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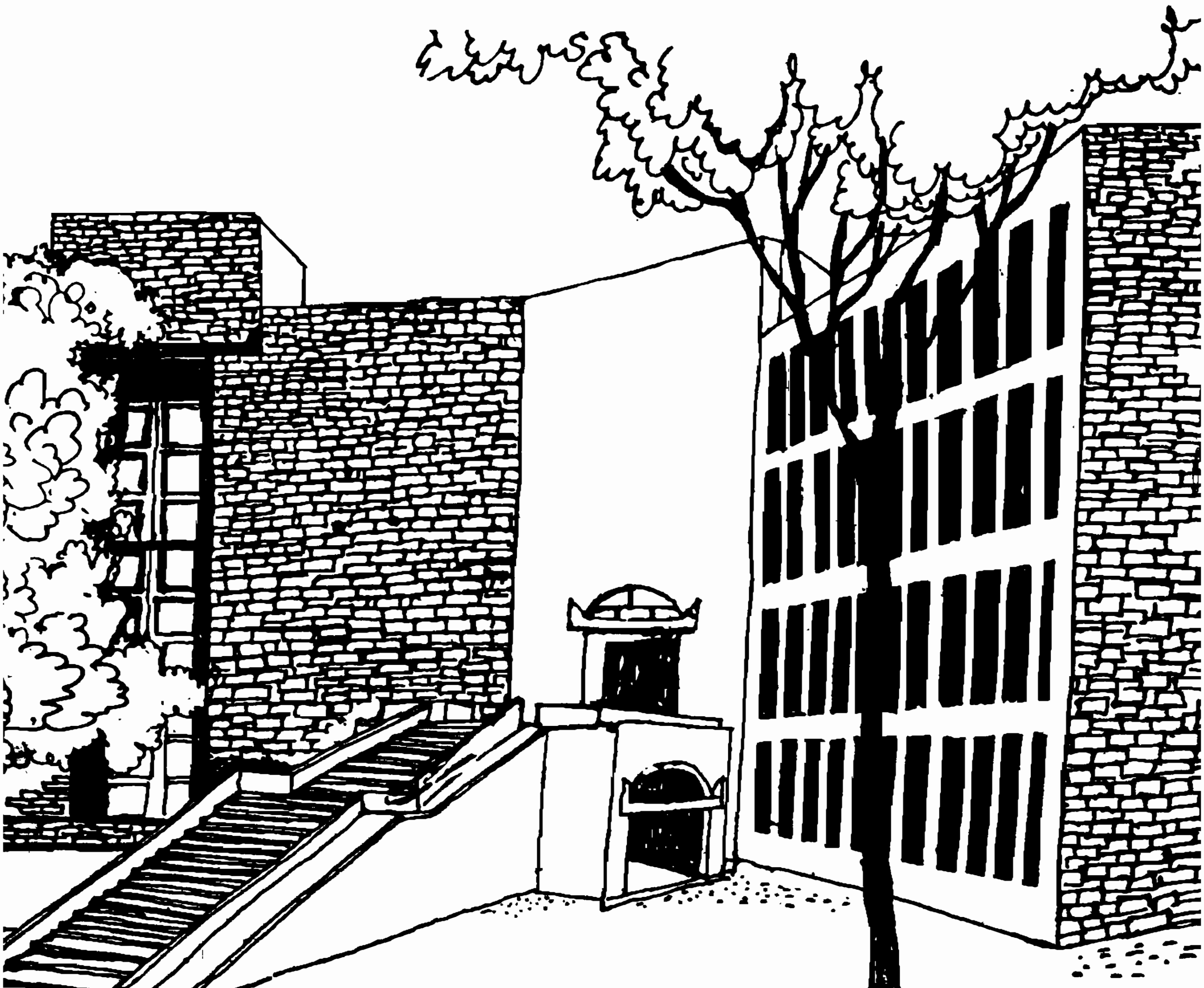

ANALYSING TECHNOLOGY STRATEGIES: SOME ISSUES

By

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Analysing Technology Strategy: Some Issues

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ABSTRACT

A firm's technology strategy is influenced by the 'technology regime' in which it operates. The regime is broadly defined by a combination of variables capturing industrial structure, nature of technical knowledge and the policy environment. Together, these variables determine the opportunity and appropriability conditions faced by a firm in a well defined industry. Given these broad relationships, firms' technology strategies may differ across industry groups. In addition, differences in technology strategies within an industry group may be induced by some firm specific characteristics like size, nature and level of diversification, technological and other capabilities.

Analyses of strategy using the modified the Structure-Conduct-Performance paradigm at the industry level have been unsatisfactory; industry heterogeneity gives rise to significant differences in the *strategies* of firms within the same industry. Dissatisfaction with the definition of industries has resulted in the use the concept of *strategic groups*, which differentiate a group of firms from others within a given industry in terms of their strategic choices. The value of the concept of strategic group lies in its role as a meaningful explanatory variable between the level of the firm and the industry. It should be capable of delineating extant structures and explaining (or predicting) conduct of firms within an industry. The major research problem with the strategic group approach is how to identify the different strategic groups in practice and how to allocate firms within an industry to the different groups which make up the industry's industrial structure. The present paper attempts a selective review of studies pertaining to technology strategy to explore parameters which can be used to define strategic groups within an industry. It is argued that nature of technology, industry and firm characteristics have major implications for theory and action related to the content of technology strategy and for the processes through which it is developed and implemented.

Analysing Technology Strategy: Some Issues

Rakesh Basant

CONTEXT

It is widely recognized now that a firm's technology strategy is influenced by the `technology regime' in which it operates. The regime is broadly defined by a combination of variables capturing industrial structure, nature of technical knowledge (e.g., complexity, tacitness and cumulativeness of the relevant technology) and the policy environment. Together, these variables determine the opportunity and appropriability conditions faced by a firm in a well defined industry. Given these broad relationships, firms' technology strategies may differ across industry groups. In addition, differences in technology strategies within an industry group may be induced by some firm specific characteristics like size, nature and level of diversification, technological and other capabilities and transactional relationships.

Till recently, economists had contributed little to the literature on firm strategy, especially technology strategy. In the early writings, economists essentially modified the Structure-Conduct-Performance (SCP) paradigm to analyse strategy related issues. These studies de-emphasize the uni-directional S-C-P linkages, and explore how *conduct*, which is given a strategic connotation, can influence performance as well as structure of the industry. Following the structuralist paradigm, initially, these explorations were done at the industry level. Industry heterogeneity gave rise to significant differences in the *strategies* (conduct) of firms within the same industry. Dissatisfaction with the definition of industries has led a number of economists to define and use the concept of *strategic groups*, which differentiate a group of firms from others within a given industry in terms of their strategic choices.

Strategic group constructs emerged largely from empirical observations; presence of a stable group of firms within an industry implied significant and enduring barriers to entry for firms outside the group, restricting mobility of firms from one group to the other within the same industry. Strategic groups are said to be isolated by *mobility barriers* over relatively long periods of time (Caves and Porter, 1977). According to Porter (1980), firms in a group follow substantially the same strategy in terms of product and process technology, market niche, channels of distribution, pricing, vertical and horizontal integration and so on. Consequently, strategic groups are seen as an outcome of deliberate intended managerial choices.

Obviously, the value of the concept of strategic group lies in its role as a meaningful explanatory variable between the level of the firm and the industry. In other words, it should be capable of delineating extant structures and explaining (or predicting) conduct of firms within an industry. (Pitt and Thomas, 1994: 81). The major research problem with the strategic group approach is how to identify the different strategic groups in practice and how to allocate firms within an industry to the different groups which make up the industry's industrial structure. The present paper attempts a selective review of studies pertaining to technology strategy to explore parameters which can be used to define strategic groups within an industry. It is argued that nature of technology, industry and firm characteristics have major implications for theory and action related to the content of technology strategy and for the processes through which it is developed and implemented.

The paper is divided into three sections. We begin in Section I with a brief discussion of the elements of technology strategy. Section II summarises the key technology, industry and firm characteristics which are likely to influence technology strategy choices. In the final section we review a few studies which have explored the linkages between elements of technology strategy and key features of technological activity and industry/firm characteristics.

I. ELEMENTS OF TECHNOLOGY STRATEGY

The broad objective of technology strategy is to guide a firm in acquiring, developing and applying technology for competitive advantage. A firm's technology strategy is also expected to serve its overall strategy in developing and exploiting firm specific advantage. In this sense, it is contingent on the firm to ensure a consistency between technology and business strategies. Given this premise, a firm's technology strategy is often seen as a set of choices about the relative emphasis on: (a) cost versus quality; (b) broad versus narrow product market focus; and (c) technology leader versus follower status.

The development economics literature has emphasized the role of *technological capabilities* in acquiring and sustaining firm level competitive advantage. These capabilities broadly relate to the ability of firms to handle technologies and cope with technological change; the ability to absorb and build on technologies. In this context, building such capabilities should be the focus of strategic technology management endeavours.

At the firm level these strategic choices get translated into a variety of decisions which cut across functional boundaries. MacAvoy's (1990) summary of these decisions (reproduced with some modifications below) brings out the complexity of the processes involved in identifying a technology strategy of the firm.

Selection, Specialization, and Embodiment: In what technologies should the firm invest? What technologies are promising from the perspective of the existing product line or for new or related products? What technologies provide opportunities for improved product performance or lower product cost? How should these technologies be embodied in new products? What performance parameters should dominate? How should proposals for new technologies/products be evaluated?

Level of Competence: How proficient should the firm become in understanding and applying the technology? How close to the state of the art should the firm be in this technology to achieve its objectives in its products and markets, given the competitive environment? How much emphasis should be placed on advancing knowledge of the technology through basic or applied research, as opposed to straightforward applications of the technology through product-development engineering?

Sources of Technology: To what extent should one rely on external sources, including contract research and licensing from individual inventors. research and engineering firms, or competitors? Under what circumstances should a firm collaborate with other firms? To what extent should it rely on internal development?

R&D Investment Level: How much should the firm invest in these technologies? What level of internal staffing or external expenditure is appropriate? Should the firm let R&D investment oscillate with company profit?

Competitive Timing: Should the firm lead or lag competitors in new-product introduction? Does the benefit from leading competitors outweigh the risk of uncertain market acceptance of a new product? Are there benefits in allowing a competitor to go first, evaluating market acceptance of that product, and developing an improved product if market conditions warrant? What response is appropriate to a competitive-product introduction?

R&D Organization and Policies: Should there be a central R&D lab? Where should it be located? How should it be structured? Should there be a separate career track for scientists? Should one use project teams, or a matrix arrangement, to allow sharing of scarce technical resources? Should the firm reward scientists and engineers on a level that is compatible with its industry, or should it be leader in compensation? How closely should top management be involved in technological decisions? What decision rules should be used to allocate funds to R&D projects? How should the firm protect its technological know-how? What should be its patent and publication policy?

In all these decisions, which are expected to develop firm specific competitive advantages, the issue of *complementary assets* will also have to be tackled. In the absence of such assets, which include manufacturing and distribution capabilities, appropriation of new technologies may be rather limited. More on this later.

II. ROLE OF TECHNOLOGY, INDUSTRY AND FIRM CHARACTERISTICS

Studies have shown that formulation and implementation of technology strategy are constrained/determined by a variety of features which distinguish technological activities from other activities and one industry/firm from the other. In what follows, we summarise some of these features.

Nature of Technology and Innovative Activities[1]

Various inter-related features of technology, technological change and innovative activities have been identified in the literature which can impinge on firms' technology strategies. These are discussed below.

Tacitness: A significant part of knowledge developed by enterprises is tacit; it is difficult if not impossible to codify. This is particularly the case in the early phases of technology development; codification usually increases as the technology matures. Tacitness also arises due to the *circumstantial specificity* of technologies. Technologies often need to be adapted to suit *local conditions of production*, including climate, raw materials, labour management relations and social institutions. Tacitness has significant implications for the transfer and appropriability of technology. Broadly, as tacitness increases, appropriability goes up but transfer becomes increasingly difficult, requiring significant efforts on the part of the buyers and sellers of technology.

Differentiated Learning: Innovation related activities are highly differentiated. Specific technological skills in one field (e.g.. developing pharmaceutical products) may be applicable in closely related fields (e.g., pesticides), but they are of little use in other fields (e.g.. designing automobiles).

Path Dependency and Cumulative Nature: Technology often evolves in certain path dependent ways conditioned by what are usually referred to as technological paradigms. What an enterprise has been able to do in the past strongly conditions what they can hope to do in future. New product and process developments for an enterprise are likely to lie in the technological neighbourhood of previous successes. Consequently, technological change is often *incremental in nature based on continuous cumulative learning; discrete/ quantum* changes in technology are few and far between. Moreover, cumulativeness like tacitness adds to appropriability of technology.

Irreversibilities: Firms often get locked into certain technologies due to the path dependency referred to above and because of the specialised investments (fixed and sunk costs) associated with an innovation. This, along with differentiation in innovative activities, reinforce the path dependencies.

Technology Supply Chain: Technological interrelatedness plays a crucial role in technological development. We shall see later that linkages with upstream and downstream technologies (users) may hinder or induce technological change in a segment. Technology supply chain may also be important in another way. Often, the full benefits of new technologies are not reaped because all elements associated with the technology are not adequately implemented within the organisation; product, processes and practices linked to a technology need to be embodied in the organisation for good results.

Interaction Among Functional Groups: Strategic decisions to move into new areas. development and implementation of new technology involves continuous and intensive collaboration and interaction among functionally specialised groups like R&D, marketing, production, organisation and finance. In fact, linkages with other technologies and complementary assets is crucial for the success of innovations. More on this later.

Uncertainty: Innovative activities are highly uncertain. Three kinds of uncertainties have been identified. *Technical* uncertainty relates to whether R&D will successfully generate technology and if so when. *Market* uncertainty relates to the likely impact of the technology when it hits the market - by how much will the process innovation reduce costs, what kind of a demand curve the new product will attract. An extension of the market uncertainty relates to the *conduct of rivals*: how rivals will react; will they match R&D programmes, attempt to win the innovation race, or will they imitate?

Appropriability: Despite various legal provisions for protecting intellectual property, appropriability of an innovation is *never* complete. How far the results of the R&D activity be internalised and how far will they constitute a public good depends on a large variety of factors including tacitness and complexity of technology, market structure and access to complementary assets etc.. What is not appropriated by the innovating enterprise *spills over*. Technology spillovers in a sector determines the potential for imitation in that sector. We now move to some of these dimensions.

Supplier-Dominated Sectors: Innovation is exogenous to this sector, embodied in purchased inputs. R&D is low and mainly adaptive due to limited technological opportunities. Appropriability and cumulativeness of technological capabilities are relatively restricted. Typical sectors are textiles, clothing, leather, wood, agriculture. The threat of entry faced by the incumbents in this sector usually emanates from machinery suppliers who control most of the technology.

Specialised Suppliers: Firms in this sector focus on product innovations that enter other sectors as capital goods. Formal R&D is low but abundant innovation opportunities are exploited through *tacit* design and engineering capabilities. Idiosyncratic and cumulative skills make for relatively high appropriability of innovations. Typical sectors are engineering, instruments, rubber etc.. The firms in this group may face user sector firms as potential competitors through vertical integration.

Scale-Intensive Sectors: Innovation is endogenous to this sector as part of production activities in large complex production systems. Production engineering and learning-by-doing are major sources of technology. R&D expenditure are high as these forms generate their own process technology in many cases and integrate vertically to make their own equipment. Appropriability is also high due to vertical integration and cumulativeness of learning. Besides, the threat of technology based entry is unlikely to be strong, given the relatively small size of the technologically strong suppliers. Typical sectors are transport equipment, glass, metal, cement etc..

Science-Based Sectors: Innovation activity is endogenous to the sector but is located in labs and based on rapid developments in underlying sciences. Technological opportunities are high resulting in high R&D expenditures. The entry barriers in the sector are high due to large R&D investments and high appropriability. Product innovations from this sector enter a wide range of sectors as capital or intermediate inputs. Typical sectors are electronics, chemicals, drugs and bio-engineering. Scientific advances often enable horizontal diversification into new product markets. Therefore, similar science based firms diversifying horizontally into related product markets are the potential competitors for firms in this sector.

It should be noted that the characterisation of these sectors can change over time. Broadly, as compared to other sectors, technological opportunities are higher in science based firms (given munificence in underlying technologies) and in specialized suppliers (given continuous pressures to improve production efficiency in user sectors). Firms in these sectors also emphasize more on product innovations vis-a-vis process innovations. We shall see later how these *technological specificities* of various industry groups can influence technological strategies of firms in these sectors.

Firm Characteristics[4]

A large variety of firm characteristics, impinging on technology strategies have been highlighted. It is impossible to cover all these features, a few dominant ones are discussed.

Firm Size: The role of firm size has already been highlighted above. Two aspects need to be stressed. One, large oligopolistic firms are often able to internalise the benefits of innovation because of the access to complementary assets which include competitive

Industry Characteristics

In the S-C-P paradigm, technological effort (invention/innovation) is a conduct variable and diffusion of innovation is expected to improve performance. Observed sectoral patterns of technical change are often seen as a result of the interplay between various kinds of market inducement, and opportunity and appropriability combinations. Structural and technological characteristics of industrial sectors affect opportunity and appropriability conditions and, therefore, impinge on technological strategies of firms in these sectors.

Structural Features[2]

Technology effort is often seen as an investment to create entry barriers, i.e., strategy (conduct) to influence the structure of the sector. Capitalist competition involves rapid imitation with innovations continuously superseding each other. Therefore, there is incentive to innovate only if one feels confident of being able to exploit that innovation rapidly. Monopoly or imperfect competition provides a better setting in which to exploit innovation. The Schumpeterian view is that monopoly power and large size of the firm facilitate/induce technological advance. This is so because the large oligopolistic firms are better able to internalise the benefits of innovation and are generally more certain of their environment. Such firms have the wherewithal to exploit new technology quickly largely due to better access to finance and complementary assets like manufacturing facility and capacity and marketing infrastructure. Therefore, oligopolistic industries are expected to be more innovative. Empirical studies, however, have not been able to discern any neat pattern of linkages between market structure and technological activity.

While the importance of complementary assets cannot be denied for any innovation, the Schumpeterian logic is probably more apt for breakthrough innovations rather than continuous improvements of the *Kaizen* variety. It is not clear if the empirical investigations are able to make a clear distinction between these two types of innovations. Furthermore, differences across and within industries in terms of product/industry life cycles, can complicate empirical investigations. The product and technology life cycles within an industry often overlap and factors influencing appropriability during the *invention*, *innovation* and *standardisation* phases may be significantly different (Magee, 1977). Besides, it has been emphasised that *market structures of both the technology generating and technology using industry are relevant for determining the nature and level of technological activity*. An enterprise will have higher incentives to invent if the user industry is competitive than if it is a monopoly. However, if the appropriability of the new technology is low, a monopolistic user may be preferable. In the same vein, without a *threat of entry*, a monopolist may not invest in technology as she is earning super-normal profits.

Effectiveness of intellectual property rights (IPRs) have been found to differ across industrial sectors. For example, patent protection is considered to be relatively more effective for chemicals and pharmaceutical sectors than other sectors like industrial machinery etc.. Will lower appropriability result in lower technological activity by firms in a sector due to lower incentives? This may not happen if faster imitation create higher competitive pressures to stay ahead and reap first mover advantages. Besides, non-innovators may also undertake R&D to absorb spillovers. In fact, Cohen and Levinthal (1989) have shown theoretically that the spillovers associated with imperfect appropriability may actually increase R&D in the industry equilibrium. They argue that there is a positive effect of spillovers on the marginal productivity of the firm's R&D as the firm's own technological effort improves its ability to assimilate the technological developments of others. Therefore, if this effect is sufficiently strong it can overcome the dis-incentive of imperfect appropriability, resulting in an aggregate R&D higher than the level it would have reached in the case of perfect appropriability. Some recent empirical investigations support this theory (see, discussion below).

Technological Features[3]

Many studies have emphasized the existence of significant inter-sectoral differences in the nature, sources, determinants and objectives of innovative activities and resulting innovations. On the basis of sectoral specificities observed in developed countries, certain categories of these sectors have been identified. On the basis of some empirical evidence from UK, Table 1 summarizes some salient characteristics of the sectors identified.

Table 1: Proposed Patterns of Technological Opportunities and Threats

	Opportunities		Threats		Appropriability	
Category of firm	Number of innovations	Percentage Product Innovations	Ratio of Innovations Purchased to those Produced	Percentage of Innovation made by firms from other 3 Digits	Average Size of Innovating Firm (Employment)	Principal Activity of Firms fitting these Characteristics
Science Based	High	High	Low	High	High	Chemicals Electrical-Electronic
Specialized Suppliers	High to Medium	High	Low	Medium to High	Low to Medium	Mechanical Engineering Instruments Rubber & Plastic Products
Scale Intensive	Medium	Medium	Medium	Low	High to Medium	Mining Food Vehicles Metals Utilities
Supplier Dominated	Low	Low	High	Medium	Low to Medium	Textile Agri. Paper Construction Printing

Source: Pavitt, Robson and Townsend (1989): Table 1, p.86.

Supplier-Dominated Sectors: Innovation is exogenous to this sector, embodied in purchased inputs. R&D is low and mainly adaptive due to limited technological opportunities. Appropriability and cumulativeness of technological capabilities are relatively restricted. Typical sectors are textiles, clothing, leather, wood, agriculture. The threat of entry faced by the incumbents in this sector usually emanates from machinery suppliers who control most of the technology.

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Firm Characteristics[4]

A large variety of firm characteristics, impinging on technology strategies have been highlighted. It is impossible to cover all these features, a few dominant ones are discussed.

Firm Size: The role of firm size has already been highlighted above. Two aspects need to be stressed. One, large oligopolistic firms are often able to internalise the benefits of innovation because of the access to complementary assets which include competitive manufacturing facilities, distribution and service networks and complementary technologies. (Teece, 1986). Two, as an activity, *often* R&D displays scale economies. Consequently, large firms with large R&D departments are often more efficient in generating innovation and also have greater incentives. This is not to deny the *inventiveness* of small scale firms, especially in the early part of the product life cycle and in sectors like bio-technology and software. However, size is still important in successful *innovation*, i.e., commercialisation of inventions.

Product Diversification: The scope of product market activities may influence the technology strategies of firms in three ways: (i) the multi-divisional multi-product firm is in a position to re-allocate cash from businesses that have positive cash flow to new businesses with negative cash flow, at least for short durations; (ii) product market portfolios of multiproduct firms can increase the payoff to uncertain R&D by increasing the probability that new products and processes resulting from corporate R&D can be commercialised inside the firm; and (iii) multiproduct firms can more readily develop and commercialise *fusion* technologies which involve the blending of technological capacities relevant to disparate lines of business.

This fusion by no means occurs automatically, and requires internal structures which are flexible and permeable. Indeed, there appears to be less diversity in innovating firms' products than in their technologies (Pavitt, Robson and Townsend, 1989). This implies that these firms develop technological capabilities beyond those strictly related to their current output. Higher technological diversification reflects synergies through links with upstream, horizontal and downstream activities. Such differences in technology vis-a-vis product differentiation can also be due to a conscious strategy to counter opportunistic behaviour by suppliers, customers or partners and uncertain future. Alternatively, it can simply be due to technical inter-dependencies requiring such technological capacity.

Nevertheless, the multiproduct firm does afford opportunities for economies of scope based on transferring technologies across product lines and blending them to create new products. Despite the path-dependent nature of technological change, the diversity of application areas for a given technology are often quite large, and it is often feasible and sometimes efficient to apply the firm's capabilities to different market opportunities.

Conglomerates: Such organisations are likely to be decentralised, and this may favour the innovation process. These can also use the internal capital market to fund the development of new technologies as has been the case in Japan and South Korea. However, the importance of this is likely to be reduced (i) the more the capital, including venture capital, is available for new stand-alone businesses, and (ii) the more the headquarters management acts like external capital market agents. Accordingly, on grounds of access to capital and diversity of activities, one would not expect the conglomerate to look too different from a portfolio of stand-alone firms with respect to its innovative capacity and technological strategy. Of course, the accounting practices used in such firms to fund new projects will matter.

Besides, there are two ways in which one might expect the conglomerate to under-perform vis-a-vis stand-alone firms with respect to innovation. One is that it is difficult for conglomerates to develop distinctive company-wide corporate cultures. Accordingly, it may be quite difficult to build a strong internal change culture at the corporate level. As compared to a stand-alone firm, getting across to employees the notion that the unit must ultimately be viable on its own will be quite a challenge. Consequently, free riding may well be accentuated. Likewise, the design of high-powered incentives for top management and employees will be hindered by the absence of an equity instrument geared to divisional performance. Therefore, it is argued that often the conglomerate does not appear to offer distinctive advantages in environments characterised by rapid technological change.

Vertical Integration: A distinction is usually made between two types of innovation: *autonomous* (or *stand-alone*) and *systemic*. An *autonomous* innovation is one which can be introduced without modifying other components or items of equipment. The component or device in that sense *stands alone*. A *systemic* innovation, on the other hand, requires significant readjustment to other parts of the system. The major distinction relates to the amount of design coordination which development and commercialisation are likely to require. Systemic innovation may be organisational as in the case of electronic fund transfer or synergistic as in augmentation of VLSI technology due to the advances in X-Ray and electro-lithography technologies. There can be synergies of an other kind; an internal combustion engine could not be used to make a motor car till the invention of the differential. Similarly, instant photography required redesign of the camera as well as the film.

With systemic innovation and synergies, internal organisation (integration) can often assist the workings of the market. Integration facilitates systemic innovations by facilitating information flows, and the coordination of investment plans. It also removes institutional barriers to innovation where the innovation in question requires allocating costs and benefits, or placing specialised investments into several parts of an industry.

External Linkages: Firms commonly need to form linkages, vertical (both upstream and downstream), lateral, and sometimes horizontal in order to produce and market their products. For example, linkages are extremely important when there are vast consumption side economies, as in computers and software development. Standardisation in such circumstances provides significant product development opportunities.

Such linkages may evolve into strategic alliances to develop and commercialise new technologies. This is likely to be so because as compared to arm's-length market contracts, such arrangements have more structure, involve constant interaction among the parts, more open information channels and greater trust. Compared to hierarchies, such alliances or networks among firms call for negotiation rather than authority and put great emphasis on boundary-spanning roles. Although firms connected through alliances have a high degree of autonomy, the relationship may well be anchored by a minority equity position, as is often done by MNEs vis-a-vis firms in other countries. These arrangements can be used to provide some of the benefits of integration while avoiding some of the costs. However, it is also feasible that such linkages constrain technological activity; strategic technological action has to be accepted by all segments of the network, else it will be ineffective.

Virtual Corporations: The term virtual corporation has been used in business parlance in the 1980s and 1990s to refer to business enterprises that subcontract anything and everything. A key question is whether the innovative capacities of such companies are impaired by the absence of in-house manufacturing and other capabilities. Virtual corporations are of course smaller than they might otherwise be (by virtue of the absence of vertical integration) and thus generally have shallow hierarchies. They might well have innovative cultures and external linkages to component manufacturers.

Defined this way, virtual corporations have the capacity to be very creative and excel at early-stage innovation activities. If they do indeed establish a strong alliance with a competent manufacturer, they may also have the capacity to be first to market, despite the absence of the requisite internal capabilities. The hazards associated with virtual structures are not unlike the hazards facing the individual inventor. The problem is that unless the firm is operating in a regime of tight appropriability, the innovator may not be able to capture value from the innovation, and the manufacturer, by integrating into research and distribution, is likely to become the firm's competitor (Teece, 1986). While virtual or hollow corporation is not a common entity in developing countries, the hazards referred to above are real for most firms using inappropriable technologies and without control over complementary assets.

III. NATURE OF TECHNOLOGY STRATEGY: EXPLORING THE ROLE OF TECHNOLOGY, INDUSTRY AND FIRM CHARACTERISTICS

Certain strategic implications of technology, industry and firm characteristics discussed above are obvious. Based on some studies, in this section we will discuss how these characteristics impinge on choices related to certain elements of technology strategy described in Section I.

Sectoral Patterns of Technology Strategies

The discussion above has already emphasized the notion that any analysis of technology strategies should explore the inter-sectoral differences in technology opportunities and that cumulative development of firm specific technology knowledge/competence may constrain/influence technology strategy. Pavitt, Robson and Townsend (1989) have attempted such an exercise on the basis of data on technological innovations in UK. The cumulative and differentiated nature of technological developments in firms suggests that the choices about the *content* of technology strategy discussed in the management literature--broad front versus specialised, product versus process, and the leader versus follower--do not take into account the enormous variety between firms in sources of technological opportunities.

Strategic implications of some key features of technological activities are set out in Table 2. The strategic problems emanating from technological variety across industrial sectors are summarised in Table 3. In addition to the sectors identified in Table 1, Table 3 includes an *information intensive* sector. In recent times, information and computing technologies have created significant opportunities for software-based technical change in processing information. The *supplier dominated* sector has been excluded since accumulated technological skills and strategic initiative lies with the suppliers. Firms intending to move away from this position try to adopt either scale-intensive strategies (e.g. in textiles) or information-intensive strategies (e.g. in retailing).

In *science-based* sectors, the key opportunities are for horizontal diversification into new product markets. Access to complementary assets to core technologies are of strategic importance for such a movement. For example, a firm moving from the production of pharmaceuticals (office machinery) to pesticides (telecommunications) will need to understand

and service a new market.

In *scale-intensive* and *information-intensive* sectors, key opportunities lie in technology fusion, if firms can progressively integrate rapidly. changing technologies into products and production systems. The firm specific competencies in these sectors are often based on scale and complexity in design in production and in marketing and co-ordination. Integration of new technologies is likely to reduce cost, increase flexibility and facilitate new product development (e.g. through CAD-CAM, robots and software). In other words, technology fusion or blending may provide *job shop* flexibility to scale intensive firms based on *assembly line or continuous process* technologies.

Overall, the evidence suggests that firms do not have completely free choice about whether or not be broad front or specialised, and product or process oriented. However, specific firms can follow more than one technological trajectory. A large computer firm, for example, can at the same time be *science-based* (electronics), *scale-intensive* and *information-intensive*. The dominating technological trajectory may need to be identified empirically.

Table 2: Characteristics of Innovative Activities and Their Implications for Management

Functional and Technical Specialisation	Implication for the Firm	
	Objectives	Means
1. Functional and Technical Specialisation	Quality in and Balance Amongst R&D, Production and Marketing	* Business Innovator with Strong Knowledge of All Functional Areas
2. Uncertainty in Outcomes	Flexibility and Speed in Decision, Cover Contingencies	* Decentralisation of Implementation * Portfolio Investment * Avoid `Sophisticated' Decision Algorithms
3. Cumulative in	Exploitation of Learning: - By Using - By Failing	* Feedback from Marketing Technical Function * Skilled Work Force in Production and Marketing * Creation of Technological `Slack' in Product & Process Designing * `Patient' Money
4. Differentiation & Speciality	Exploitation of Technological Trajectories	* See Table 3

Source: Pavitt, Robson and Townsend (1989).

Table 3: Basic Technological Trajectories

Technology, Industry & Strategy Features	Categories of Firms			
	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 Specialised Producers Goods (Reliability and Performance)
Typical Product Groups	.Electronics .Chemicals	.Basic Materials .Durable Consumer Goods	.Financial Services .Retailing	.Machinery .Insurance .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 Disintegration(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.'

Source: Pavitt (1990)

Make, Buy and Copy Strategies

As discussed in section I, a firm has two broad (but not mutually exclusive) choices regarding the acquisition of technology: it can internalize the innovation process by pursuing specific activities or it can use existing markets to purchase technology. The decision whether to develop indigenous technology or to purchase technology is influenced by benefit-cost comparisons which have to take account of factors like technology spillovers, possibilities and costs of imitation etc. Obviously, the policy regime influences this decision significantly. Broadly then, the technical knowledge available to a firm can be divided in terms of three alternative sources of acquisition:

(a) knowledge generated by firm on its own;
(b) knowledge purchased by the firm; and
(c) spillovers created by knowledge generation of other firms.

The purchased knowledge can be disembodied in the form of technology licenses or embodied in the inputs (including new vintages of capital) the firm purchases. Besides, licenses and inputs can either be acquired domestically (within the country) or from foreign sources. In the same vein, technology spillovers or imitation potential can be created from knowledge generation of domestic agencies (firms, government and private research institutions, individual researchers etc.) and from knowledge generation abroad.

Basant and Fikkert (1993) and Basant (1993) and Basant (1997) have explored the determinants of these technology acquisition choices in the context of the Indian corporate sector. Some conclusions of these studies are interesting and suggest significant implications of imitation potential, firm size, foreign equity participation and import of embodied inputs on the make/buy strategies of Indian firms.

1. Disembodied technology purchase and R&D are substitutes in production. This implies that on average strategies based on technology purchase, at least in the short run, are accompanied by a reduction in firm's own technology effort.

2. Existence of domestic technology spillovers (or copying potential) induce a strategy based on firm's own R&D presumably to internalise the R&D done by other domestic firms in the sector. Such spillovers significantly reduce the probability of solely relying on technology purchased from abroad. However, in the presence of such imitation potential firms may use the strategy of supplementing their own effort by foreign technology purchase. Such a strategy probably was partly responsible for the Kaizen type of continuous improvement.

3. Foreign technology spillovers increase firms' R&D efforts. Increases in such spillovers also increase the probability of foreign technology licensing but reduce the chances of combining it with indigenous R&D efforts. Apparently, absorption of foreign technology spillovers is attempted through two strategies: internalise such spillovers through one's own technology effort or learn more about it by purchasing foreign technology. Interestingly, the data suggest that the second strategy is inefficient as foreign technology spillovers have significant positive impact on firm output only when combined with firm level R&D.

4. Large firm size and the import of embodied technology in the form of capital and other inputs induces R&D and increases the probability of doing R&D, licensing foreign technology or both relative to being technologically inactive. There are, however, some interesting sectoral differences. Large firm size increases the probability of doing R&D, licensing foreign technology or both relative to being technologically inactive. The firm size has the most significant impact on the choice of doing only R&D for chemical firms and relying only on technology purchase for industrial machinery firms. Besides, both sets of firms are also likely to combine indigenous effort with licensing of foreign technology than being technologically inactive with increases in firms size. This implies that the utility of relying only on R&D increases with increases in firm size for chemical firms and that of relying only on technology

licensing for industrial machinery firms. We need to understand whether these strategies are policy-induced or reliance on one's own R&D efforts is not adequate for large firms in industrial machinery industry. This may also be linked to the type of technology sought; larger industrial machinery firms probably seek product technology from abroad which requires relatively less local adaptation. Besides, given the technological capabilities in this industry, local adaptation may also be more feasible in this industry. Therefore, relying on foreign technology licensing alone is possible in many cases. Such processes were, however, not dominant among chemical firms.

5. Foreign equity participation increases firms' R&D efforts. Such participation also increases technology licensing expenditure. On average, firms with foreign equity participation are most likely to combine technology licensing with their R&D efforts. Here again some sectoral differences are noteworthy. Foreign equity participation improves the utility of technological dynamism among chemical firms and not among firms engaged in producing industrial machinery. In fact, such participation significantly decreases the chances of relying on R&D alone among industrial machinery firms. It improves the probability of licensing foreign technology and combining it with their R&D efforts among chemical firms. Apparently, foreign equity participation influenced technology strategies in the two sets of firms differently. The peculiarities of the patent regime and the importance of formal R&D may have induced chemical firms with foreign equity participation to undertake more indigenous R&D.

6. For all sectors put together, import of embodied technology in the form of capital and other inputs induces R&D and increases the probability of doing R&D, licensing foreign technology or both relative to being technologically inactive. However, capital imports improve the probability of relying on technology licensing alone among chemical firms and on R&D alone for industrial machinery firms. Of course, for both sets of firms, the probability of combining the two also improves with capital imports. Adaptation to suit local conditions seems to be more important for industrial machinery firms, while tying of capital imports with technology licensing was perhaps more prevalent among chemical firms. Other imports seem to significantly reduce the need to license technologies to produce them domestically by chemical firms while such a process was not significant among industrial machinery firms. Once again, adaptive R&D induced by such imports is perhaps more significant among industrial machinery than chemical firms.

Integration, Licensing and Strategic Partnering

The variety of arrangements to link organisations is almost unlimited, and the resultant forms quite diverse. A constellation of licensing, manufacturing and marketing agreements will typically characterise many inter-organisational arrangements. R&D joint ventures, manufacturing joint ventures, co-marketing arrangements and consortia are just a few of the resultant forms. Some of these arrangements constitute extremely complex open systems, and some may be unstable. The managerial functions in these inter-organisational networks are quite different from the authority relationship which commonly exists in hierarchies. Managers have to perform boundary-spanning roles, and learn to manage in circumstances that involve mutual dependency. This section discusses some studies which explore the impact of technology characteristics, appropriability and complementary assets on some of these inter-organisational arrangements.

Specialised Complementary Assets[5]

In the initial phases of new technology commercialisation. competition is among designs. Uncertainties are about which design will emerge as dominant. It is of strategic relevance in this phase to make efforts to create the dominant (standardised) design closer to firm's specification. After the emergence of the dominant design, price (and delivery) competition becomes more relevant. Consequently, reduction in costs through process innovation, scale economies and learning becomes crucial. These processes get reflected in the empirical observation that when new technologies are commercialised, process innovation often follows product innovation. With the slowing of the rate of product innovation, designs tend to become more standardised, providing the opportunity for large scale production and the deployment of specialised assets. While this perspective on the technology life cycle is instructive, it implicitly assumes that a *breakthrough innovation* underlies this transition. Recent developments and the success of the Japanese firms, especially in the auto sector, have challenged this linear-dichotomous (product versus process innovation; design versus price competition) characterisation of the processes at work. Even during the *phase of process innovation*, significant product innovations may take place; firms compete on new variations of the old designs with significant reductions in lead times. Within the broad technology life cycle, product life cycles are increasingly becoming shorter with high rates of product obsolescence.

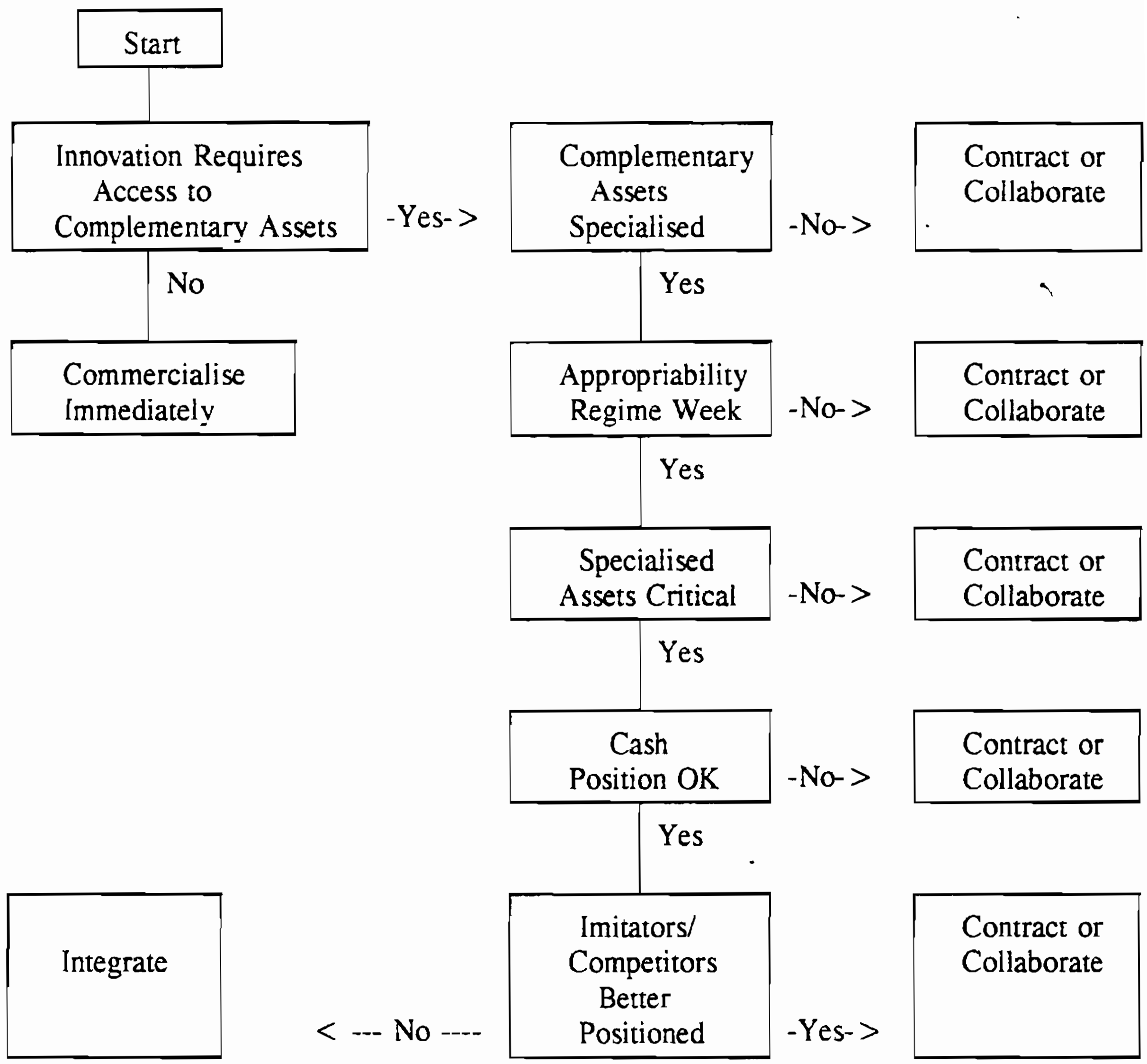
In almost all cases, the successful commercialisation of an innovation requires that the know-how embodied in the innovation be utilised in conjunction with such complementary assets as marketing, competitive manufacturing and after sales support. Complementary assets can be generic, specialised or co-specialised. Generic assets are general purpose assets that do not need to be tailored to the innovation. Specialised assets are tailor-made for the innovation, and are necessary for the implementation of the innovation. Co-specialised assets are those for which there is bilateral dependence. Whether the assets required for least cost production and distribution are specialised is important for strategic decisions regarding integration and collaboration.

The flow chart (Exhibit 1) suggests that when managers make R&D and commercialisation decisions, they must identify, preferably ahead of time, the complementary assets that the innovation will need for successful commercialisation. Contractual or collaboration alternatives will make strategic sense if the complementary assets are not specialised, or if the appropriability of the innovation is ironclad. Collaboration/contract modes can also be acceptable if (i) the required complementary assets are not critical; or (ii) for assets which cannot be procured by the innovating firm due to lack of financial resources; or (iii) for assets in which imitators are already irrevocably better positioned. Otherwise, the integration (in-house availability of complementary assets) alternative ought to be preferred to capture the value of the innovation.

Technology Strategy-Manufacturing Strategy Interface

Given limited appropriability of technology, strategies that employ co-specialised assets and other inter-dependencies are advocated to generate and protect the economic rents from innovation. Manufacturing capability is often seen as one such asset. Empirical evidence has shown that competitive manufacturing provides significant learning potential and the

Exhibit - 1: Decision Flow Diagram



Source: Teece (1986).

associated cost, quality, delivery and flexibility advantages.

Just like successful commercialisation of certain innovations is dependent on access to good manufacturing facilities, nature of existing manufacturing facilities can condition nature of innovation activities (even technology strategy) undertaken by the firm. Competitive manufacturing is also likely to be critical in many circumstances because technology and product (and industry) life cycles are not co-terminus; a given embodied technology may be able to provide various generations of new products. It is pertinent in this context to note that DeBresson and Lampel (1985) have questioned the conventional wisdom that organisational design (manufacturing and sales modes) is significantly constrained by technology's evolution, as reflected in the technology life cycle. The shift from product to process innovation during the technology life cycle is expected to be accompanied by shifts in production modes from custom to batch and line process. DeBresson and Lampel (1985) broadly agree with this progression but emphasise the flexibility available to choose from these modes at any given point in time to suit the firm's strategic choices regarding market segments to be served. Such flexibilities need to be exploited for strategic advantage but the chosen production modes must be compatible with (i) the projected product design (performance oriented, applications, standardised); (ii) the technical environment (rapidly changing, stabilising, stable) and (iii) the market objectives (niches, segments, or dominant mass markets). Alternatively, enterprises can mix modes by adopting different manufacturing processes in different plants.

Strategic Technology Partnering

Focused R&D projects involving vertical technology partnering (supplier-user; backward-forward linkages) have been quite pervasive for the acquisition of complementary assets. Intra-industry horizontal linkages among competitors for developing technologies or setting standards is a relatively recent phenomenon, presumably induced by increasing technological complexity. R&D diversification or technology fusion through inter-industry technology development is the emerging phenomenon fueled by rapid and radical changes in the frontiers of technology and the related changes in competitive environment.

R&D co-operation (joint R&D networks etc.) typically occur when risks and R&D costs are high. Given the risks and costs, such arrangements take place when the strategic advantages arising from expected future gains in knowledge given the risks and costs, such an arrangement (due to synergic technology creation through interaction and dynamic technological accumulation) are higher than the considerable co-ordination (co-operation costs and possible rent losses). In addition, the costs may also include a loss of or possible leaking of tacit knowledge, leading to dilution of profits. New technologies require multiple sets of complementary technical developments, which often go beyond the scope of even the largest firms. These and many other motives induce strategic technology partnering (See Table 4).

Theoretical contributions inspired by transaction cost economics view inter-firm partnering as an economic phenomenon between market transactions and hierarchies. Although, there are a large number of motives for such partnering, market and technology related motives dominate (See Table 4). Hegedoorn (1993) has analysed a large data base of nearly 10,000 technology co-operation agreements to analyse the motives for such partnering. All these agreements involved combined innovative activity or an exchange of technology. His analysis highlights certain sectoral differences in such partnering. Technology-related motives are dominant in so-called high-tech sectors; in other sectors, characterised as mature industries or sectors that undergo a process of consolidation, a large variety of market related objectives could be linked to strategic partnering.

Moreover, a wide variety of strategic technology alliances are associated with different modes of organisational linkages. For example, complex inter-organisational modes of strategic technology partnering such as joint ventures are applied by firms if they aim at a wider set of objectives than when they primarily intend to improve innovative efforts. Such a set of objectives with both market access and technology related motivation demands a larger span of control by the enterprise than one dimensionally motivated agreement.

Table 4: An Overview of Motives for Strategic Interfirm Partnering

I Motives related to basic and applied research and some general characteristics of technological development:

- Increased complexity and intersectoral nature of new technologies, cross-fertilization of scientific disciplines and fields of technology, monitoring of evolution of technologies, technological synergies, access to scientific knowledge or to complementary technology
- Establishing agreed upon technological trajectories and thereby reducing and minimizing and sharing of uncertainty in R&D. Also reducing irreversible commitments
- Reduction and sharing of costs of R&D
- Setting standards, norms, rules, and system and interface specifications (Sony Betamax, and 8 mm Commander). One may not be able to set standards alone. Cooperation may reduce such technological uncertainty

II Motives related to concrete innovation processes:

- Capturing of partner's tacit knowledge of technology, technology transfer, technological leapfrogging
- Shortening of product life cycle, reducing the period between invention and market introduction
- Scale Economies in R&D. Search and evaluation procedure for a more varied possible combinations of products and processes. Internalisation implies limited scope of search/synergies. Reducing duplicative research races.
- limitations of market related information flows relevant for innovation process

III Motives related to market access and search for opportunities:

- Monitoring of environmental changes and opportunities
- Internationalization, globalization and entry to foreign markets
- New products and markets, market entry, expansion of product range

IV Motives related to the reduction of market uncertainty:

- Super-additive advantage/positive sum game: Joint innovative profits, quasi rents as in the case of a monopoly.
- Reduce uncertainty about opportunistic behaviour by other firms
- Reduction in information costs and subsequently not excluded or faced with entry barriers (strategic). Creating "Collectively" entry barriers for non-partners. (Same is the case in setting standards).
- Stable partnerships, innovate once successfully, tendency to do it again as transactions costs collapse after the first successful innovative interaction

Source: Partly based on Hegedoorn (1993), p 273

Tacitness and Technological Uncertainty

Till recently, most analyses of technology strategy concentrated on those cases where property rights are well defined, technology is stable and products are standardised. In practice, however, most strategies (choices) involve some degree of uncertainty concerning technological outcomes and the appropriation of benefits. All technological transactions bear a number of common characteristics; system interdependence, indivisibilities, asset specificity, market and technological uncertainty and limited appropriability. Exhibit 2 charts out two of these environmental variables (uncertainty and appropriability) along with an entrepreneurial characteristic, risk and uncertainty proneness or aversion.

The lower left hand corner of the vertical plane characterising standardised product, stable technology and clear property rights has limited validity as technological transactions are uncertain in so many respects. The upper right hand corner of the vertical plane characterises the extreme case of technological and appropriation uncertainty. Typically, with the aging of technology, uncertainty will decline and codification will accompany standardisation.

It has been suggested that extreme cases of uncertainty will result in high transaction costs in the market and therefore internalisation within an organisation is a substitute. But such is not always the case: the existence of networks and co-operative ventures points to the fact that certain types of inter-organisational linkages (e.g. among component suppliers, assemblers and key costumers) are also appropriate for technological transactions, in particular to develop innovations. This is despite the fact that under uncertainty, contractual agreements are difficult to specify and monitor and post-contractual opportunism common.

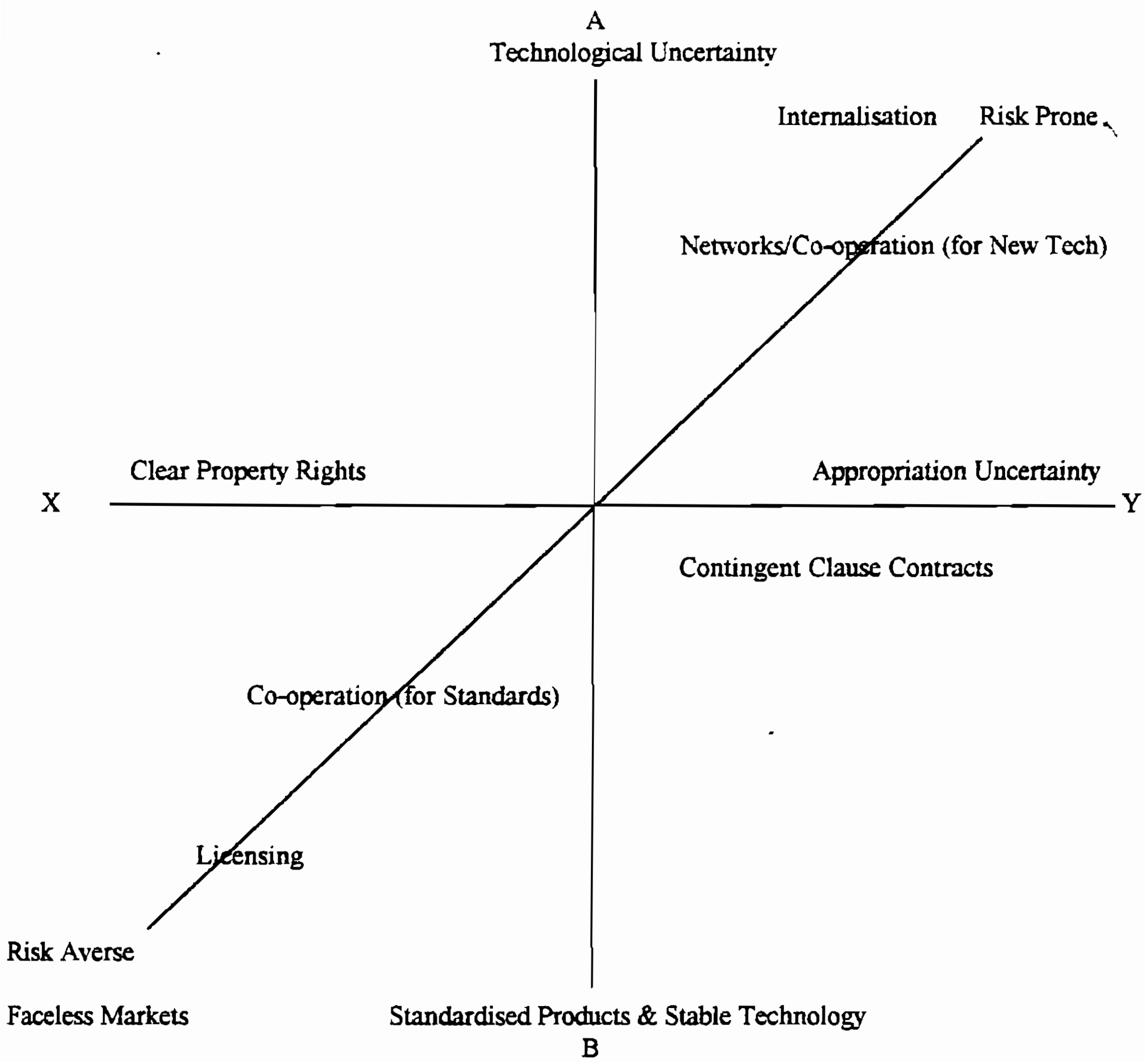
Tacitness of an innovation can also impinge on strategic actions to ensure appropriation (Exhibit 3). In the phase of new product and market creation, the left hand side of Exhibit 3 is the most likely strategy; in the phase of product standardisation, the right hand side of the exhibit becomes relevant. Both are associated with different types of linkages among firms.

CONCLUSION

It has been my endeavour in this paper to show, through a selective review of literature, that nature of technology, industry and firm characteristics have major implications for theory and action related to the content of technology strategy and for the processes through which it is developed and implemented. These elements can also form the core for defining strategic groups within an industry. More complexity can be added to the processes discussed above by explicitly factoring in the role of macro-economic and other state policies which impinge on firm level decision making. These have been deliberately not discussed here.Simple prescriptions for technology strategy need be avoided and the complexity introduced by various parameters discussed here will need to be tackled squarely. Recognition of such complex processes is a good starting point for such endeavours.

What implications does this review have for the Indian corporate sector? Of course, a lot will depend on the firm, technology and industry characteristics. Besides, the technology strategy

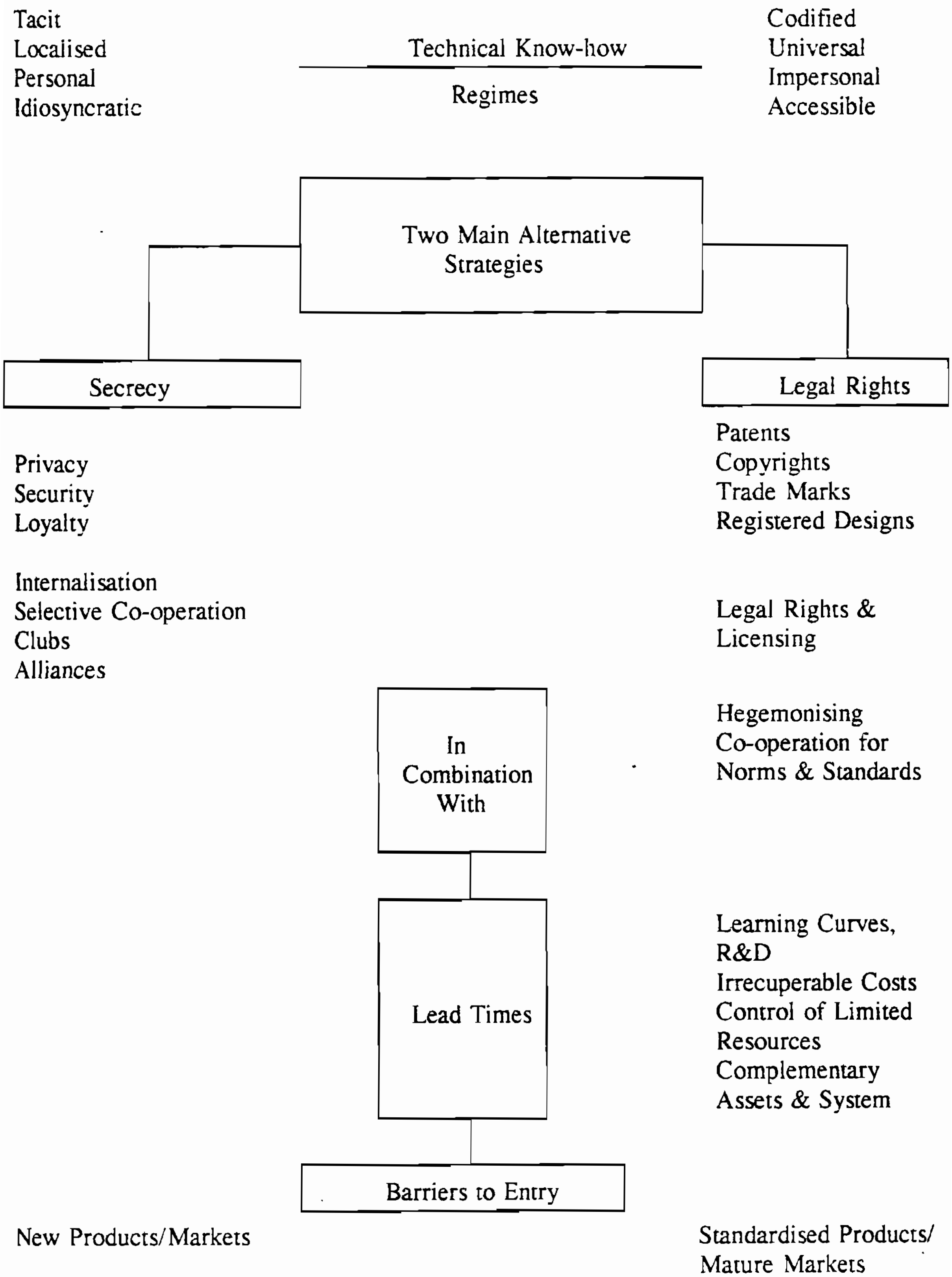
Exhibit - 2: Typology of Transactions



Note: Over the Technology Life Cycle, one would expect a movement from A to B and, in some cases, from Y to X.

Source: Adapted from DeBresson and Amesse (1991).

Exhibit - 3: A Strategic Grid for Appropriation



Source: Adapted from DeBresson, C., and Clark, P. (Undated): "Strategic Acts, Networks and Sector Transformation", mimeo, University of Quebec in Montreal, Canada.

will have to be explicitly linked to the corporate strategy of a firm and the strategies of its competitors. However, a few things seem obvious. By and large, the Indian firms are *followers*, trying to *catch-up* with the firms in more advanced countries. In the medium run, for most firms, a strategy of quick assimilation and improvement is likely to be more rewarding than a strategy of technology generation. Foreign technology flows are useful. However, *indigenous R&D to assimilate foreign technology and exploit technology spillovers along with access to complementary assets (especially competing manufacturing and marketing) to appropriate benefits* appear to be urgent and necessary for a successful implementation of such a strategy.

End Notes

1. This section draws from Davies et. al., 1991; Evenson and Westphal, 1994; Pavitt, 1990; and Teece, 1996.

2. This section is mainly based on Davies et al (1991).

3. The discussion in this section is based on Dosi, 1988; Pavitt, 1984 and Pavitt, Robson and Townsend, 1989.

4. The discussion in this section draws heavily from Teece (1996).

5. This section is largely based on Teece (1986).

6. This section draws from Debresson and Amesse (1991) and DeBresson and Clark (Undated).

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