Overview

What We Know about the Strategic Management of Technology

Keith Pavitt

In high wage countries, both the competitiveness of firms and more general welfare depend critically on the ability to keep up in innovative products and processes and in the underlying technologies. Recent statistical studies show that the levels of companies' investments in technology explain international differences in productivity and in shares of world markets.[1] In the increasingly turbulent, uncertain, and competitive world since 1973, the rate of growth of business funded R&D activities in the OECD area has actually increased.[2] In sectors like electronics, aircraft, and fine chemicals, companies' expenditures on R&D are greater than their investments in fixed equipment and plant.

In the UK, it has been recognized for some time that in spite of improvements in certain aspects of economic performance, national technological activities and international competitiveness remain unsatisfactory in many sectors. Similar concerns about technological competitiveness have spread to other countries as a consequence of the dynamism of Japanese firms. These concerns have been particularly marked in the United States, where sectors of earlier technological strength—steel, automobiles, and now electronics—are under threat from Japanese firms that spend about 30 per cent more of their output on R&D activities than do their U.S. counterparts.[3]

As a result, there has been increased interest in the 1980s among management scholars, consultants, and practitioners in the role of technology

This paper is based on a keynote address to the Annual Meeting of the British Academy of Management. An earlier version has been published in R. Mansfield, ed., *Frontiers of Management* (London: Routledge, 1989). It is based on the research program on Science, Technology, and Energy Policy, funded by the UK Economic and Social Research Council. I am grateful to Alan Cawson, Mark Dodgson, Mike Hobday, Ian Miles, and David Mowery for their suggestions and criticisms.

in such matters as corporate strategy, operations management, global competition, strategic alliances, and the like. However, it must be put in a proper historical perspective. Technology became an explicit element in management practice and strategy at the end of the 19th century with the growth of large chemical and electrical companies, particularly in Germany and the U.S.[4] Indeed, the industrial R&D laboratories central to this growth can be seen as part of the functional and professional specialization that defines much of modern management practice. Even before World War I, firms in these and other industries had extensive networks of external technological contacts, competed globally, and formed strategic alliances, often as part of world cartels.

Parallel to this accumulation of practical experience in the management of technology has been the scholarly research related to it. Although the importance of technological change had been acknowledged by earlier writers, it was Schumpeter who stressed the central importance of innovation in competition among firms, in the evolution of industrial structures, and in processes of economic development; and it was Schumpeter who gave us the most useful definition of innovation as consisting not just of new products and processes, but also of new forms of organization, new markets, and new sources of raw materials.[5] Schumpeter also made the distinction between "administrative management," which is management of what is well known, and "entrepreneurship," which is the creation and implementation of the new. However, Freeman has pointed out that Schumpeter never developed a theory of the innovating firm and had little to say on the sources of innovation and the importance of continuous incremental improvements.[6] More specifically, Schumpeter had little to say about the organizational characteristics of the major sources of technical change in established firms.

Characteristics of Technological Innovation

Innovation research has helped delineate four key characteristics of innovative activities in the firm:

- First, they involve continuous and intensive collaboration and interaction among *functionally and professionally specialized groups:* R&D, production, and marketing for implementation; organization and finance for strategic decisions to move into new areas.
- Second, they remain profoundly *uncertain* activities. Only about one in ten R&D projects turns out to be a commercial success with the other nine either not meeting technical objectives or (more often) commercial ones.
- Third, they are *cumulative*. Most technological knowledge is specific, involving development and testing of prototypes and pilot plants. Although firms can buy-in technology and skills from the outside, what they have

been able to do in the past strongly conditions what they can hope to do in the future.

- Fourth, they are highly *differentiated*. Specific technological skills in one field (e.g., developing pharmaceutical products) may be applicable in closely related fields (e.g., developing pesticides), but they are not much use in many others (e.g., designing and building automobiles).

These characteristics have major implications for theory and action related to the *content* of technological strategy, to the *processes* through which they are developed and implemented, and to *institutional continuity* in the face of *technological discontinuity.*

The Content of Technological Strategies

The cumulative and differentiated nature of technological developments in firms suggests that the choices about the *content* of technological strategy normally presented in the management literature—broad front versus specialized, product versus process, and the leader versus follower—do not take into account the enormous variety between firms in sources of technological opportunities and in the rate and direction of their development.[7] In particular, the innovative opportunities open to a firm are strongly conditioned by a firm's size and by its core business.[8]

This technological variety is summarized in Table 1. Innovating small firms are typically specialized in their technological strategies, concentrating on product innovation in specific producers goods such as machine tools, scientific instruments, specialized chemicals, and software. Their key strengths are in their ability to match technology with specific customer requirements. The strategic management tasks are to find and maintain a stable product niche and to benefit systematically from user experience.

Large innovating firms, on the other hand, are typically broad front in their technological activities and are divisionalized in their organization. Their key technological strengths can be based in R&D laboratories (typically in chemicals and electrical-electronic products), or in the design and operation of complex production technology (typically in mass production and continuous process industries), or (increasingly) in the design and operation of complex information-processing technology (typically in finance and retailing).

In R&D-based technologies, the key opportunities are for horizontal diversification into new product markets. The strategic management tasks are those of mobilizing complementary assets to enter new product markets (e.g., obtaining marketing knowledge when a pharmaceutical firm moves into pesticides) and continuous revision of divisional responsibilities to exploit emerging technological opportunities (e.g., personal computers

Table 1. Basic Technological Trajectories

	Definition			
	Science-Based	**Scale Intensive**	**Information Intensive**	**Specialized Suppliers**
Source of Technology	R&D Laboratory	Production Engineering and Specialized Suppliers	Software/ Systems Dept. Specialized Suppliers	Small-Firm Design and Large-Scale Users
Trajectory	Synergetic New Products Applications Engineering	Efficient and Complex Production and Related Products	Efficient (and Complex) Information Processing, and Related Products	Improved Specialized Producers Goods (Reliability and Performance)
Typical Product Groups	• Electronics • Chemicals	• Basic Materials • Durable Consumer Goods	• Financial Services • Retailing	• Machinery • Instruments • Specialty Chemicals • Software
Strategic Problems for Management	• Complementary Assets • Integration to Exploit Synergies • Patient Money	• Balance and Choice in Production Technology among *Appropriation* (Secrecy and Patents), *Vertical Disintergration* (Cooperation with Supplier), and Profit Center • "Fusion" with Fast-Moving Technologies • Diffusion of Production Technology among Divisions • Exploiting Product Opportunities • Patient Money		• Matching Technological Opportunity with User • Absorbing User Experience • Finding Stable or New Product 'Niches.'

cutting across previous responsibilities in computers, office machinery, and even consumer electronics).

In production-based and information-based technologies, the key opportunities are in the progressive integration of radical technological advances into products and production systems and in diversification vertically upstream into potentially pervasive production inputs (e.g., CAD-CAM, robots, and software). The strategic management tasks are to ensure diffusion of best practice technology within the firm and to make choices about the degree of appropriation (i.e., internalization) of production technology.

Firms do not have completely free choice about whether or not to be broad front or specialized, and product or process oriented. Similarly, they do not have a completely free hand about being a leader or a follower. In many areas, it is not clear before the event who is in the innovation race, where the starting and finishing lines are, and what the race is about. Even when it is, firms may start out wishing to be a leader and end up being a follower. Teece has shown that while there are some advantages in being first, particularly when there are strong regimes of property rights of cumulative learning, it is sometimes advantageous to be second, particularly when product configurations are not fully fixed, so that followers can learn from the mistakes of leaders who find themselves without the required range of complementary assets.[9]

Furthermore, given that firms develop their technological competences cumulatively, the uncritical application of conventional project appraisal techniques will result in myopic technology strategies. Such strategies neglect the benefits from the knowledge accumulated in a project that can be deployed subsequently to exploit technological opportunities in the future. Since these accumulated benefits are time-consuming, dynamic strategies that take them fully into account are more likely to emerge in companies and countries where performance is judged over the long term, and where managers are capable of making informed and reasoned judgement about the strategic implications of likely future developments in technology.[10]

The Implementation of Technology Strategy

A major criticism of the "content" view of technological strategy is that it neglects the context within which—and the process whereby—technological strategies are generated, chosen, and implemented. These processes are bound to involve more than the purely technical function. Production and marketing are inevitably involved with R&D in implementation, with finance in setting ground rules for evaluating and monitoring programs and projects, and with organization and the strategic function in decisions about entering new areas.

Company structure and company strategy thus play a major role in the formation of technological strategy. Hobday has pointed out that the ambitious technological strategies of Japanese electronic components firms depend in large part on their vertical integration with electronic equipment manufacture and on the relatively strong emphasis put on long-term growth compared to short-term profits. More generally, Japanese firms are apparently more likely than those in Europe and the U.S. to have a member of the main board responsible for technological policy.[11] Sharp argues that recent initiatives in European technological cooperation in ESPRIT have taken off rapidly precisely because they involve chief executives rather than R&D directors.[12]

Given that technology strategy involves many functions and professions, as well as major uncertainties, its formation and implementation are bound to be a choice territory for the advocacy, battles, and negotiations to which analysis in the process school of strategy give such great importance.[13] This was recognized some time ago by Freeman when, after reviewing the disappointing experience that firms had had with formal, quantitative methods of R&D project selection and technological forecasting, he concluded that

> empirical evidence confirms that decision making in relation to R&D projects or general strategy is usually a matter of controversy within the firm . . . uncertainty means that many different views may be held and the situation is typically one of the advocacy and political debate in which project estimates are used by interest groups to buttress a particular point of view. Evaluation techniques and technological forecasting, like tribal war-dances, play a very important part in mobilizing, energizing and organizing.[14]

However, technology strategy cannot be described solely in terms of political negotiation between hostile professional and functional tribes. In the market system, the ability to satisfy user's needs better than the competition is the ultimate measure of success and profitability within the firm. Innovation research has come to robust conclusions about the management factors associated with successful innovations. In addition to the quality of technical work, these include strong horizontal linkages among functional departments, with customers, and with outside sources of relevant technical expertise.

Either by conscious choice or by trial and error, successful innovating firms are more likely to develop "routines" (or rules of thumb) that reflect these ingredients. Given the high uncertainties involved, trial and error are inevitable in the development and implementation of innovation. In fact, the major importance of *development*—as opposed to *research*—activities in industrial laboratories can be considered as a systematic form of trial and error. Theory and computer simulations are not powerful enough to predict the performance of technological artifacts with a high enough degree of certainty to eliminate the costly development and testing of prototypes and pilot plants.

In addition, the ability to learn from experience—whether internally (learning by doing) or from suppliers, customers, and competitors (learning by using, learning by failing, reverse engineering)—is of major importance in the management of innovation. As Dodgson has pointed out, learning from experience actually dissolves sharp distinctions in the strategy debate between content, process, and context.[15] This is because *processes* of learning about the *context* help define the *content* of strategy, the implementation of which in turn helps define both the nature and directions of subsequent learning *processes* and changes in *context*. More simply put, content definition and implementation become indistinguishable, given the central importance of learning.

Comparative empirical research has demonstrated the importance of employee training for the effective exploitation of technology.[16] Particularly in the large firm, learning is also a collective activity requiring frequent communication among specialists and functions. Since knowledge accumulated through experience is also partly tacit, and the task to which such knowledge is applied are complex are loosely structured, personal contact and discussions are the most frequent and effective means of communication and learning. Policies for effective learning therefore go beyond training and organization to include those of geographical location. Allen and other scholars have shown the importance of physical location in influencing patterns of communication, both within the technical function and between the technical and other functions in the firm.[17] Howells has shown that decisions about the location of R&D laboratories by firms in the UK pharmaceutical industry have been strongly influenced by the requirements for effective internal communication with other functional areas.[18]

Technological Discontinuities and Institutional Continuities

With the present wave of radical technological change in micro-electronics and information technology, considerable emphasis is being placed in management theory and practice on the notion of "technological discontinuities," which imply a radical increase in the rate of technical change and a marked shift in its associated skills and required organizational forms.[19] It is often argued, on the basis of either Schumpeter's notion of creative destruction or the so-called product cycle theory, that technological discontinuities are associated with the emergence of new small firms that exploit them, given the conservatism, obsolescence, and bureaucracy in established large firms.

The evidence does not necessarily confirm this view. In electronics (the main sector of "discontinuity") in the UK since 1945, the proportions of significant innovations made by both large firms (with more than 10,000 employees) and by small firms (with fewer than 1,000 employees) have both been increasing at the expense of the medium-sized firms in between.[20] Mowery has shown that the growth of industrial R&D in the 20th Century has been associated in certain periods with greater stability among large firms.[21] Established chemical firms have successfully survived and indeed benefitted from successive waves of radical innovations in synthetic products. IBM was a world leader in the earlier, traditional electro-mechanical technologies of office machinery before it moved into computers.[22]

Some of the most revolutionary business applications of information technology today are to be found not in new technology-based firms, but among the oldest, largest, and most conservative of capitalists: banks, financial services, and large-scale retailing.[23] Two factors help explain why *technological discontinuities* can co-exist with *institutional continuities:*

- First, large established firms normally have specialized and professionalized R&D laboratories and other technical functions with accumulated skills and experience in orchestrating and integrating inputs from a wide variety of scientific and technical disciplines. They are therefore experienced in hiring and integrating professionals from promising new areas. Examples include the hiring of computer experts by IBM[24] and of aerodynamic and hydraulic engineers by Sulzer for the development of the shuttle-less loom.[25]

- The second reason was identified by Schumpeter in his later writings. Large firms have considerable oligopolistic power. In some countries, they are not subject to a strong, short-term profit constraint. They therefore have both the resources and the time to explore the implications of technological discontinuities for their business and to link them with core competences within the firm, through learning and incremental change, before deciding whether or not to move into commercialization. One observable feature of innovating firms is precisely that they develop technological capabilities beyond those strictly related to their current output.

Perez correctly pointed to the dangers of a mismatch between institutional routines and skills, on the one hand, and the effective exploitation of technological discontinuities, on the other.[26] Given its long-term importance, we need to know more about how many established business firms successfully overcome any mismatch, and how they assimilate and exploit technological discontinuities. Recent analyses of information technology in service firms by Barras[27] and by Thomas and Miles[28] suggest a process can be described either as a "reverse product cycle" or as the equivalent of technical change in production-centered firms (information technology is first used in such firms to improved processes and, after a sometimes long period of learning, becomes the basis of products sold outside). Further empirical studies are needed to see whether this model can be extended to other sectors, or to other technical areas like biotechnology.

Conclusions for Management: Beware the Conventional Wisdom

The major conclusion for management to emerge from this review of research into the innovation process is that some of the conventional wisdom from business schools and management consultants about technology strategy is irrelevant and even misleading.

First, it is not useful for a firm's management to begin by asking whether its technology strategy should be leader or follower, broad or narrow front, product or process. These characteristics will be determined largely by the firm's size and the nature of its accumulated technological competences, which will jointly determine the range of potential technological and market opportunities that it might exploit. There is no easy and generalizable recipe for success.

Second, the implementation of technology strategy is just as important as its definition, and an integral part of it. Given the cumulative nature of firm-specific competences and the inevitable uncertainties surrounding innovative activities, the capacity for in-house learning from experience will be fundamental for success. Being an essentially collective activity, such learning will depend on good systems of communication.

Third, convention methods of project appraisal and divisional organization will result in myopic technology strategies that neglect the effects of innovative choices today on the ability to exploit technological opportunities in the future. Such strategies also hinder the development of product opportunities that do not fit tidily into established divisional markets or missions. The continuing stream of new high-technology firms established by former employees of large firms confirms the importance of this problem.

Management's role is inevitably constrained by the accumulated organizational and technological characteristics of the firm. At the same time, coping with continuous change is not easy and requires more than a tribal chief organizing war dances or a charismatic prince playing Machiavellian politics. The successful management of technology requires:

- the capacity to orchestrate and integrate functional and specialist groups for the implementation of innovations;
- continuous questioning of the appropriateness of existing divisional markets, missions, and skills for the exploitation of technological opportunities; and
- a willingness to take the long view of technological accumulation within the firm.

References

1. J. Fagerberg, "A Technology Gap Approach to Why Growth Rates Differ," *Research Policy,* 16/2-4 (1987); J. Fagerberg, "International Competitiveness," *Economic Journal,* 98/391 (1988).
2. OECD, *Research and Development in the Business Enterprise Sector, 1963-1979,* Basic Statistical Indicators, Volume D, (Paris: OECD, 1983); OECD, *Recent Results: Selected Science and Technology Indicators, 1979-1984* (Paris: OECD, 1984).
3. K. Pavitt and P. Patel, "The International Distribution of Determinants of Technological Activities," *Oxford Review of Economic Policy,* 4/4 (1988):1-21.
4. D. Mowery, Industrial Research and Firm Size, Survival and Growth in American Manufacturing, 1921-1946: An Assessment," *Journal of Economic History,* 43 (1983).
5. J.A. Schumpeter, *Capitalism, Socialism and Democracy* (New York, NY: Harper and Row, 1950).
6. C. Freeman, "Schumpeter's 'Business Cycles' Revisited," paper prepared for Schumpeter Society Conference, Siena, 1988.
7. E. von Hippel, *The Sources of Innovation* (Oxford: Oxford University Press, 1988); F. Scherer, "Inter-Industry Technology Flows in the United States," *Research Policy,* 11 (1982).
8. K. Pavitt, M. Robson, and J. Townsend, "Technological Accumulation, Diversification and Organization in UK Companies, 1945-1983," *Management Science,* 35/1 (1989).

9. D. Teece, "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy," *Research Policy,* 15 (1986).
10. Pavitt and Patel, op. cit.
11. P. Patel and K. Pavitt, "Is Western Europe Losing the Technological Race?" *Research Policy,* 16/2-4 (1987): 59/85.
12. M. Sharp, "Corporate Strategies and Collaboration—The Case of ESPRIT and European Electronics," in M. Dodgson, ed., *Technology Strategy and the Firm: Management and Public Policy* (New York, NY: Longman, 1989).
13. A. Pettigrew, *The Management of Strategic Change* (New York, NY: Blackwell, 1987).
14. C. Freeman, *The Economics of Industrial Innovation* (London: Penguin, 1974).
15. M. Dodgson, "Introduction: Technology in a Strategic Perspective," in M. Dodgson, ed., *Technology Strategy and the Firm: Management and Public Policy* (New York, NY: Longman, 1989).
16. C. Pratten, *A Comparison of the Performance of Swedish and UK Companies* (Cambridge: Cambridge University Press, 1976); S. Prais, "Educating for Productivity: Comparisons of Japanese and English Schooling and Vocational Preparation," *National Institute Economic Review,* 119 (1987).
17. T. Allen, *Managing the Flow of Technology* (Cambridge, MA: MIT Press, 1977).
18. J. Howells, "The Location and Organization of Research and Development: New Horizons," *Research Policy* (forthcoming).
19. M. Tushman and P. Anderson, "Technological Discontinuities and Organization Environments, in Pettigrew, op. cit.
20. K. Pavitt, M. Robson, and J. Townsend, "A Fresh Look at the Size Distribution of Innovating Firms," in F. Arcangeli et al., eds., *Frontiers of Innovation Diffusion* (Oxford: Oxford University Press, forthcoming).
21. Mowery, op. cit.
22. K. Pavitt, "'Chips' and 'Trajectories': How Does the Semiconductor Influence the Sources and Directions of Technical Change?" in R. MacLeod, ed., *Technology and the Human Prospect* (London: Pinter, 1986), pp. 31-54.
23. R. Barras, "Towards a Theory of Innovation in Services," *Research Policy,* 15 (1986).
24. B. Katz and A. Phillips, "Government, Technological Opportunities and the Emergence of the Computer Industry," in H. Giersch, ed., *Emerging Technologies: Consequences for Economic Growth, Structural Change and Employment* (Tubingen: Mohr, 1982).
25. R. Rothwell, "The Characteristics of Successful Innovators and Technically Progressive Firms," *R&D Management*, 7 (1977).
26. C. Perez, "Structural Change and Assimilation of New Technologies in the Economic and Social Systems," *Futures*, 15/4 (1983): 357-375.
27. Barras, op. cit.
28. G. Thomas and I. Miles, "Strategic Options for New Telecommunications Services," in M. Dodgson, ed., op. cit.