The sourcing of technological knowledge: distributed innovation processes and dynamic change

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This paper outlines the knowledge and technology sourcing practices of a range of key firms and organisations across the UK based on primary research, and analyses the key factors related to managing the technological knowledge boundaries of the firm. In particular, the paper considers the dynamic dimension considerations to such issues. As such it outlines important differences between short and long time horizons, before analysing in more detail some of the implications for firms of technological change over the long term. The paper seeks to highlight the importance of the time dimension in helping to explain why and how firms source technological knowledge externally and how they align their sourcing activities to their strategies associated with developing current and future capabilities.

1. Introduction

Increasingly firms have come to acknowledge that it is difficult for them to create and exploit technological capabilities on their own. As a result there has been a widespread trend by firms and organisations to acquire and utilise external sources of knowledge and technology. Thus an increasing proportion of innovations are produced not by individual firms that are self-sufficient with respect to technological resources but through combinations of capabilities that may be located in other firms and institutions. Across many sectors, a company's competitiveness now depends not merely on the capabilities that it can create and exploit internally, but on the effectiveness with which it can gain access and utilise sources of technological knowledge and capabilities beyond its boundaries. Increasing global competition, decreasing product cycle times, increasing technical complexity and market uncertainties all serve as catalysts for firms to acquire external sources of technological knowledge.

The focus of this paper is on the strategic sourcing of technological knowledge by firms; in particular on the sourcing of *new* technological knowledge, rather than on *existing* technological knowledge (see, for example, Steensma and Corley, 2001) through such activities as technology licensing.[1] The term 'technological knowledge', though, is used in a wide sense and includes both basic scientific knowledge right through to more applied and experimental development, design and protype work, not just R&D-based knowledge (although it does not cover more general managerial or marketing knowledge). Technological knowledge sourcing has become an important phenomenon as firms have come to realise that they can no longer solely rely on in-house technological and knowledge capacity to generate new products, processes and services. Firms are therefore increasingly having to confront the problem of how to decide what elements of their technological knowledge requirements should be sourced externally and those that should be generated in-house. This phenomenon is reflected more generally in the growth of externally funded R&D and in the expansion of external technological collaboration, partnering and contracting with other firms and organisations.

2. Research background and methodology

This paper draws on a research project on the sourcing of technological knowledge. The objective of the study is to establish criteria for the effective management of company decisions regarding the use of in-house knowledge generation versus external knowledge acquisition and outsourcing, through the development of a Decision Support Framework (DSF) model.[2] The project has a number of core industrial partners which include member companies and organisations of the UK Association of Independent Research & Technology Organisations (AIRTO) and a range of other companies including: Abbey National, AMTRI, BT, ICI, and Pilkington. A more detailed list of survey firms and organisations are provided in Table A1 in Appendix 1.

Given the complex nature of the issues to be addressed and the wide range of factors, which are brought to bear in each individual case, meant that in-depth case study interview work was the most appropriate method to collect and analyse the detailed and, more particularly, sensitive data that was collected. The study included a first tier group of 'core' firms and organisations which were involved in detailed case study work, together with a group of second tier firms who were also to be surveyed and who provided more general feedback on the research being undertaken.

More specifically, the survey also involved a detailed study of some 20 cases of knowledge and technology projects, which examined the detailed decision-making process about where the technology or knowledge for such projects should be 'sourced'. This involved longitudinal work targeted at the beginning of each project, when the crucial decisions about the project were made. However, experience of previous projects in terms of their successes and failures and how they were managed were also important in terms of their feedback on the decision-making process and examination of these sets of issues were also included. The study therefore sought to help companies to best optimise the balance between internal and external technological knowledge sourcing through the creation of a Decision Support Framework (DSF) based on widely accepted stage-gate decision procedural models used by industry. This is also in conjunction with a wider assessment of industry needs and problems associated with technological knowledge sourcing. A prototype of the DSF was developed, piloted and fully tested with the project's industrial partners. Real-time use of the DSF was then undertaken and monitored against a wider range of companies before the final version was established and the broader results of the study were disseminated across both industry and academic audiences. Some initial results of this part of the research are outlined in Howells *et al.* (2003).

3. The knowledge base and boundary of the firm

There is a growing recognition that an organisation's knowledge base is a valuable company asset and that enlarging that knowledge base and improving its use can contribute to the competitiveness of the firm (see, for example, Nonaka and Takeuchi, 1995; Tsoukas, 1996; Howells, 1996; Cole, 1998; Klein, 1998; Metcalfe and James, 2000; Cavusgil *et al.* 2003). Whilst much of the management literature on organisational knowledge has focused on managing and measuring knowledge use *within* the firm, a number of studies have sought to explore how companies can access know-how and experience from *outside* the organisation and effectively import and absorb that technological knowledge (Leonard-Barton, 1995; Powell, 1998; Ruggles, 1998). Thus, in different ways, recent studies have emphasised the potential openness of the firm to the acquisition of external knowledge and the possibilities that this presents for the firm to increase its potential to create radically new knowledge (Coombs and Hull, 1998). Critically, as firms increasingly use these external relationships to acquire new knowledge they need to develop the capability for learning both *how* and *what* to learn through external sources (Powell, 1998).

Nevertheless, although much has been made of knowledge and knowledge management, many of the firms involved and supporting the research project have been found to have problems with the concept of knowledge. Although the focus of the research is on technological *knowledge* sourcing and it is a process the firms are concerned with and want to know more about, they still have difficulties approaching the issue. Ultimately they realise that undertaking research and technological activity in-house, or seeking external sources for it, is about maintaining future competitiveness of the company and the future core competencies and capabilities of the firm (Ford and Farmer, 1986). This links in with the work of Winter (1987) and Prahalad and Hamel (1990) in relation to their respective and related notions of 'strategic assets' and 'core competences' of the firm. Both approaches emphasise that firms have key assets or competences that have resulted from previous rounds of investment and from learning-by-doing. These core competencies can be seen as 'resources' (Hall, 1992) as well as capabilities which are accumulated over the long term which firms seek to both develop and deploy to gain competitive advantage (Penrose, 1959; Richardson, 1972). Coombs (1996) has indeed sought to employ the 'core competence' model as a lens through which to analyse changes in the strategic management of R&D over time. Clearly the core competencies model is a valuable conceptual approach in that it provides a more holistic and structured framework from which managers can make *a priori* judgements regarding the internal/external technology boundaries of the firm and *a posteriori* make evaluations about their success.

However, care must be taken when emphasising both the benefits to firms of such trends towards R&D and technical outsourcing and the implications of such a shift in terms of in-house research and technical effort. Coombs (1996, p. 354), suggests why firms may be over-reaching themselves in their desire to decentralise and outsource their R&D portfolios, ultimately weakening their core technological competencies (although this view is somewhat at variance with researchers who have sought to highlight the 'virtual organisation' (Chesbrough and Teece, 1996) and more especially the virtual organisation of R&D activities (Chiesa and Manzini, 1997)). Häusler *et al.* (1994) have also emphasised that current literature tends to give a rather positive image of external research links, even though there are good reasons against co-operation. Historical insights into the process are also valuable here. Mowery (1984, p. 52), for example, has highlighted the British reliance on the external contracting of R&D and 'market' mechanisms as a key factor *hampering* innovation and expert performance amongst British firms before 1950. In particular the use of consulting engineers in the British electrical industry in the late nineteenth and early twentieth centuries hindered innovation and the design process in the industry (Byatt, 1979). In the latter context, the increase in external outsourcing of research and technical activity does not imply that there is necessarily a contingent decline of in-house R&D activity. Thus, Mowery (1983, p. 369), in the context of independent research organisations during the period of 1900–40, has noted that 'rather than functioning as substitutes, the independent and in-house research laboratories were complements during this period, exhibiting a division of labour in the performance of research tasks.' Similarly, Arora and Gambardella (1990, pp. 373–4) have suggested external collaboration of research is complementary to, rather than a replacement for, in-house research activity.

A new era in terms of research and technical competencies and collaborative patterns for firms may now be emerging as companies seek a more balanced and holistic approach to their research and technical requirements. External technological knowledge acquisition is best seen as being complementary to the development of in-house capabilities rather than a substitute. Recent studies have shown that successful firms are increasing both their in-house innovation capacity as well as 'buying in' more external technology and knowledge (Arora and Gambardella, 1990; Pisano, 1990, 1994). A good in-house knowledge base of R&D, engineering and design is necessary to provide the absorptive capacity for effective learning from external knowledge acquisition (Cohen and Levinthal, 1990). However, there are examples where firms have outsourced so much of their research and technical activity that they no longer have the internal capability to adequately deal with and absorb the knowledge and technology they are acquiring externally. This draws attention to the potential dangers to a company's knowledge base of inappropriate decisions regarding the sourcing of technological knowledge (Attuahene-Gima, 1992; Welch and Nayak, 1992).

Certain factors can be identified as underlying these fundamental shifts in the internal-external balance of knowledge in and beyond the firm. These explanations can be broken down to a number of key 'meta' parameters, namely changes in the:

- nature of R&D and technical work;
- the emergence of a functioning research and technical 'market' and new collaborative and institutional arrangements of innovation; and the
- macro innovation task environment, associated with the life cycles of technologies and industries.

There have clearly been factors associated with the changing nature of the research process that have encouraged outsourcing of these activities. The most frequently cited factors here are the increasing complexity of the research process and the cost and risks of R&D. As many of the simpler scientific and technical discoveries have now been made, companies increasingly have to deal with much more difficult and intractable scientific problems. Products are also becoming more sophisticated catering for these new more complex problems and consumer demands. The number of technologies per product (TPP) is therefore increasing in many consumer and business products. An often-cited example here is the shift from mechanical to electro-mechanical systems in the automobile industry (Miller, 1994, p. 30). Most companies simply do not have the necessary scientific resources to cope with additional burdens and seek outside support to overcome internal technical limitations (Haour, 1992). Many of these new (fundamental) research issues cover several scientific and technical disciplines and further encourage collaboration between organisations with strengths in different fields. This growth in the need for interdisciplinary research has been reflected in the shift from what Gibbons *et al.* (1994) have termed Mode 1 to Mode 2 research operations.

The increasing complexity and inter-disciplinary nature of the R&D process in turn has increased the cost of research. Research may therefore become less attractive without partners to share the cost. More simply, the firm may lack the financial resources to undertake research even if it remains an attractive proposition. Associated with this, the traditional barriers between scientific and technical disciplines are being broken down, as the interchange between basic research and development work grows. This pressure to improve the interface between basic research on the one hand and applied and developmental work on the other also stems from the pressure to reduce innovation cycle times. Scientific and institutional inertia may also play a key role. Pisano *et al.* (1988, pp. 191–3) have, for example, outlined the defensive response by many major pharmaceutical companies in the 1980s, as these chemistry-based companies sought links with new biotechnology firms and universities to gain research expertise in biotechnology.

The above have described mainly 'push' factors associated with firms seeking outside research and technical support, but there are also a number of key 'pull' factors encouraging the trend towards further external R&D collaboration. These cover the relative attractiveness of external sources of expertise over internal firm resources which the firm may not possess or only very inadequately. Such factors also cover other motives such as the desire to enhance the scope and testing of in-house scientific and technical activities, as a general scanning mechanism of technological opportunities existing outside the company and as a means to network with other organisations and to enable in-house staff to be part of a wider 'invisible college' within the specific research community. Lastly, there are government policies and incentives to participate in collaborative research and technical projects. These push factors have been emphasised by Ringe (1992, pp. 28–9) who found that the desire to gain specialist expertise was the most frequently cited motive in his UK survey for contracting out R&D, together with access to specialist techniques or equipment. The need to tap additional manpower was the third main factor, followed by the ability to gain tight control of R&D timescales and budgets, in order to get the job done.

These last points in turn relate to developments in the technological knowledge 'market' (Howells, 1999a,b). Many companies are still reluctant to outsource 'critical' technologies to outside suppliers, but they are increasingly willing to contemplate the sub-contracting of more routine, low value-added research and technical activities. As the technological knowledge 'market' continues to develop, less of this routine R&D and technical work will be undertaken 'in-house' and instead will be the responsibility of research partners or contractors and their employees either working on- or off-site. The technological knowledge 'market' appears to be highly dynamic, not only in terms of the appearance of more dedicated independent laboratories, but also of a much wider set of partial players, who may over time become more central participants. Research and technology outsourcing is 'coming of age' and seen as a major industry in its own right. It is also becoming more complex in its form. Research and technology outsourcing is no longer just appearing in a 'pure' market form, but is also occurring in more hybridised, quasi-market and relational transactional forms.

Indeed this has been acknowledged by Williamson (1996) himself in his reworking of the Transaction Cost Economics model more generally. He notes that there has been a plethora of new forms of firm collaboration emerging within the economy. There are therefore many more types of hybrid arrangement that firms can find themselves in aside from in-house work (hierarchy) or simple subcontracting (market-based) forms. This is evident more specifically within the field of research and technology relationships where these hybrid forms range from, for example: collaboration without equity participation; co-operation with equity participation; joint ventures with or without prior 'exit' strategies and varying degrees of equity stakes between the two partners; complex 'multi' ventures involving more than one firm; project specific collaborative networks with varying participants apportioned different intellectual property rights (IPRs) and commercialisation rights. Some of these relationships are time or project specific, others are more open-ended. Some collaboration may be centred on a technology or a specific innovation; other co-operative agreements have research and technology as a more indirect outcome of the collaboration which may be based on 'market' access, industrial or financial considerations. Even aside from the middle of the governance spectrum, both 'ends' also involve more complex arrangements. Thus the 'pure' hierarchy of internal R&D modes does in fact vary considerably from a centralised (U-form) of corporate structure to a more decentralised (M-form) structure which is nearer to the 'market' and more responsive to 'market' signalling (Croisier, 1998, p. 291).

Equally at the other end of the spectrum, supposed 'market' based contracts in relation to research and technology can differ substantially and have evolved over time. These can range from fee-for-service arrangements, such as fixed-price contracts; and cost-plus contracts; through to performance-based service arrangements, ranging from fixed royalty payments to variable royalty payments based on successful outcomes. Even with performance-based service arrangements firms pursue different strategies based on one-off contract deals usually involving high royalty deals to more long term 'relational' low royalty deals with more familiar clients.

The boundaries within and between these different hierarchy-market based forms are therefore becoming more blurred as firms learn about collaboration and governance strategies. With the increasing range and diversity of these options firms are more likely to find the right 'fit' encouraging them to externalise their R&D and technical effort whereas before they may have decided that it was better to 'play safe' and retain the project or technology in-house. Moreover, the more they experiment and learn from these external forms of technology sourcing the more comfortable they feel in making future external R&D relationships.

4. Sourcing technological knowledge and time horizons

A key, but largely unexplored issue for firms is how the time horizon affects technology and knowledge sourcing relationships and how this issue is in turn linked to the long term technological and strategic trajectory of the firm. Developments in the conceptualisation of the technological sourcing strategies of firms have been largely from a static framework (Howells and James, 2001). Such perspectives have yielded important insights into such processes at a given point of time, but there remains an important, indeed crucial, dynamic perspective that is lost in such analyses. It is presented here that there will be significant differences in firm technology sourcing requirements and conditions according to timescale. In particular knowledge and technologies are sought by the firm to augment its current technology base and providing additional 'external capabilities' (Langlois, 1997) which can be deployed by the firm. These external sources in combination with the in-house generation of new knowledge are then deployed to produce new and improved products and processes, which are hopefully aligned with future market requirements.

The following discussion will begin with outlining the differences between these two time horizons, before analysing in more detail some of the implications for firms of technology change over the long term. The time dimension is important here in exploring why and how firms seek to source technological knowledge externally and how they align this to their strategies associated with enhancing and developing the current and future capabilities.

Table 1 seeks to outline some of the main differences between technological knowledge sourcing between the short term and the long term along a number of different dimensions. The differences centre on: the objectives and expectations of knowledge sourcing over the short and long term; the varieties of relationship involved with such sourcing; the types of knowledge involved; the desired characteristics of the ex-

Table 1. Technological knowledge sourcing and time horizons.

	Technological knowledge sourcing attribute	Short term	Long term
1	*Objectives of the relationship (expectations)*	New or improved product or process	(a) Aligning future technological competence with future markets (b) Developing new businesses and activities
2	*Type of relationship*	Contractural, formal	(a) Reciprocal, informal (b) Ownership-based
3	*Types of knowledge involved*	Higher codified component	Higher tacit component
4	*Desired characteristics of partners*	Dependable	Explorative, flexible
5	*Organisational responsibility and functional focus*	Development/production	Research/marketing
6	*Expertise 'locale' within firm*	Development/production	Research/marketing
7	*Degree of uncertainty*	Low	High
8	*Degree of risk*	High/Medium	Low/Medium
9	*Technological profile*	Incremental	Discontinuous/disruptive
10	*Market prospects*	Predictable	Speculative
11	*Performance measurement*	Metrics	Positioning against perceived rivals
12	*Importance of IPR Issues in Links*	High	Medium/Low

Source: based on survey interviews.

ternal partners; which corporate functions are responsible for coordinating such links and the locale of expertise for managing such relations; the technological 'profile' concerned; the degree and risk associated with such collaborations; the nature of the market involved; what types of metrics are deployed to measure the performance of such relationships; and, the intellectual property right (IPR) issues associated with such linkages.

As such, short term external technological knowledge collaborations involve a very different profile from those concerned with long term knowledge relationships. Not unexpectedly, short term sourcing relations are centred around mainly specific outcomes associated with new or improved products and processes and where such relationships are usually based on formal contracts. In terms of Cyert and March (1963, p. 279) conceptualisation, these short run knowledge and technology relations would be centred on 'problem-oriented' innovation and the objectives for such links would be on specific 'sub-unit' (not organisation wide) goals. The main channels for these technology inputs in the firm are via the development and production functions. Uncertainty levels for these are low, although risks associated with failure can be high if the required inputs are unsatisfactory or not made available on time as fixed investments made by the firm at this stage have been already committed (i.e., sunk costs in terms of, for example, research, design, testing and tooling up). Associated with this, the technological environment and market prospects are also more specific and predictable.

Performance measurements for short term technology relationships can be measured against a set of specific targets, indeed in some instances the use of external technological knowledge may be specifically used by the firm as a benchmarking exercise and a cost comparator for in-house projects (Tapon and Thong, 1999). The last issue where time is an important variable is over the question of IPR. Where the objectives and known outcomes of a collaboration are much more certain, it is possible to specify the division of IPR rights between partners in advance. However, for longer term research relations this is much harder to do as unpredictable research changes and events makes it difficult to specify contractual provisions in advance.

Turning to the short term, what types of collaborative arrangements are most likely to be associated with these short term requirements? It is presented here that there are three broad types of collaborative mechanisms associated with technology and knowledge sourcing: *contractual*, *reciprocal* and *ownership* (although it should be noted that these categories are not necessarily mutually exclusive and that certain hybrid inter-organisational links may span more than one type of category (Figure 1)).

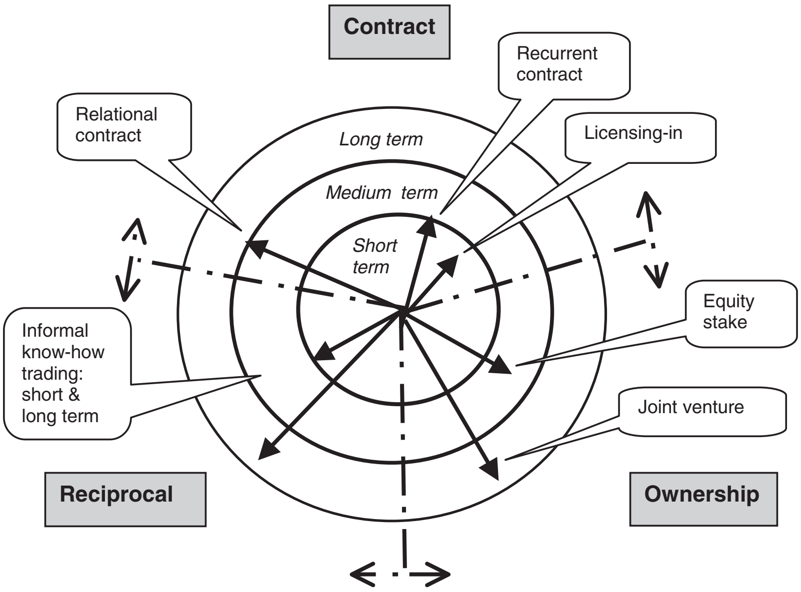

Figure 1. Dynamic dimensions towards technological knowledge sourcing and collaboration.

The types of collaborations which are likely to be mainly *contract* based are either in terms of licensing in *existing* technologies or through specific, *short-term* research or technical contracts (Figure 1). The most immediate and short term source of external technology is via licensing in specific technologies (Attuahene-Gima, 1992; Lowe and Taylor, 1998). Research contracts are also seen as being shorter term in nature, as long term contracts are unsatisfactory when most of the relevant contingencies cannot be delineated (Teece, 1976, p. 13). This problem centres on the contractual incompleteness argument noted above in relation to intellectual property, where it is not possible to stipulate exhaustively the appropriate conditional responses in a contract. However, Ring and van de Ven (1992, p. 487) have gone on to distinguish between two types of contract: *recurrent* and *relational*. Recurrent contracts involve repeated exchanges and their duration is relatively short term. However, relational contracts were seen as involving longer term investments where the partners actually do accept that outcomes cannot be fully specified in advance and frameworks are provided for future negotiations according to a set of rules. Indeed examples of such relational contracts exist amongst our study firms and they appear to be becoming more frequent.

Reciprocal collaborations involve those inter-organisational links that involve informal and non-contractual, non-monetary relationships based on reciprocity. Here the time dimension can vary considerably from short term, one-off contacts to long term informal know-how trading that may span many years (Von Hippel, 1987; Katz, 1986; Carter, 1989). These types of relationships, by their nature, are more likely to be based on personal contacts and this can be a factor in their often abrupt ending as staff leave to join other companies. Nevertheless as in the inter-war years with the major chemical companies, such as Du Pont, ICI and IG Farben, whole company cultures may be built around long term informal relationships with certain industrial partners (the case of technological sharing, as well as rivalry, between Du Pont and ICI is the most obvious example here (Hounshell and Smith, 1988; see also Marsch, 1994)).

The category with the longest time dimension is that of *ownership* links although even here there is considerable variation. Joint ventures can last over very long periods, and are generally long term investments (although not always; see, for example, Harrigan, 1985). However, amongst our partner firms the use of equity stakes in new technological start-ups often has a relatively short time horizon in terms of when an investment will be ended (or increased to potentially a full-scale acquisition). One of our major partner companies had established a whole series of investments in new technological start-up companies and the time horizon for many of these stakes was between three and five years. If the technology that the new start-up was developing proved to be commercially valuable the company had options to increase its stake or make an outright purchase of the company. The partner firm in question was instituting this process at the same time as developing its own corporate venturing unit and technology investment fund, and a number of the companies it was collaborating with were in fact spin-offs from its corporate technology unit.

By contrast, the use of external technology and knowledge for long term purposes centres on somewhat different objectives, as uncertainty about what might be required in the future and what will actually be delivered in terms of technology to meet these requirements are extremely high (see also Doctor *et al.*, 2001). These twin uncertainties have therefore a profound influence on how the firm uses long term knowledge and technology relations with other firms and organisations and are reflected in the two essential objectives of such external links. The first main objective is to help align the future technological competence of the firm with future market conditions so that the future core capabilities of the firm are in a good position to deliver future new products and services to satisfy the market and to be competitive in this respect against other existing and potential firms. Associated with the second, more specific objective of developing whole new sets of products and services in the form of new businesses and activities which are in different business categories to those which the firm is currently in, and which prospectively may be spun out at some stage. However, again this would involve aligning future technological competences with future market opportunities. It is important to acknowledge here that it is as important to identify technologies and markets *not* to move into and satisfy, as much as selecting those to enter and develop. If the 'knowledge base' of the firm can be narrowly defined as the specific technologies and markets of which it has experience, (Metcalfe and de Liso, 1998) then the focus here is on the firm positioning itself in relation to what it wants as its future knowledge base.

These long term objectives may seem straightforward, but they are highly complex and difficult to ascertain and achieve. To be successful, not only does the firm have to predict future technological and market conditions fairly accurately, but with regard to its technological base the firm has to decide what technologies it should provide internally and what it requires from external sources. Underlying this technology framework, the company needs to position its knowledge requirements, both in internal knowledge generation and external knowledge acquisition, to meet these technological needs. This is centred on the interplay between the nexus of the capability of the firm to exploit its knowledge and the unexplored potential of the technology (Kogut and Zander, 1992, pp. 391–2).

5. Knowledge boundaries of the firm in a dynamic perspective

The above process describes the way that knowledge and technology is sourced and channelled by the firm, however the firm needs a clear strategy for this and a 'roadmap' to navigate its way. The route a firm follows can be said to describe its trajectory (see Dosi, 1984), although it is not as circumscribed or 'path dependent' as the technological trajectory model implies. Indeed, the purpose of such long range planning is to avoid 'lock in' on technologies that may be superseded by new technological paradigms, and to modify its routines. The company has to be constantly aware that it should try and avoid institutional lock in as well as being flexible and responsive enough to be able to meet the demands of the future. A firm's inherited resources therefore help to simultaneously enable and constrain what the firms are able to do at least over the short and medium term (Ghoshal *et al.*, 2000, p. 150).

The firm seeks to develop its existing set of core capabilities[3] and competencies in such a way as to meet the demands of future technological changes and market conditions (Figure 2). The use of research and technological collaborations form an important process helping to guide such a process and in shaping the existing and future knowledge boundary of the firm. They allow scanning of the firm's task environment in relation to its technological and market conditions and interactively and iteratively also can provide some guidance of likely changes in these two realms in the future. The iterative nature of this process is important in terms of providing a feedback on the whole process, but is also important in delimiting the knowledge boundary of the firm.

This knowledge boundary then helps to delimit the knowledge base of the firm, which is in turn part of its core capability. Decisions about technological routes and how these are sourced (whether internally and externally; and, if externally, with whom) therefore influences the future knowledge boundaries of the firm and its ancillary capabilities (Langlois and Robertson,

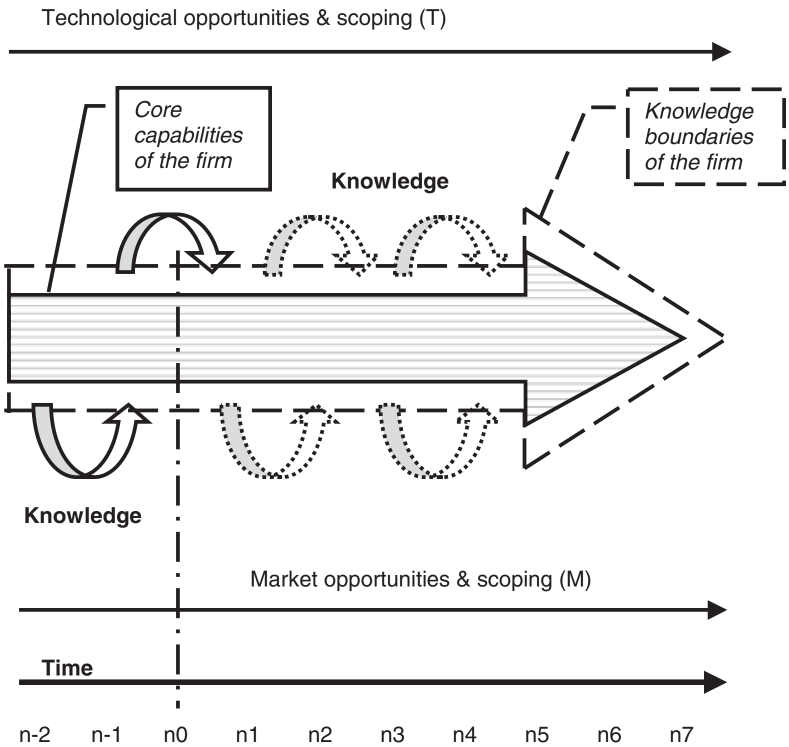

Figure 2. Aligning future technology competences of the firm with future market opportunities to create new core capabilities.

1995, p. 7) which in turn will change to meet these requirements by helping to guide the firm to meet these future technological challenges (Murray, 2001). As noted earlier, long term strategic positioning of knowledge and technology is complex and uncertain. Even the processes described above are over-simplified because of the distributed nature of: (a) decision-making, and (b) the innovation process.

As regards (a), decision-making, it is striking that much of the discussion concerning decision-making in relation to knowledge management is within the context of a single monolith, the firm. However, it should not be forgotten that decision-making is made by individuals, sometimes on their own, but more often in distributed small groups (Fischoff and Johnson, 1997). These groups of individuals may have agendas which are not as closely aligned with that of the firm as often made out; they may not follow the procedures or 'routines' of the firm that are ostensibly laid out (often in turn because they are overly complex; see Fusfield and Spital, 1980, p. 159). This departure from a firm's standard routines and procedures is often greatest where separate Strategic Business Units (SBUs) have been allowed, or gained, considerable autonomy. One large firm that was interviewed indicated that there were considerable differences in the way groups of key individuals approached decision-making related to technological knowledge sourcing and this was reflected in divergent processes and norms in technology-related decision-making between (and even within) SBUs in the firm, and above all for the technology 'visions' these groups held in terms of how they saw technology developing and where the firm should be positioned within this. Thus, rather than following one knowledge or technology path, many firms will in fact develop sets of different knowledge and technology routes.

The trend towards the decentralisation of much technological activity and the removal or downsizing of central R&D laboratories has important implications here. The decentralisation of R&D activity coupled with the closure of corporate R&D units by many companies in the 1980s and 1990s has meant that potential for more fragmented knowledge pathways is now much greater. With no corporate R&D unit, or one which is now much smaller in size, means that co-ordination over future technological routes is now much harder to achieve for these firms. Strategies as regards know-how and technology requirements and positioning can become increasingly divergent or potentially competing.

This is not to deny that companies should not consider 'technology hedging' mechanisms, where they may consciously fund two or more competing technologies (a policy that BT has used), as part of their overall technology strategy. However, this difficult to manage process can become positively dangerous if it is not properly thought out or coordinated. Less specific, but in the long term potentially more damaging, is the lack of a shared technological vision within the firm, which instead pursues multiple sets of technology routes and scenarios.

Rather than a single technological route and knowledge pathway for a firm illustrated in Figure 2 therefore (type (a) in Figure 3), large and even medium-sized firms are more likely to display multiple technological routeways (types (b) to (d), Figure 3). If the firm has managed to establish a coordinated approach to these separate technological pathways they may be seen to be subsets of a larger programmatic vision (b) or at least they are harnessed together into some established framework (c) with agreement and cross-referral between research and technology managers across the different units. By contrast, lack of a coordinated approach can lead to multiple sets of divergent and discordant visions (d) within a firm.

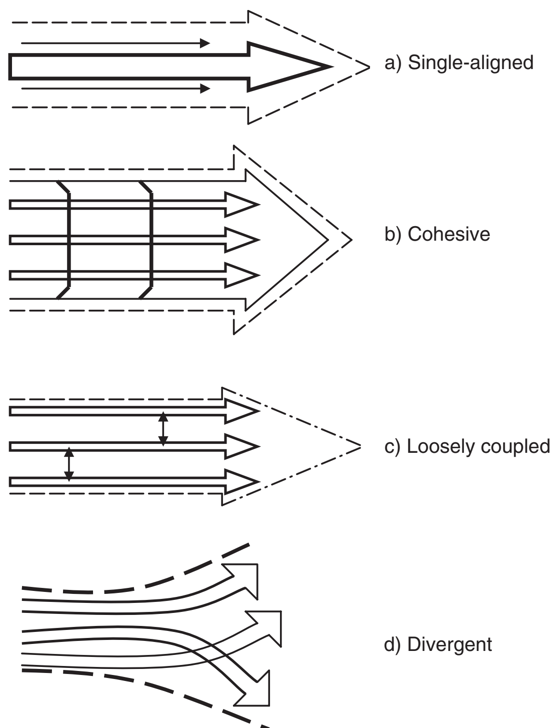

Figure 3. Future technological competence: alignment and cohesion.

In one of our business partners in particular, this has raised issues about the role of the corporate centre in sourcing decisions and in facilitating the transfer of technological knowledge between SBUs. There is often a lack of clarity within the organisation as to who is ultimately responsible for signing-off decisions on the sourcing of knowledge. A number of the survey companies indicated that the decisions that had been taken by managers with responsibility for a particular project or business unit, had subsequently proved to have major implications for the technological direction of the company as a whole. In this context it is important to guard against the 'tyranny of the strategic business unit' (Prahalad and Hamel, 1990). Indeed, in an organisational environment where decision rules are unclear, or sometimes non-existent, and many decisions are taken with limited consideration of their wider implications for the core capabilities of the corporation, it is little wonder that companies fear the danger of inappropriate sourcing of knowledge and technology. The more frequent problem for the firm, therefore, is not deciding upon and managing a single knowledge path (as has been highlighted in the academic literature) but rather in identifying and managing a whole set of different knowledge and technology scenarios scattered between different parts of the firm.

6. Strategic dynamics and distributed innovation: technology and the innovation community

Not only is decision-making about internal and external technological knowledge sourcing increasingly distributed, but so also is its pattern and configuration. Such organisational decision making processes can no longer be regarded in terms of a simple, one-to-one 'make or buy' decision, which characterises the static and single transaction perspective taken by Transaction Cost Economics regarding decision-making in sourcing decisions (Ring and Van de Ven, 1992, p. 491). By contrast, in a distributed framework, firms are making decisions to externally source knowledge and technology in the future based on serial and parallel decisions which in turn are founded on historical precedent and experience. The choice of what to develop internally and what to source externally becomes, in effect a decision on the technological trajectory that the firm is to pursue, the sources of its distinctive competitive position and how the firm is to locate itself within a complex (one-to-many), distributed innovation community. Over time, as the nature of innovation has become more complex, firms have to deal with whole sets of other firms, universities and research organisations simultaneously. The shift from *serial* to *simultaneous and parallel* working in innovation has therefore become more commonplace. Indeed, the ability of a firm to come to robust decisions on what to source externally and where to develop external relationships is becoming a key competitive advantage in many sectors.

The increasingly distributed nature of innovation places a much greater 'architectural' burden on firms when considering future technological commitments.[4] The potential source or coupling point of the newly emerging technology and knowledge base has to be considered not only in terms of its direct potential for achieving technological objectives but also the likely commercial and market contexts for that technology and the network relationships of the technology supplier. It has already been acknowledged that future technologies may be successful in meeting their technological requirements but for various reasons, may not then be commercially successful. An increasingly important factor in commercial success is now network-dependent, either in terms of being part of the actual or de facto industry standard or in an innovation community that becomes the dominant design. Selecting a potential technology or knowledge route can have major strategic implications if it places a firm in a 'non-winning' innovation community or network. In mobile telecommunications, certain supplier companies in relation to technologies or components, have faired much better with being in the Nokia innovation community than that of Ericsson's, Motorola's or Phillips',[5] although the technologies they have delivered or acquired have been equal or superior in technology and design terms.

The distributed nature of innovation means that firms are therefore becoming more interdependent upon each other for successful outcomes in their technological routing. By being a member of an innovation network in one sense can be said to lower the risks of technological failure, as the burden for exploiting the new technology is no longer borne by one firm. However, in another sense, risks are increased for firms as they no longer have to evaluate their own capability of being successful but also their partners. In addition, except for a few major, lead companies, most firms now can therefore be said to be in less control of their technological destinies than they were. Risks of failing in the technology may now be subsumed under the wider risk of not being in the right network or community. Staying in the technological race may now be less about satisfying the specific technological requirements of the project but more about satisfying the requirements of the wider network and these requirements may be much more burdensome. This echoes Ring and Van de Ven's (1992, p. 487) comment that 'A recurring source of risk in all transactions is the need to make a decision in the face of uncertainty of accomplishing tasks that require sustained cooperation with others, particularly when they represent difficult or novel ventures.'

By seeking to deliver a certain new technology (which in turn then requires external knowledge and technology inputs from other partners) within a newly emerging innovation community can therefore have a long term impact in relation to the future shaping of a firm's technological profile. The partners and the network may be just as important in determining the success of the technology as the technology per se. The position of the firm within the network or community, and what network is selected are all critical decisions here.

7. Conclusions

As has been noted, therefore, decisions about the sourcing of knowledge and technological inputs, the selection of partners and the management of such relationships can take on a crucial importance, particularly in terms of how it shapes the future innovative capabilities of the firm. The capacity to use tools and techniques to anticipate future technological developments, locate emerging sources of valuable technological knowledge and identify potential external partners for collaborative ventures is becoming increasingly critical. Integrating these company foresight techniques into technology planning represents a key challenge for companies as they seek to look over the horizon for 'weak signals' of technological opportunities and discontinuous technological change and the new partnerships that they have to build in increasingly distributed innovation systems. It is a sobering thought, though, that Gold's (1971, p. 229) comment that 'scientists and engineers do not have access to widely accepted models of the terrain beyond current research frontiers (including the identification of promising targets and of the means as well as the risks of reaching them)' still holds true, at least in many of the firms we have studied.

Perhaps this is not surprising given that the process is much more complex and dynamic than commonly understood or conceptualised. The paper has sought to highlight a number of key issues that are frequently overlooked in terms of technological knowledge sourcing, namely that:

(1) time horizons are extremely important in framing the sourcing decision;
(2) it is a highly dynamic and iterative process;
(3) it should not be considered in isolation, either temporally (since past decisions are important in framing future ones) or spatially in terms of other parts of the organisation;
(4) technological knowledge sourcing has an important impact on the future knowledge boundaries of the firm;
(5) it should not be conceived as simply a serial, stand-alone process but more frequently as a simultaneous or parallel process; and that
(6) such decisions are not just about the technology or knowledge involved, but also need to consider about the competitive 'fitness' of the partners and networks they are in.

However, by acknowledging these complex issues, those involved in undertaking such decisions should at least provide a solid starting point for building a better, more realistic *and* realisable future for their firm or organisation.

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Appendix 1

Table A1 lists those firms and organisations participating in the survey over the period 1999–2003. Those organisations starred under the core partner column represent the core partner organisations to the project who provided financial funding or contributions in kind to the project and who were more closely associated in advising and shaping the project. As noted in the main text, the first organisation listed in row 1 is Association of Independent Research and Technology Organisations (AIRTO). AIRTO provided access and feedback to all its member

Table A1. Participating companies and organisations.

	Name:	Core partner	Member of AIRTO
1.	AIRTO	*	
2.	Abbey National plc	*	
3.	AMTRI Limited	*	*
4.	BAe plc		
5.	BT plc	*	
6.	CERAM Research		*
7.	Generics		
8.	ICI plc	*	
9.	LGC Limited		*
10.	Manchester Healthcare Trust (NHS)		
11.	Oakland Limited		
12.	PERA		*
13.	Pilkington plc	*	
14.	Reuters plc		
15.	Scipher Limited		*
16.	RTS Robotics		
17.	CVD Technologies Ltd.		

organisations, but in addition a number of its member organisations wanted to be more closely involved in the project and these members are starred in the last column entitled 'Member of AIRTO'.

Notes

1. Although this whole process can be seen as part of a wider spectrum of technological and knowledge driven activity (see Lowe and Taylor 1998, p. 264).
2. The Decision Support Framework (DSF) model takes the form of a toolkit containing a set of guidelines and procedures to support company executives making decisions on whether to source knowledge internally or externally to the firm.
3. Kay (2000, p. 191) rightly questions that these are not necessarily 'unique', particularly in the context of R&D assets (p. 202).
4. And, in turn, when making decisions about such commitments (Radner, 1997, p. 338).
5. Although some firms' can manage to place themselves in multiple innovation networks for specific technologies or product groups.