Press.
La Porte, Todd R. 1965. “Conditions of Strain and Accommodation in Industrial Research Organizations.” *Administrative Science Quarterly* 10(1):21–38.
Lam, Alice. 1994. “The Utilisation of Human Resources: A Comparative Study of British and Japanese Engineers in Electronics Industries.” *Human Resource Management Journal* 4(3):22–40.
———. 2000. “Tacit Knowledge, Organizational Learning and Societal Institutions: An Integrated Framework.” *Organization Studies* 21:487–513.
Liebeskind, Julia Porter, Amalya Lumerman Oliver, Lynne Zucker, and Marilynn Brewer. 1996. “Social Networks, Learning, and Flexibility: Sourcing Scientific Knowledge in New Biotechnology Firms.” *Organization Science* 7(4):428–43.
Liyanage, Shantha, Paul F., Greenfield, and Robert Don. 1999. “Towards a Fourth Generation R&D Management Model—Research Networks in Knowledge Management.” *International Journal of Technology Management* 18(3/4):372–93.
Manwaring, Tony. 1984. “The Extended Internal Labour Market.” *Cambridge Journal of Economics* 8:161–87.
Marcson, Simon. 1960. *The Scientist in American Industry*. Princeton: Industrial Relations Section, Princeton University.
Meyer-Krahmer, Frider, and Ulrich Schmoch. 1998. “Science–based Technologies: University–Industry Interactions in Four Fields.” *Research Policy* 27:835–51.

Murray, Fiona. 2002. "Innovation as Co–Evolution of Scientific and Technological Networks: Exploring Tissue Engineering." *Research Policy* 31:1389–1403.

Niosi, Jorge. 1999. "Fourth-Generation R&D: From Linear Models to Flexible Innovation." *Journal of Business Research* 45:111–17.

OECD. 2000. *Industry-Science Relationships: Proceedings of the Joint OEC German Government Conference on Benchmarking Industry Science Relations.* Berlin: October.

Owen-Smith, Jason. 2003. "From Separate Systems to a Hybrid Order: Accumulative Advantage Across Public and Private Science at Research One Universities." *Research Policy* 32:1081–104.

Polanyi, Michael. 1962. *Personal Knowledge: Towards a Post-Critical Philosophy*. Chicago, IL: University of Chicago Press.

Powell, Walter W., and Jason Owen-Smith. 1998. "Universities and Markets for Intellectual Property in the Life Sciences." *Journal for Policy Analysis and Management* 17(2):253–77.

———, Kenneth W. Koput, and Laurel Smith-Doerr 1996. "Interorganizational Cooperation and the Locus of Innovation: Networks of Learning in Biotechnology." *Administrative Science Quarterly* 41:116–45.

Randle, Keith, and Al Reinnie. 1997. "Managing Creativity, Maintaining Control: A Study in Pharmaceutical Research." *Human Resource Management Journal* 7(2):32–46.

Reger, Guido, and Dorothea von Wichert-Nick. 1997. "A Learning Organisation for R&D Management." *International Journal of Technology Management*, Special Issue on R&D Management:797–817.

Reich, Robert. 1992. *The Work of Nations*. New York: Vintage Press.

Rothwell, Roy. 1992. "Successful Industrial Innovation: Critical Factors for the 1990s." *R&D Management* 22(3):221–38.

Slaughter, Sheila, Teresa Campbell, Margaret Holleman, and Edward Morgan. 2002. "The 'Traffic' in Graduate Students; Graduate Students as Tokens of Exchange Between Academe and Industry". *Science, Technology & Human Values* 27(2):282–312.

Shepard, Herbert A. 1956. "Nine Dilemmas in Industrial Research." *Administrative Science Quarterly* 1(3):295–309.

Stephan, Paula E., and Sharon G. Levin. 1997. "The Critical Importance of Careers in Collaborative Research." *Revue D Economie Industrielle* 79(1):45–61.

Turpin, Tim, and Adrian Deville. 1995. "Occupational Roles and Expectations of Research Scientists and Research Managers in Scientific Research Institutions." *R&D Management* 25(2):141–57.

———, Sam Garret-Jones, and Nicole Rankin. 1996. "Bricoleurs and Boundary Riders: Managing Basic Research and Innovation Knowledge Networks." *R&D Management* 26(3):267–82.

Tushman, Michael, L. 1977. "Special Boundary Roles in Innovation Process." *Administrative Science Quarterly* 22(4):587–605.

Twiss, B. 1986. *Managing Technological Innovation*. London: Longman.

Whittington, Richard. 1991. "The Fragmentation of Industrial R&D." In *Farewell to Flexibility*, ed. Anna Pollert, pp. 84–103. London: Blackwell.

Zucker, Lynne G., Michael R. Darby, and Maximo Torero. 2002. "Labor Mobility from Academe to Commerce." *Journal of Labor Economics* 20(3):629–60.

———, Michael R. Darby, and Jeff S. Armstrong. 2002. "Commercializing Knowledge: University Science, Knowledge Capture, and Firm Performance in Biotechnology." *Management Science* 48(1):138–53.