ADVANCES IN INFORMATION TECHNOLOGY AND THE INNOVATION STRATEGIES OF FIRMS*

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The ability to appropriate newly-generated technical knowledge is a key to the strategic behaviour of firms. Therefore, institutional and organisational arrangements are eventually challenged and transformed by major new (Schumpeterian) innovations. The effects of recent, revolutionary advances in information technology provide an especially striking illustration of this interplay. Although these tensions have always existed, their current dimensions are new. The seemingly inexorable development of highly-efficient, global information networks is transforming the strategic responses of firms to changing market conditions. Nowhere is this transformation more evident than in the changing role of property rights to firm-specific technical and market knowledge.

Keywords: Information technology, information strategies, firms, knowledge acquisition, monitoring.

INTRODUCTION

In 1516, Franz von Thurn und Taxis was granted a charter to establish the first scheduled, public postal service. In the same year, his relays of mounted messengers began delivering mail between Vienna and Brussels. A few decades later, the service connected most of Europe's political and commercial centres. Even government officials had started to rely on the mail in preference to sending their own couriers. After the Thirty Years War, the monopoly of the house of Thurn und Taxis was broken, and soon a dense network of competing routes, most of them operated by small states and municipalities, covered Europe.[1]

Although the use of relays to transmit urgent messages was not a novelty, the development of regular, long-distance mails represented a genuine breakthrough in communication technology. For the first time, ordinary merchants, bureaucrats, scientists, and other men of affairs could avail themselves of a service that reliably carried letters to their destination at the unprecedented speed of 130 to 150 kilometers per day.

The innovation's characeristics were shaped in good part by existing technical and institutional conditions. Thus, for example, although carriages would have had a clear advantage in capacity, the absence of

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decent roads meant that messengers on horseback could move much faster. As Werner Sombart pointed out in a biting commentary, the states had no interest in improving roads, for the slower the progress of carriages through their territory, the greater the earnings of innkeepers and craftsmen.[2] Even in the late 18th century, for example, the roughly 200-kilometer trip by mail coach from Frankfurt to Stuttgart took 40 hours. Of course, the layout of messenger routes was also influenced by the location of inns or other places that could serve as relay stations. And the existence of numerous political units, each with its own commercial interests, produced a hodge-podge of frequently duplicative services that failed to realise the efficiency gains that might have been obtained through what we nowadays call systems integration.

On the other hand, the innovation also helped to transform existing institutions and established ways of doing things. Perhaps its most significant impact was to undermine the power of large merchant houses, whose access to information through their far-flung branches had given them a distinct competitive advantage. Furthermore, major nodes in the postal system soon attracted all kinds of organisations dependent for their business on timely information. Improved communications among these centres also fostered the development of standardised commercial practices.

Equally important was the innovation's effect on the spread of technical knowledge. Historians agree, for example, that without regularly receiving information from abroad, a scholar like Georgius Agricola would have been unable to write his famous *De re metallica,* a classic survey of the state of the art in mining and metallurgy at more European locations than he could possibly have visited in person.

Soon, however, there arose concern that some of this diffusion of knowledge via the postal services might not be quite what the senders had in mind. According to contemporary accounts, messengers were frequently suspected of "using subtle practices to open the letters of learned men and having their contents copied. Then they sold these copies and thus unwittingly contributed to the spread of new ideas."[3] The refinement of such subtle practices obviously was another manifestation of technological progress. In this connection, it is worth mentioning also that the authors of technical and commercial compendia frequently were accused by businessmen of publicising their trade secrets.[4]

My brief account of an early breakthrough in information technology is not meant to imply that its technical feaures, the speed of its diffusion, or its socioeconomic ramifications are comparable to those of late 20th century innovations. Nevertheless, I want to use this historical example to suggest that, although the dimensions of the current revolution in information technology are unprecedented, its contours represent familiar variations on a few persistent themes:

- there is the influence of existing institutions, interests, and practices on the rate and direction of technical progress;

- there is the potential of major innovations to transform, and in many instances to revolutionise, prevailing social and economic arrangements; and
- there is the concern of actors (individuals and organisations) that their ability to appropriate new knowledge, as well as to hold on to old knowledge, may be threatened by innovations in the transmission of information.

In considering how the new information technologies have affected the innovation strategies of firms, the economist's interest is drawn, quite naturally, to the possible conflict between the benefits of improved communication and the perceived risks of losing firm-specific knowledge. In particular, I want to reflect on the implications of those technical advances that have greatly increased the possibiliies for exchanges of information among firms, given the fact that each firm still regards its special body of knowledge as its most important asset.

Evaluations of these possibilities have ranged from exuberantly optimistic to more or less skeptical. Thus, for example, one observer concluded that organisations are "moving inexorably toward electronic interdependence,"[5] and another judged that "the communication and computing networks which serve us are making step-function changes to the manner, *richness of content* (my emphasis), and modes of our interactions."[6] Conversely, Peter Drucker complained some time ago that, despite technological advances, "[t]he communications gap within institutions and between groups in society has been widening steadily."[7] Even Adam Osborne, pioneer and ardent booster of microelectronics development, cautioned that there are activities where computers should not be used for the collection and transmission of information because of the risks of abuse.[8] And, on a more philosophical plane, Jesse Shera commented on the potential of the new technologies to produce information overload and thus to stifle creative ideas, with a poignant, "Data, data everywhere — and not a thought to think![9]

Since my attempt at an assessent focusses on a thin slice of the problem, I must define terms that have come to be used in a confusing variety of meanings. I follow that master of economic semantics, the late Fritz Machlup, in considering information a flow concept, and knowledge a stock concept.[10] Information is transmitted to a recipient (an individual or an organisation) from an external source through communication, adding to the recipient's stock of knowledge; however, I shall suggest below, this stock can also be increased by means having nothing to do with information, in the sense in which I use the word. My only excuse for this narrow definition is that it serves my purposes, and that it permits me to avoid considering those embodiments of information technology that might enhance the execution, though not the conception, of innovation strategies. In other words, the impact of stand-alone computers, CAD/CAM systems, robots, industrial controllers, knowledge-based systems, artificial intelligence, etc., is beyond my purview.

HOW FIRMS ACQUIRE KNOWLEDGE

Most economists accept the notion that firms survive in competition by possessing technical and market knowledge that is in some sense different from the knowledge of their rivals. Therefore, firms' innovation strategies will be aimed primarily at protecting and enhancing such firm-specific knowledge. Their success in doing so will depend, in the first instance, on how and over what period of time they acquired the knowledge.

For the purposes of an economic evaluation, one may usefully distinguish four main determinants of the rate at which a firm acquires technical knowledge; these are not, of course, independent of one another.

The rate at which the firm produces new knowledge internally.

The most obvious examples here are research, development, design, and engineering (R,D,D&E). These are costly and risky activities, and without the prospect of being able to appropriate sufficient returns from the investment, firms would have little incentive to undertake them. In other words, it is essential that a substantial proportion of the newly-generated knowledge not spill over into the firm's environment, especially not to competitors.

Equally significant is knowledge about the technical requirments of their customers, generated by firms as a byproduct of their ongoing marketing effort. The strategic exploitation of this knowledge once again requires that it be internalized. What matters in this connection is not necessarily that the firm acquires objective data that are unavailable to competitors, but that it be able to convert generally accessible data into (subjective) information giving it some sort of competitive advantage.

Another internal source of new technical knowledge is *learning by doing*. By definition, firms accumulate this type of knowledge in the process of pursuing their current activities. Some of the results of learning may be codified, but others consist of the *know-how* acquired by individuals as well as of *organisational routines*.[11] Learning requires some continuity in basic technology and thus may become an impediment to major innovation, causing firms not to utilise information obtained from their environment. This, however, is an issue beyond the purview of my observations.

There is a negative corollary to all of this — *forgetting by not doing*. Individual know-how and organisational routines will atrophy without continuing exercise.[12] In the case of technological innovation, this implies not only a decline in the ability to generate new ideas, but also a concomitant reduction in the ability to absorb and interpret information from outside the firm. In this sense, at least the internal acquisition of new knowledge and the utilisation of 'outside knowledge' are complements rather than substitutes.

The rate at which the firm acquires public goods-type knowledge from its environment.

At any given time, there exists a vast body of knowledge of value to a firm that is in the nature of a public good. By definition, such a good can be 'consumed' by any one economic agent without thereby impairing the consumption of the same good by other agents. In the sphere of technology, channels whereby firms acquire public goods knowledge include, for example, scientific and technical publications, the patent record, databases, free-access information networks, technical meetings, informal exchanges among personnel, study tours, plant visits, and a host of others.

In their chain-linked model of innovation, Kline and Rosenberg refer to the activities involved in obtaining this kind of information as monitoring.[13] Generally, the marginal cost of obtaining information through these channels is so low that monitoring can involve a wide range of possible sources. Efficiency gains are more likely to come from careful organisation and management of the relevant activities than from an *a priori* restriction of their scope.[14] The success of the Japanese in becoming 'fast seconds' in innovation has often been attributed to their highly developed monitoring systems.

There can be little doubt that modern information technology has enabled firms to draw on public goods knowledge to an unprecedented extent. Where at one time hard-copy publications and contacts among people were the firm's main sources, a multiplicity of techniques for the storage and transmission of such information now provides strategists with a seeming surfeit of inputs into their decisions. At the same time, the fact that R&D activities in many sectors still tend to cluster regionally is evidence of the continuing importance of personal interactions in innovation. Although such clustering may have some straightforward economic explanations, one suspects that the often-cited synergy effects also depend on people communicating face-to-face, rather than through electronic media.[15]

The rate at which the firm acquires other firms' proprietary knowledge.

Technical knowledge can be transferred from one firm to another by a variety of formal and informal methods. Among the first, arm's-length and know-how transfer agreements are the most obvious. The second include reverse engineering, the hiring away of people from competitors, and direct exchanges of information among employees.

This last mechanism deserves special mention because it reflects, at the level of individuals, precisely the conflicting forces that are one of the key themes of my observations. Just as firms derive returns from proprietary knowledge, so do members of these organisations. Their personal knowledge helps to define their status role. Therefore, they are often less likely to share such knowledge with fellow employees than with their professional counterparts in other firms, including competitors.

The last decade has seen a rapid growth of bilateral, co-operative arrangements in procurement, production, and marketing. Whether organised as formal joint ventures or in other ways, these arrangements generally have been based on the exploitation of asymmetries in the knowledge of firms. Although institutionalised exchanges of this type often start out quite modest in scope, the realisation of mutual benefits tends to lead to more intensive linkages, through which an increasingly widening range of information is transferred.[16]

The rate at which the firm generates new technical knowledge jointly with other firms.

For reasons having to do with high costs and high risks, as well as with the need to bring complementary bits and pieces of knowledge to bear on the solution of common problems, firms in many industries have increasingly relied on multilateral co-operation for the development of generic (pre-competitive) technical knowledge. In many instances, such co-operation has been stimulated and subsidised by national governments.

Nevertheless, even in this framework the issue of individual participants' interest in appropriating results arose very quickly. Outstanding examples are provided by the American Microelectronics and Computer Technology Corporation (MCC) and the British Alvey Programme. Both were hampered by conflicts about intellectual property rights and soon reached the point where pressures for short-term achievements at the commercial level frequently won out over the intended, longer-term objectives of these programs.[17]

HOW FIRMS ATTEMPT TO APPROPRIATE TECHNICAL KNOWLEDGE

The discussion so far suggests that strategists of a profit-oriented organisation have to do a balancing act between the benefits of relying on their own resources for innovation and the obvious gains of drawing relevant information from the firm's environment. The consensus seems to be that modern information technologies have made the balancing act more difficult, precisely because they have created the potential for electronic interdependence. But whatever the outcome of individual decisions, the goal of turning information into firm-specific knowledge lies at the roots of all strategies.

A recent report of the US Office of Technology Assessment put the problem very succinctly:

> . . . the new information and communications technologies available today are challenging the intellectual property system in ways that may only be resolvable with substantial changes in the system or with new mechanisms to allocate both rights and rewards. Once a relatively slow and ponderous process, technological change is now outpacing the legal structure that governs the system.[18]

In focussing solely on the legal protection of knowledge, however, this statement both over-dramatises and oversimplifies the issue. To be sure, the patent and copyright systems continually have been put to the test of accommodating the results of technological advances, yet these systems are but one of a number of mechanisms for appropriating the returns from innovation.

Nevertheless, at least in some industries and for some new knowledge, seeking patent protection has been the preferred strategy of firms. They have done so from a variety of motives: to prevent duplication in the case of new ideas from which they drew direct commercial benefit; to shelter existing technology against inroads by competitors; to derive returns from licensing the technology to others; and to retain rights to knowledge that may become useful at some time in the future.

Ostensibly, patents grant temporary monopoly rights to knowledge; however, from a dynamic point of view they have limits, as Alfred Marshall pointed out a 100 years ago:

> In many businesses only a small percentage of improvements are patented. They consist of many small steps, which it would not be worth while to patent one at a time. Or their chief point lies in noticing that a certain thing ought to be done; and to patent one way of doing it is only to set other people to work to find other ways of doing it against which the patent cannot guard.[19]

From this observation, Marshall went on to extol the benefits of secrecy as a means for appropriating new technical knowledge. There is little need to belabour the point that efforts to maintain secrecy are often seen as threatened by the advent of new information technologies. Indeed, as many incidents have shown, these technologies provide a host of "subtle practices" for intruding upon the intellectual terrain of others.

Yet another form of protection of technical knowledge is provided by a firm's existing know-how. This implies not only the ability quickly to absorb new information, but even more importantly the ability to organise and manage activities. Wherever firms impose restrictions on the movement of employees to competitors, for example, they presumably try to prevent the outward transfer of know-how.

A fourth strategy is to rely on lead times in innovation and on a quick move down the learning curve to appropriate returns from innovation. Short-lived as such advantages may be, they frequently give innovators a sufficient competitive headstart, especially if they can also rely on established marketing and service networks.

Finally, vertical integration of all relevant operations is a strategy aimed at securing full control over a technology. It is particularly attractive in situations where the alternative would be to share knowledge with suppliers who are also serving a firm's competitors. Control over old and new technical knowledge through integration also has been one of the major motives of multinational corporations in their efforts to adapt to different markets and yet to avoid large spill-overs.[20]

STRATEGIC IMPLICATIONS

Strategies over the technology life cycle

At the outset of the preceding section I addressed the need for strategists to do a balancing act between internally-generated knowledge and external sources of information. Although success or failure depends on a host of highly firm-specific and industry-specific factors, empirical investigations nevertheless suggest certain regularities with respect to the determinants of shifts in the balance.[21] These have to do mainly with the effects of the technology life cycle on firms' strategies.

The features of the life cycle have been elaborated in an extensive literature. For our purposes, a highly stylised version suffices, in which the evolution of a basic technology is characterised by reductions in technical uncertainty, and subsequently in commercial uncertainty, while at the same time there occurs a steady increase in the technology's complexity.

Reductions of technical uncertainty are the results of accumulating knowledge about the workability of an idea. In the early phases of the cycle, the search for such knowledge typically is concerned with an understanding of broad principles and generic problems underlying the successful operation of a new technology. Continuing investment in R&D produces increasingly specific knowledge through bench tests, prototypes, pilot operations, etc.

Up to a point, commercial uncertainty is attenuated through cost studies and market surveys; beyond this point, however, only actual experience will result in further useful knowledge. It seems clear, in any event, that firms accumulate this kind of knowledge through both their own efforts and through information obtained from the observable experience of others.

Increases in complexity are an inevitable accompaniment of the development of successful basic technologies. They have two sources. The first involves a proliferation of technical features that are highly specific to a new device or process; these are mitigated in part by the standardisation of some components. The second has to do with the increasing specificity of the socio-technical systems evolving around an innovation.[22] To say that technology is complex is not the same as saying that it is complicated. Thus, early computers were complicated because they involved large numbers of vacuum tubes, connections, and switches; they became complex only as assemblages of previously-known components were replaced by product-specific components. Similarly, the electronic systems of commercial aircraft are complicated as long as they involve miles of wires and thousands of connections; they become increasingly complex as digital data bus terminals using microprocessors replace traditional methods of signal transmission.[23] Needless to say, innovations that successfully reduce technical uncertainty by increasing complexity tend to take on a public goods character; conversely,

innovations that introduce complexity for the sake of product differentation or cost reduction are often highly firm-specific.

Figure 1 illustrates how changes in the three variables — technical uncertainty, commercial uncertainty, and complexity — might influence the strategic balance between stand-alone efforts and reliance on information exchanges with other firms.

FIGURE 1 EXAMPLES OF CHANGING STRATEGIC BALANCE OVER THE TECHNOLOGY LIFE CYCLE.

Life-cycle Phase	Stand-Alone Effort in Technology Dev.	Reliance on Information Exchanges
Dominance of technical uncertainty	Expected appropriability of generic knowledge high (required capacity in place; property rights obtainable; anticipation of first-to market advantages).	Expected appropriability of generic knowledge low (complementary inputs required; information flows assured).
Dominance of commercial uncertainty	Competitive advantage in marketing & distribution; complementarities between existing products and new technology.	Informational asymmetries among firms; advantage of standardisation; government sponsorship.
Dominance of complexity	Enhancement of existing products & processes. Cost reduction; product differentation.	Information gaps (technology slip); economies of scale and scope.

The point of these examples is to emphasise that strategies are guided not by objective facts but by managerial perceptions about the current and likely future states of a technology and therefore about the benefits and costs of going it alone or of relying on exchanges of information with other firms. Clearly, the accuracy of these perceptions hinges on the extent to which credible forecasts of technical developments can be made, a subject on which experts differ.[24] At the same time, however, one must recognise that when certain perceptions become part of an industry's conventional wisdom, they may turn into self-fulfilling prophecies. Thus, if decision-makers in a mature-technology industry believe that the costs, risks, and prospective returns no longer justify stand-alone efforts at major innovation, they will consider joint efforts the only viable alternative.

One of the crucial questions, then, is to what extent the rapid diffusion of new communication and information technologies has influenced strategists' perceptions about the respective merits of the two approaches to acquiring new technical knowledge. Casual evidence would suggest that these technologies have accelerated the trend toward co-operation, albeit with consequences for individual firms' long-run competitive position that are far from clear.[25]

For the student of the economics of technological change a somewhat disconcerting conclusion follows from these speculations about strategic behaviour: observed life-cycle phenomena are the result of a mixture of whatever objective laws may govern the development of technologies and of subjective managerial assessments of opportunities for innovation. While these two influences usually can be disentangled with the wisdom of twenty-twenty hindsight, they make the predicting of industrial growth patterns, based on the logic of technological evolution, a quite hazardous undertaking.[26]

Effects of the Revolution

The main line of my arguments so far has been that, other things equal, firms surely would prefer having strong property rights to their existing knowledge as well as appropriating all new technical knowledge generated through their innovative efforts. It is the nature of technological revolutions, however, that they do not leave other things equal. The recent breakthroughs in communication and information technology did not change the motives of participants in the economic game, but they have begun to transform the rules of the game as well as its institutional setting in ways we are only beginning to understand. Were it not for the persistence of old modes of thought, one would hardly need to state the obvious: the new technologies no more represent just faster means for transmitting data and messages through networks than the automobile represented just a faster substitute for the horse-drawn carriage!

In his 1989 CIRCIT seminar, Bela Gold made an ardent plea for a 'top-down', strategic approach to harnessing the potentials of information technology in the internal operations of firms.[27] His argument, that 'business as usual' will not do, applies with equal force to the development of strategies for interfirm communication. Competitive survival will force firms to adapt to the emerging new environment.

Given the uncertainties of the current situation, it would be tempting to derive guidance from the experience of sectors that are leading in their utilisation, such as banking and finance. While the technical, structural, and institutional transformations wrought there by the electronic revolution have been spectacular,[28] they probably offer little in the way of guidance as to the directions of change in other sectors. Depending on one's perspective, it is encouraging or sobering to realise that a short two decades ago no one would have dared to predict how the world's financial markets would be affected by these technological advances!

Nevertheless, it is clear already that the global transformation of these markets has profoundly affected the allocation of capital and other resources, changing their relative values in the process. One observer concluded rather sweepingly that, "[T]he communications revolution,

in short, is altering the very foundations of modern society and the economic, social, and strategic importance of information.''[29]

When one descends from such a high level of generalisation, the picture very quickly becomes cloudy. Any effort to disentangle the implications of the information revolution for innovation strategies probably should start with a distinction between direct and indirect effects on particular industries. Among the former, I would count all the issues having to do with the difficulties of appropriating the returns from innovation in the information sector itself. The software, direct satellite broadcasting, sound and video recording industries come to mind as prime examples. A detailed consideration of these would go well beyond the scope of my observations.

What I want to speculate about is the indirect, but in a broader sense more profound, effects on the industrial sector in general, including those industries whose own technologies are generally regarded as mature. Here one can discern the revolution's effects in some developments that would have been quite unattractive, and perhaps even impossible, without modern communication and information technologies. Virtually every one of these developments is likely to undermine the foundations of firms' traditional strategies for acquiring and protecting knowledge, as I outlined them in preceding sections. The range of examples is wide, but I restrict myself to a few that I have come across in my work involving manufacturing industries:

(1) While multifirm R&D consortia are not new in themselves, their current scope and intensity are difficult to imagine in the absence of concurrent advances in the participants' ability continuously to exchange information. From the individual firm's point of view, the pervasive trend toward such co-operation in the generation of basic technical knowledge has forced a re-evaluation of the benefits, costs, and risks of stand-alone efforts. One may well venture the guess that, in most industries, the luxury of going it alone in major innovation will be open only to dominant firms. Nevertheless, these firms may then face coalitions offering serious challenges to their positions. The problem, here, is of course not just one of business strategy; rather, the trend toward co-operation has raised serious questions for traditional competition policy, at least in the United States.[30]

(2) The rapid growth of production joint ventures similarly has been made possible by the communications revolution. This is especially true in those cases where manufacturing is carried out in widely dispersed locations and the final product assembled elsewhere. One of the most spectacular examples is provided by the European Airbus venture, with components of each plane produced in several countries. Even more than in mass production, success in this kind of operation hinges on the continuous exchange of information among the participants. From the economist's point of view, the most interesting consequence of these developments is that they have put into question the traditional arguments for economies of scale and of agglomeration. It is only fair to point out, however, that technological progress in transportation has

also played a major role in the establishment of geographically-dispersed production joint ventures.

(3) The growth of permanent subcontracting networks, now widespread in many manufacturing industries, presumably could not have occurred without the communication and data processing facilities developed in the last two decades. Whereas in the past firms tended to maintain an arm's-length relationship with their suppliers, the establishment of long-term ties has now begun to replace short-term and spot transactions. This has affected not only production processes themselves but has spilled over into involvement of suppliers in the R&D, design, and engineering phases of product development by their customers.

(4) A further corollary has been the development of manufacturing services on the basis of new communication technologies. To an ever-increasing degree, manufacturing firms are spinning off to outside companies a number of service functions traditionally performed in-house. Outsiders could not perform these specialised functions, typically related to design, engineering, finance, and marketing, without continuous interchanges of information with their principals.

(5) Effective and efficient communications technologies have also helped to accelerate interfirm co-operation in the distribution of products. Joint wholesale and dealer networks are becoming more common in all those industries dependent on a wide dispersion of sales effort. As a consequence, traditional notions about the minimum efficient size of dealer networks, have had to be revised, and such co-operation has made entry into new markets easier than before. At the same time, firms have had to revise their notions as to the strategic importance of such factors as the exclusiveness of distribution systems.

(6) In many industries, customer involvement and customer feedback during the R&D stage is becoming increasingly important. Therefore, continuous interaction with customers plays an important role in all phases of the process whereby new products are brought to market. Medical technology offers an outstanding example of this development.

Other examples could be added, but I hope the point is made: new information technologies have expanded the range of strategic options available to firms, and they have at the same time forced a reassessment of the goals of innovative activity. Even more important, they have begun to change the assumptions and conceptual foundations of strategy formulation by shifting the traditional boundaries between private and public technology. If the incremental cost of acquiring information is sufficiently low, and if rapid technological advances create no more than transitory advantages for firms possessing unique technical knowledge, then one would expect these firms to place less emphasis on appropriability, and more on co-operatively-generated knowledge.

These observations raise the question whether the resulting increases in the homogeneity of technical knowledge possessed by firms will tend to undermine their respective competitive advances. If it is true that firms survive in competition by being different from their rivals, where will

the differences come from? Conventional economic theory would suggest that, when all firms in an industry are 'on' the same production function, only differences in input prices can explain their competitve performance. The empirical evidence does not, however, support such a simple explanation. In fact, the last two decades have seen an increasing interpenetration of markets by firms possessing essentially identical, formal technical knowledge.[31] Furthermore, studies of comparative performance show that accelerated transfers of technical knowledge *per se* have done little to eradicate interfirm differences in organisational capabilites, in the quality of managements, and in the speed and effects of learning. The evidence also suggests that this kind of knowledge is much more difficult to transfer from one setting to another, even if one sets aside questions about the influence of sociocultural factors on industrial performance.

CONCLUDING OBSERVATIONS AND EXTENSIONS

In market economies, neither the recent breakthroughs in communication and information technology nor any of the preceding technical revolutions have changed the basic motive of firms in committing resources to innovation: the prospect of being able to appropriate (at least some of) the returns from the investment. However, such sweeping advances are often preceived as threatening appropriability, and therefore they impinge on the strategic balance among both the methods whereby firms acquire new technical knowledge and the means whereby they protect this knowledge.

Although these effects are just beginning to be understood, one may speculate that they depend in large measure on how firms adapt their strategies in different phases of their basic technologies' life cycles. There can be little doubt that the improved quantity and quality of information flows, as well as their reduced costs, have played an important role in the trend toward interfirm co-operation in technology development. This trend probably has been accelerated by the increasing cost of major R&D projects and by the belief that life cycles in many industries have been shortened, thus reducing the benefits a firm might capture from a stand-alone strategy and emphasising the ostensible benefits of co-operation in the reduction of technical uncertainty.

When all this has been said, however, there remains the fact that competitive survival depends only in part on bold innovation. While the often stunning successes of technological pioneers make for fine case studies, the great majority of businesses succeeds in global competition by capitalising on other strengths, such as established brand names, well-developed marketing networks, and excellence in service. No doubt the information revolution has affected the performance of these firms as profoundly as it has that of technology-driven companies. As Gold[32] has pointed out, technological superiority, although widely regarded as *the* key to market success, is but one of a number of equally important factors.

The matter deserves attention only because the capability-expanding and integrative powers of the new communication and information technologies are so often seen in a high-technology context only. Like all technological revolutions, however, they have spilled over into all sectors of the economy and offered opportunities for efficiency gains even in areas well inside the technological frontier. It is useful, in this connection, to remind oneself of Friedrich v. Hayek's observation that, "[T]o know of and put to use a machine not fully employed, or somebody's skill which could be better utilised, or to be aware of a surplus stock which can be drawn upon during an interruption of supplies, is socially quite as useful as the knowledge of better alternative techniques."[33]

Even after recognising this aspect of the new technologies' impact, however, we are left with issues that transcend the scope of my review. Crucial among them is the question of how, in the longer term, the information revolution will affect the formal and informal institutions supporting the appropriation of technical knowledge. An answer to this question clearly must go beyond the problems raised whenever innovations undermine the existing legal and organisational frameworks, such as in the cases of property to software and data bases. If the formation of global networks is indeed the essence of the revolution, then a greater international co-ordination of laws, regulations, and business practices becomes a necessary first step in the adaptation of the strategic environment. But such adaptation is purely reactive and will do little to deal with the more fundamental transformations brought about by the rapid diffusion of information technologies.

One of these transformations will no doubt have to do with the changing context for government policy. There is, first of all, the sovereign right of states to control information flows across their borders; but the exercise of this right assumes that control be technically possible, surely an unwarranted assumption even at the present stage of development! More seriously, however, the information revolution raises the question as to what end a state would want to control information flows. Setting aside matters of military security, it is becoming increasingly difficult unequivocally to define a set of national interests that might guide policy. As the interests of commercial and industrial organisations become more and more intertwined with but small regard for national boundaries, the formulation of technology policies and industrial policies is bound to run up against the problem of weighing benefits and costs that completely transcend the traditional perspectives of policy-makers.

A final observation about the consequences of these developments requires no great predictive powers: Unless the nations that have regarded themselves as the historical leaders in technology can sustain a rate of innovation that is higher than the rate at which technological knowledge is diffused among economies, the worldwide convergence of technical capabilities becomes a matter of simple arithmetic. The point would

hardly be worth making, were it not for the copious writings that bemoan this convergence as a loss of competitiveness. They do so from a point of view that seems largely irrelevant to contemporary assessments of the relative merits of competition and co-operation in innovation. If business decision-makers increasingly regard the globe as their proper playing field, competitiveness defined in purely national terms is bound to lose significance as a guide to policy and strategy. In the end, this may well turn out to be the most important transformation wrought by the information revolution.

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14. G. Rosegger, 'Technologie-monitoring: Konzeption und Anwendungen', *Der Wirtschaftsingenieur,* 21, 3, 1989, pp. 24-7.
15. This argument is elaborated in E.J. Malecki, 'The R&D location decision of the firm and "creative" regions', *Technovation,* 6, 3, August 1987, pp. 205-22.
16. An illustration of this tendency is provided in G. Rosegger, "Co-operative research in the automobile industry: a multinational perspective", in A.N. Link and G. Tassey (eds), *Co-operative Research and Development: The Industry-University-Government Relationship,* Boston, Kluwer, 1989, pp. 167-86.

17. See, for example, Office of Technology Assessment, *Commercialising High-Temperature Superconductivity,* Washington, DC, US Government Printing Office, 1988, esp. p. 135; and B. Oakley and K. Owen, *Alvey: Britain's Strategic Computing Initiative,* Cambridge, Mass., MIT Press, 1989, p. 28 and elsewhere.
18. Congress of the United States, Office of Technology Assessment, *Intellectual Property Rights in an Age of Electronics and Information,* Washington, DC, US Government Printing Office, 1986, p. 3.
19. A. Marshall, *Principles of Economics,* 1890, 8th edn, New York, Macmillan, 1920, p. 281n.
20. The desire to internalise knowledge is, of course, one of the main reasons given for the existence of multinational firms. For implications of interest in the present context, see R.D. Pearce, *The Internationalisation of Research and Development by Multinational Enterprises,* New York, St. Martin's Press, 1989.
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