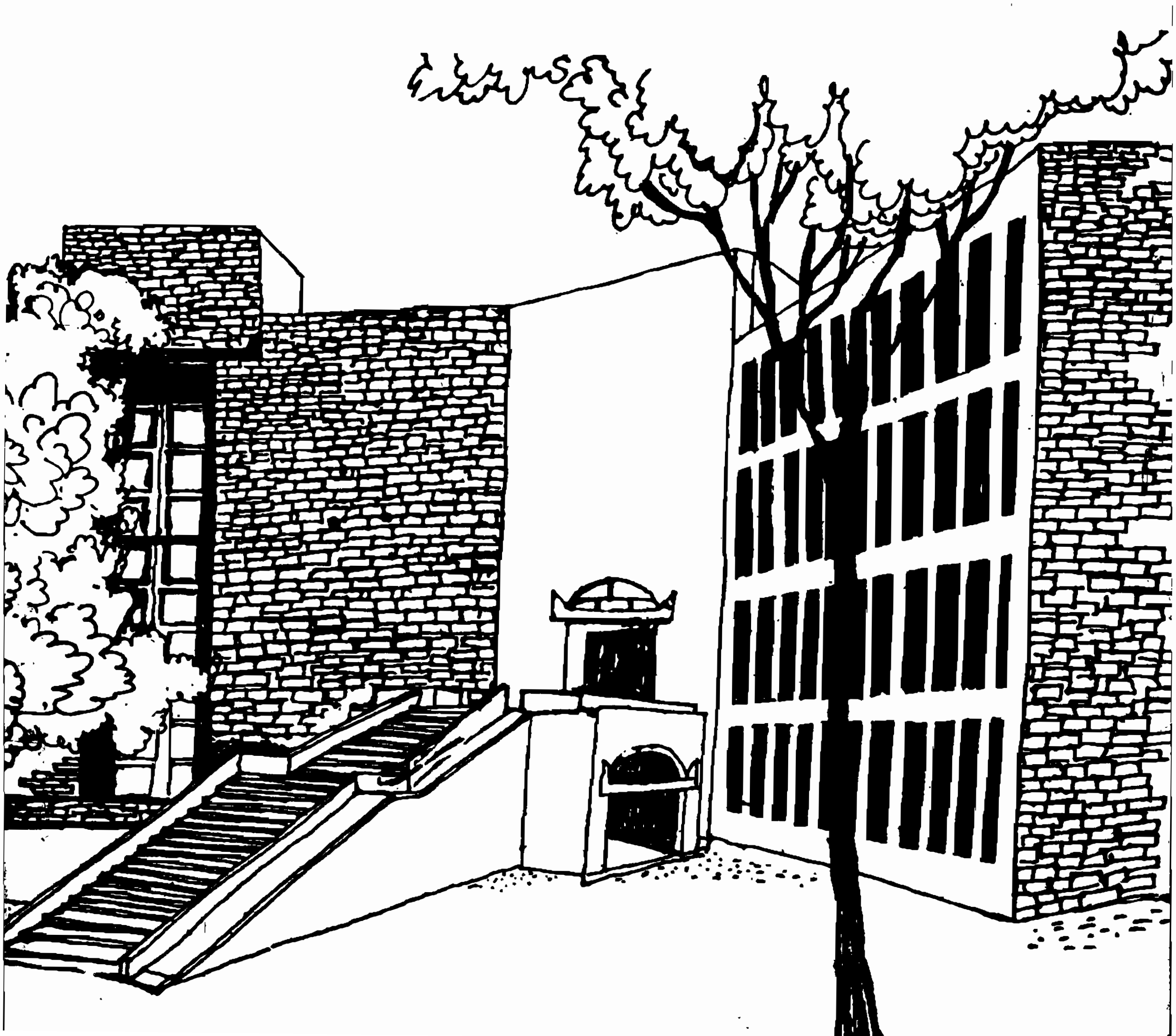
Working Paper



TECHNOLOGY STRATEGY OF INDIAN FIRMS: SEARCHING FOR THE ROLE OF COMPLEMENTARY ASSETS AND TECHNOLOGY SUPPLY CHAINS

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Working Paper No. 98-12-01
November 1998

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Abstract

As a consequence of economic reforms, the Indian manufacturing sector faces a variety of technology related challenges. It not only has to quickly develop world-class manufacturing capabilities but also gear up to develop new products and processes. In this paper we analyse the technology strategies of six Indian firms in different product groups which are trying to build competitive manufacturing & technology capabilities. The linkages between corporate, technology, and manufacturing strategies are explored and the role of complementary assets is studied in order to identify patterns through which these firms are building capabilities of various kinds. Specifically, we evaluate the extent to which firms use supply chains to develop product & process technologies.

I. INTRODUCTION

The Indian economy is in transition. Protection and controls are being replaced by a competitive and deregulated open economic system. Unlike in the earlier regime, continuous foreign technology import through FDI, technology licensing and imports is feasible as the restrictions on such flows have been considerably reduced. At the same time, indigenisation requirements through import substitution etc. are also not very significant anymore. Available evidence suggests that FDI and embodied technology import has increased considerably in recent years. Arms length technology licensing (technology purchase expenditures as a proportion of sales) has also increased along with other foreign technology flows while the R&D expenditures (as a proportion of sales) have either fallen or not increased as much as technology purchase expenditures. It has been argued that with more liberalisation and better intellectual property rights regime, better quality technology will flow into the Indian economy and improve firm level productivities. The critical issue is whether such technology imports are adequate for Indian firms to effectively compete in the global markets? Available studies have suggested that firms need to make a variety of R&D and other investments in capability building to benefit from such technology flows (Basant, 1993, Kokko, 1992). Therefore, it is important to know about the second round effects of such technology imports. How do such imports affect firm level investments to absorb and assimilate these technology flows and the associated technology spillovers? What technology strategies Indian firms have adopted to benefit from these technology flows? This paper attempts to explore these questions with the help of case studies of six Indian firms.

The focus on technology strategy of Indian firms is important for another reason. Technological innovation has been the driving force behind industrial growth around the world. In the Post GATT-94 scenario technology is seen as the main source of competitive advantage. Innovating firms recognize the need to develop (and "own") strong complementary assets (e.g., effective manufacturing bases) inorder to appropriate maximum returns on their innovations. These technologically active firms are increasingly finding it difficult to transact in the "market for know how" alone. Such firms, consequently, will want to "own" manufacturing bases. At the margin, innovators in developed countries may not want to forge technology based alliances with developing country firms having strong manufacturing capabilities due to the fear of creating competitors. Such domestic firms may either get incorporated as "complementary assets" of external innovating firms or may have to innovate themselves inorder to independently compete domestically and overseas. As Indian firms “catch-up” and become competitive, more and more of them may be seen as potential competitors and consequently either get excluded from the technology flows (which now seem abundant) or lose their independence. Technology related transactions on equal terms would require building up of significant technological capabilities among Indian firms. Therefore, technology strategies of firms will need to be evaluated from this perspective as well.

This paper is organized as follows: to put our case-studies in a wider context the next two sections develop a heuristic framework for analysing technology strategies at the firm level. The next section identifies various elements of technology strategies and section 3 discusses the technology, firm and industry characteristics which influence the formulation of these strategies. This section also highlights the role of technology supply chain and complementary assets in the formulation and implementation of technology strategy. The details of technology strategies of six Indian firms are discussed in section 4. Section 5 reviews these cases to highlight some common features of technology strategies followed by these firms and the role played by technology supply chain and complementary assets in developing technological capabilities. The final section concludes with some hypotheses that emerge from the six case studies.

II. ELEMENTS OF TECHNOLOGY STRATEGY

Technology can be characterized by the knowledge which is embodied in products, processes, and practices[1]. These three entities together define technology. Both tacit and procedural knowledge is present in each of the above. Products comprise the knowledge of how things' work, their design, and their interface with other products. Processes comprise knowledge on the laws of transformation, on how a product can be produced or changed, and on the relationship between different components that comprise the process. And practices consist of the grammar or the language necessary to manage the product-process combine and the knowledge re-generation process. Firms have impacted on one or more of these entities to bring about technological change. Nations have also systematically affected them to change the innovative and consequently the industrial activities in the different sectors that comprise the economies. This conceptualization takes a "whole business" perspective. The role of managing technology boils down to: effectively employing combinations of the suitable types & different levels of each of these and in designing systems which will assist in the regeneration & development of the underlying knowledge. For example, in the software industry, products could be defined by the applications developed by the system designers & the programmers; process would comprise computers, programming softwares (or the tools), telecommunications, storage devices, the system designers and the programmers; while practices would consist of the grammar behind the programming & product development languages (e.g., parsing rules), rules for organizing codes, debugging & test procedures, implementation related information, service considerations etc. Now, let us consider the banking sector -- another element in a supply chain that employs the output of the software industry. In a similar way, the technology of this sector can also be characterized. For the banking sector, products could be the different instruments of lending & borrowing, different investment schemes, services provided to customers etc.; processes could be the asset management software developed for the investment banking division, various banking norms, banking personnel, forecasting procedures etc.; and practices would be the rules of operations, scheduling, staffing & allocating tellers, designing quality in services, researching new investment options to support new product development etc..

Two issues emerge from this framework: first, the three entities defining technology, i.e., product, process and practice are inter-linked through transfer of tacit or codified knowledge. As a result, optimum technological change can be brought about when changes in each are synchronized and sequenced. This is not to say that improvements cannot be brought about by changing one of the entities, though the effect will be limited. Second, technological change should be viewed in terms of its delivery across the entire supply chain for a given sector. The emergence of Japanese industrial practices and the new innovation paradigm point towards the usefulness of this type of coordinated thinking which requires a long term perspective.

The above conceptualization is useful in several ways: (a) it will allow the designers of industrial and technology policy to identify appropriately and address a specific technology component which would enhance the effectiveness of the policy; (b) it will enable firms to design effective

[1] This conceptualization of technology is drwan from Chandra (1995).

technology strategies over a period of time; (c) it will help firms to focus on issues that will be required to develop technological capability; and (d) it will assist firms to manage the micro and strategic changes that will enhance the economic welfare of the society in the long run. It is necessary to discuss here, albeit briefly, the instruments and the process of technological change. An underlying assumption is that firms react to the macro-economic environment in order to maximize their profits. So the key questions before us are: how should firms bring about technological change and how should an economic policy elicit such a change-based response from individual firms. It is well appreciated that to bring about technological change we have to adopt, adapt and diffuse (and modify) knowledge. Since knowledge is embedded in technology, i.e., in products, processes, and practices, we can do the same by affecting either or all of these entities resulting in differing extents of change. What should also be understood clearly is, where that change has to be brought about and how to go about doing it (i.e., the decision making aspects of problem resolution or project management)? This is where this characterization of technology comes in most handy. Depending on the different constraints (e.g., risk bearing ability, economic environment etc.) a firm can first establish links between the various entities of technology and then define issues and decision-making domains. Interestingly enough, this exercise will lead to a dynamic re-examining of the policy parameters that define the environment. In other words, policy should become an enabling factor. It should be also appreciated that enabling factors change with time and economic growth. And since market requirements have been changing quite rapidly, a policy should aim at the development of technological capabilities. Once again, our conceptualization of technology will be useful in such an endeavour.

Conventionally, 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. The development economics literature has emphasized the role of *technological capabilities* in acquiring and sustaining firm level competitive advantage (Evenson and Westphal, 1994). 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 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, processes and practices ?

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? Should it be a part of or develop innovation networks?

Level of Competence and Capability Building: 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? What should firms do to build internal technological capabilities? Will conformance to certain standards help in this endeavour? What role exports play in this process ?

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? What response is appropriate to a competitive-product introduction?

R&D Investment, Organization and Policies: How much should the firm invest in these technologies? What level of internal staffing or external expenditure is appropriate? 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? 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.

III. ROLE OF TECHNOLOGY, INDUSTRY AND FIRM CHARACTERISTICS[2]

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.

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 summarize some of these features.

Nature of Technology and Innovative Activities

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.

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[2] This section draws heavily from Basant (1997).

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 and where circumstantial specificity is high. 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 and Cumulative Nature of 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). 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.

Technology Supply Chain: Technological interrelatedness plays a crucial role in technological development. Linkages with upstream and downstream technologies (users) may hinder or induce technological change in a segment (see below). Such a network of "linked" innovators or the 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 organization; product, processes and practices linked to a technology need to be embodied in the organization for good results.

Traditionally, technology development has been analyzed within the boundaries of a firm. The role of input-output linkages the firm has with other entities is usually ignored. Suppliers of products and processes are, at best, seen as "borrowed blue-print makers" who would fabricate only on the basis of given designs. The problem with this approach is that innovation is viewed as a compartmentalized and discrete activity. However, empirical evidence suggests that successful development of technology, either in the form of products, processes or practices, has often involved interaction of firms across industrial sectors. Technology development in these supply chains takes advantage of the synergies of technological capabilities in their respective sectors. For example, improvements in weaving processes in a textile mill may call for a close interaction with a textile machinery firm which in turn may have to depend on the assistance of firms in machine tool and micro-electronics sectors. Technology supply chains form natural clusters for continuous improvement of products processes and practices.

In economic terms, these technology supply chains can be seen to form the core incentive structures for technological activity. It is the joint interest of the suppliers and users of technology which induces continuous innovation.

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 specialized groups like R&D, marketing, production, organization 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 internalized 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 determine the potential for imitation in that sector.

Benefiting from Technology Development : Role of Complementary Assets

In the initial phases of new technology commercialization, 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 (standardized) 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 commercialized, process innovation often follows product innovation. With the slowing of the rate of product innovation, designs tend to become more standardized, providing the opportunity for large scale production and the deployment of specialized 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) characterization 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. Besides, both product and process innovations may require *simultaneous* attention for reaping full benefits of product innovations as an exclusive focus on product innovations may delay commercialization due to delays in ramp-ups etc. (Pisano and Wheelwright, 1995)

In almost all cases, the successful commercialization of an innovation requires that the know-how embodied in the innovation be utilized in conjunction with such complementary assets as competitive manufacturing, marketing and after sales support. Complementary assets can be generic, specialized or co-specialised. Generic assets are general purpose assets that do not need to be tailored to the innovation. Specialized 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 specialized is important for strategic decisions regarding integration and collaboration.

It has been suggested that when managers make R&D and commercialization decisions, they must identify, preferably ahead of time, the complementary assets that the innovation will need for successful commercialization. Contractual or collaboration alternatives will make strategic sense if the complementary assets are not specialized, 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. (Teece, 1986)

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 associated cost, quality, delivery and flexibility advantages.

Just like successful commercialization 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. As the technology moves from early design to the stable stage, manufacturing ought to move through job shop, batch and continuous process modes. Depending on product variants and volumes, the focus of the manufacturing facility, capacity levels, and manufacturing infrastructure changes to meet the strategic technology needs. This, in essence, characterizes the manufacturing strategy of a firm. Sometimes, production capabilities provide strategic choices for in-house innovation for new product and process introduction.

Industry Characteristics

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: 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 internalize 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 *standardization* phases may be significantly different (Magee, 1977).

Technological Features: 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 (see Pavitt, 1984, 1990) as follows:

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.

Specialized 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.

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.

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. Product innovations from this sector enter a wide range of sectors as capital or intermediate inputs.

It should be noted that these are not watertight categories and a firm may show features of more than one category. Besides, the characterization 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).

Firm Characteristics

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 internalize 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. 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 commercialization of inventions.

Product Diversification: A multiproduct firm has 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.

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. With systemic innovation and synergies, internal organization (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 specialized investments into several parts of an industry, along the supply chain.

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. Standardization in such circumstances provides significant product development opportunities. Such linkages may evolve into strategic alliances to develop and commercialize new technologies. These arrangements can be used to provide some of the benefits of integration while avoiding some of the costs. They may also help exploit the technology supply chain linkages to firm's advantage. 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.

IV. ANALYSING TECHNOLOGY STRATEGY: CASES OF SIX INDIAN FIRMS

In the context of our frameworks discussed in the last two sections, we present findings from an ongoing research study (which commenced three years ago) to analyze the technology capabilities of some Indian firms. Of the six firms under study, four are based in Ahmedabad. The methodology adopted was case research spread over the last three years. The purpose was to understand the capability building process through visits to plants & primary data collection, interviews with managers, company documents, and secondary sources of published and un-published documents. Industry reports and databases were also consulted. The six chosen firms (Amtrex Limited, Patel Brass Works Private Limited, Standard Batteries Limited, Torrent Pharmaceuticals, Arvind Mills Limited, and Tata Engineering and Locomotive Works Limited are quite representative of the different levels of capabilities existing in Indian firms as well as the size that span the organized industrial sectors in the country. They also cover a broad range of product groups.

In the following paragraphs we describe briefly the technology strategy and related issues for each of these six firms and in the next section summarize some common elements of their capability building processes. Broadly the description covers some information on the industry & business strategy, technology strategy and learning, manufacturing strategy, exploitation of technology supply chains and prognosis of likely trajectories. Table 1 contains a summary of what we describe below in this section.

Amtrex Limited

Amtrex Limited is a part of the Lalbhai Group of Companies. It produces window & split airconditioners (AC) , industrial AC, and coolers of various sizes. Its annual turnover is about Rs

1 billion[3] . The company wants to become a leader in the tropical AC market by developing low cost ACs for new market segments. Currently, it is the fourth largest AC producer with a market share of about 7 per cent in the domestic market. During the last few years, competition in this market has intensified.

Amtrex has been a typical `blue-print manufacturer.'[4] Technology in the form of blue prints for product design as well as moulds for production came from the licensors, Hitachi of Japan. However, the reluctance of the Japanese licensor to share any tacit knowledge led to the development of in-house design capabilities by hiring experts from other firms in the industry. The design team unbundled the AC technology, using modern methods of design, and created a superior product for the domestic climatic conditions. It then sought similar foreign markets for the product. Amtrex has sought (and received) ISO and other international certifications (e.g., UL-484) to improve its ability to achieve conformance to international product quality levels. It has also been using the export route (mostly supplying to other brands) to learn about global markets and practices. The company has managed through its in-house efforts to unbundle the technology embodied in an AC. Though this process they were able to identify capabilities which needed to be developed in-house and those for which it needed external help. Based on this assessment, it has developed an innovation network comprising several vendors, including a few abroad, one of the best design institutes in the country and a machine tool institute. The activities of the design centre revolve around design of AC and testing and is limited to mostly physical parameters of the product.

Manufacturing strategy at Amtrex has followed the technology strategy with a time lag. Production takes place at two locations -- the first one assembling the AC except for installation of the compressor which is done at the second plant. This strategy is used to reduce some local taxes by operating at the second location. It, however, increases the coordination cost to the firm. The production capacity at Amtrex is small compared to the leading competitor in the domestic market. While it outsources some of its operations to vendors in the vicinity of the plant, it sources a large number of components from various vendors globally. The firm has upgraded its manufacturing facilities in recent years. Fabrication, shaping of cooling coils (which are batch processes) and assembly of AC are done in-house. Last couple of years have seen implementation of a variety of shopfloor practices likes 100% inspection of despatches, streamlining of layouts, implementation of Kaizen suggestion scheme, Kanban based pull production between assembly and other feeder sections etc. While lot of shopfloor interventions have been tried to improve the cycle times, most worker related practices and accounting systems remain as before. Moreover, training investments have been moderate.

The firm can be categorized at scale intensive operations with limited science base in the form of recent role of electronics and microprocessor controls in AC. Both the product and the process technologies will not change drastically in the foreseeable future. Amtrex was a classical "blue

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3 US $ 1 = Rs 42 (approximately, 1998)

4 Technological response has been categorized as passive assembly, blue-print manufacturing, advanced blue-print manufacturing, and imitation & development. Passive assemblers procure all components and assembles according to blue-prints provided with no technology development focus. The blue-print manufacturers acquires designs through arms-length arrangement and uase their production capabilities to manufacture the product.The advanced blue-print manufacturers enter into alliances with technology supplying firms and use the latter's know-how to implement the design. The imitators & developers develop their own variant of existing or new designs based on their internal R&D capabilities (Basant and Chandra, 1996).

print manufacturer" that produced to the codified specs provided by the licensor. Interestingly, Amtrex started to face competitive pressures from MNCs operating in the domestic market who were introducing a large number of new products. Amtrex's nascent development facilities were unable to match with this rapid rate of new product introduction. It went back to its licensor (who had also lately become keen to enter India and had become more confident of Amtrex's manufacturing capabilities), entered into a JV arrangement with them, and have recently introduced a large range of their collaborator's products in domestic market based on Japanese design technology and blue prints. Essentially, Amtrex has moved back to becoming a `passive assembler'.

In the earlier phase, when the company had an arms-length licensing agreement with Hitachi and the quality of technology flows was inadequate, it was strategically required to develop tacit design & engineering skills which would have helped align original objectives with new found manufacturing strengths especially for new domestic applications. However, in the new context when Amtrex has a JV with Hitachi (with talks of the MNC acquiring the domestic partner), these strategic choices are difficult to define. In principle, many of the capabilities of the Japanese partner can be exploited. Whether this will happen will depend upon Hitachi's long term perspective vis-a-vis this JV.

Standard Batteries Limited (SBL)[5]

Standard Batteries is part of Williamson Magor Group of Companies. It produces automotive and industrial batteries and has a turnover of Rs 1.07 billion. SBL's business strategy is to find new markets for its old products and also try to fulfil the requirements of the new auto-entrants in the domestic market. It is among the two largest automotive battery producers in the country with a market share of about 25 per cent. However, the competitive pressures have increased and almost all organized sector players have alliances with foreign firms.

Standard Batteries' technology development process had been similar to Amtrex though it has a longer history of technology adaptation and assimilation. The licensor of technology at SBL was also a Japanese firm, Furukawa - a leading battery producer in Japan and the supplier of Suzuki in that market. Unlike Hitachi, Furukawa, lent its name to the product (i.e., the auto batteries were branded as `Standard Furukawa') and offered a range of battery constructions and wattage to SBL. The batteries were adapted to Indian environments by SBL. Furukawa also ensured that they were adequately tested in their own labs in Japan before introduction in India. They provided support on technical processes whenever SBL desired. Furukawa also helped SBL to obtain the OEM supply contract for MUL (an affiliate of Suzuki in India and the most successful passenger car company in India todate). SBL secured both ISO9000 & QS9000 certifications (and became the first battery firm in Asia to get the latter) in order to secure sole supplier status for new OEMs entering the Indian market. The firm also started to produce a variety of battery standards likes JIS, DIN etc. Other than Furukawa, SBL did not have any technology links with firms or institutions outside. Its relationship with its fourteen suppliers was largely arms-length though lately it had developed a new carton printing process with one of its suppliers. SBL has a separate R&D facility but both investments and scope are limited. Most work pertains to reverse engineering, developing appropriate battery constructions (i.e. no. of chambers etc.), and making improvements in performance. Testing is another key task.

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[5] This description is based on Basant and Chandra (1998b).

SBL's manufacturing strategy has followed its corporate strategy to increase its market share in automotive batteries. Following partnership with Furukawa, SBL closed its old plant in the heart of Mumbai to a new location at Taloja -- about 50 kms. from the city in an industrial estate. This greenfield location allowed it to develop a new design for the plant, new unidirectional layouts for effective production and material handling, younger workforce which was trained in new processes and manufacturing techniques and new managerial practices. The factory focus, based on product groups, permitted higher utilization levels with medium volumes. Outsourcing is limited and quality is based mostly on inspection and acceptance sampling. However, efforts are on to put a quality improvement programme in place. The process is a hybrid batch/assembly process. The lead time and WIP levels, by industry standards, are still high. Training is mostly manufacturing oriented, on the job designed whenever new equipment purchased or at the time of entry in the firm.

SBL's production process is scale intensive and neither the product nor process technology has changed radically in the last few decades. It can be classified as an "approved blue print" manufacturer which is developing modification skills and is trying to match them with low cost, good quality production facilities. It aims to develop competitive manufacturing capabilities by continuously improving lead times and reducing WIP on the shopfloor. Technology, however, is expected to flow from its Japanese collaborator.

Patel Brass Works Private Limited (PBW)[6]

Patel Brass Works is a relatively small stand alone company with a turnover of Rs 150 million. It produces large variety of customized bimetal and trimetal bearings and bushes. It sells branded products in the replacement market. The company plans to diversify into the automotive segment and to other new applications (that are new to PBW). Though, it is a minor player in the market, its competitors have started sources certain types of bearings & bushes from it.

A salient feature of PBW's technology strategy has been its emphasis on product development through process adaptation and innovation. As a consequence, process technology and equipments have been a key characteristic of their strategy as well as their insistence on development through indigenous capability building. While import substitution policies have facilitated such capability building, PBW's learning culture has helped them more than others in exploiting these policy induced opportunities. Imitation was seen as an important vehicle of innovation. For instance, the firm has become a reliable global supplier of replacement bearings for compressors used in engine rooms of ships by simply imitating models from compressors retrieved during ship breaking, creating a CAD design and then manufacturing it to specifications quickly. In the initial stages, the firm developed all processes in-house and then built special purpose machines as well to manufacture the products. Lately, they have sourced some equipment from global machine suppliers. PBW has effectively interfaced with consultants to develop process development capabilities in-house. Exports have also helped them acquire information on materials and product characteristics through their customers. Interestingly, one of their customers is the largest bearing machinery manufacturer in Europe. Such a linkage along with ISO certification has helped them develop international quality perspectives. PBW's presence in critical bearings segment has lent credibility to its other products. Recently it has set

6 This description is based on Basant and Chandra (1998a).

up a new plant to produce sintered strips for automotive applications. Most of the critical equipments were developed in-house at a considerable savings on cost.

PBW is located in Rajkot (in Western India) which is a strong `cluster' of diesel engine manufacturing and engineering products industry (most of them in the small scale sector). It has very effectively leveraged the skills of subcontractors or specialised job shops in the cluster to develop specific competencies in bearing manufacturing and to reduce costs of manufacturing. It has helped many of these suppliers to set up facilities and develop their respective innovations. While R&D investment is not high (around 1 per cent of sales), the facility is geared towards state-of-art testing, CAD systems and making minor improvements in metallurgical properties of alloys. PBW has a separate facility to fabricate, for in-house use, special purpose machines & most of its toolings. Formal training, traditionally, has not been provided: most of it is acquired via learning by doing and mentoring by supervisors. Advanced engineering skills are scarce at PBW.

Manufacturing has been an integral part of PBW's long term strategy for growth and has been directly linked to process innovation approach. It has multiple plants operating in batch/job-shop mode. Layout is cellular and plants are segregated by product groups. The most recent plant is a focused factory which has a dedicated line for sintered products. Volumes in the new plant is large as compared to the old plants. Low precision jobs are outsourced to local subcontractors with whom the firm has long term relations. Housekeeping at PBW is excellent -- almost close to being a religion (Note: This philosophy could be an extension of most homes in Gujarat -- location for PBW -- which are kept exceptionally neat and clean). Most new practices have been internalized and followed intuitively while many others have been implemented by executives after reading books on related issues. Quality systems are weak and use of analytical problem solving tools is minimal. Data collection, however, is an important activity though it is not being used as much. Not much attention has been paid to formal training and acquiring advanced engineering skills though its need is being felt.

PBW falls under the specialized supplier category which competes through niche product markets. Certain metallurgical skills have to be matched with process innovation to address new user needs. While the core process technology is stable (e.g. centrifugal casting), products keep changing based on user requirements. The firm has graduated from "blue-print manufacturer" to being an `advanced blue-print" producer. Strategic technological challenges include developing tacit design and engineering skills to exploit more sophisticated product opportunities.

Torrent Pharmaceuticals[7]

Torrent Pharmaceutical is part of the Torrent Group. Its turnover is around Rs 4 billion and it produces a range of pharmaceuticals (within chosen therapeutic classes) and cosmetics. It is among the top ten pharma companies in the country (including the MNCs). Its business strategy has been to be the first firm to introduce drugs (mainly off-patent) in the domestics market. They are now trying to develop new products at their R&D centre but this activity is at a nascent stage.

[7] *Information* here also draws upon the Integrated Torrent Case Exercise (Dixit et al., 1998).

Torrent's predominant technology strategy in the past had been to purchase molecules for generic drugs from global markets (chiefly Europe) and become the first firm to commercialize it in India. Its strengths lay in synthesizing the molecule through alternative processes that were cheaper. The patent regime in India permitted only process patents in the pharmaceutical industry. This has facilitated development of very strong organic and analytical chemistry skills in the Indian pharma industry. Of late, Torrent has been seeking product patents for new molecules based on their indigenous research. While the pharmaceutical business is chiefly fuelled by internal developments, they hope to do joint R&D with one of their JV partners. Another feature of their technology strategy was to scan technological innovations globally, interpret patent related information and perform clinical trials quickly.

Exports have also played an important role in learning to develop quality and safety conformance systems which have helped them in the domestic markets. Torrent's production facilities already conform to various international standards like WHO, MCA (UK) etc. and is in the process of obtaining USFDA approval. While most research is proprietary in nature and done in-house, several national and international laboratories have been involved with Torrent R&D. Recently, significant investments (about Rs. 750 million) have been made to set up a new state-of-art research centre. Various well-known physicians and academicians world-wide have been involved in setting up this research facility. This stand alone centre is amongst the best in the country in terms of resources & infrastructure. The firm has recently entered into a JV with Sanofi of France for development, manufacturing and marketing of pharmaceutical products.

Manufacturing at Torrent, always played second fiddle to marketing and development. Its role has not been strategic but to set up adequate capacity to deliver what marketing desired. Manufacturing which is mostly batch process (with continuous process at the bulk drug facility and assembly at the formulation packaging stage) is currently located in a single facility with some third party producers for specialized products. Different lines exist for different delivery mechanisms (like tablets, injectibles & capsules). As a conscious strategy, Torrent has built excess capacity to cater to volume increase and new product introductions. As part of international quality guidelines (e.g. USFDA), Torrent has started to strictly monitor manufacturing & material handling and storage practices at supplier's locations and is getting involved in helping them improve the same. While adequate attention is paid to good manufacturing practices from safety & hygiene perspectives, shopfloor interventions to improve productivity have not been adequate. Training is missing on many of these aspects especially those related to productivity improvement. Productivity gains are seen to chiefly come from better and faster machines.

Torrent is a combination of science based and scale intensive technological operation where product life cycles are relatively short and time intervals between process changes are long. So far, the firm has grown based on limited development activity but with impending changes in the IPR regimes, it has shifted its scale of R&D activity to a higher gear. The supply chain focus would now include rapid integration of developments in the laboratory with development of flexible manufacturing (especially at the bulk drug level) operations.

Arvind Mills Limited

Arvind Mills is a part of the Lalbhai Group of Companies. Its turnover is Rs 10 billion and it produces textiles (chiefly denim) and garments. It is one of the top five denim producers in the world in terms of sales. Recently, it has developed its own brands for garments and has also entered into alliances with various global brands. Apart from forward integration into apparel production, the firm's business strategy has been to produce at low costs inorder to enter new markets globally.

Arvind's strategy like many others has been to embody knowledge in process technology through state-of-art machinery. While some proprietary knowledge has been generated in-house for improving yarn and fabric strength, finishes etc., improvements in quality have been obtained mainly through new & precision equipment that has been purchased from global suppliers. Nevertheless, there has been one instance of a very significant process innovation which has been responsible, to some degree, for the success of Arvind in global markets. Its process R&D people designed modifications to airjet looms which would allow it to weave thick fabric like denim (until then such looms would weave fine fabric). Through its trading partner, C. Itochu of Japan, it got Tsudakoma of Japan to install the modifications on the looms and manufacture them exclusively for Arvind for a limited duration. This increased the productivity of the firm tremendously as compared to its competitors in the global markets. So, in essence, the capability building process has been a mix of both internal activities and external support. Though there have been several innovations coming from the internal R&D, none has been as dramatic as the one mentioned above. Almost all of Arvind's facilities are ISO certified. Its export units have the same labour to capital ratio (in terms of capacity) as any plant in North America or Europe. It has often worked with local textile research institutions and chemical laboratories in the country to improve on existing processes or on new products (e.g. jute based products). R&D facility is a separate entity and the current Group Chief Executive Officer is an erstwhile scientist at the R&D Centre. R&D investment has been significant but mostly in testing and process improvements (e.g. better finish, fire resistant, etc.) There have been efforts to even improve cotton yield in farms owned by Arvind.

There has been a strong linkage between Corporate, technology and manufacturing strategies at Arvind. The key manufacturing strategy is to develop focused factories at different levels of the value chain. Their recent entry into garments & retailing makes them a highly vertically integrated group. Most production processes are batch oriented though blow room, sliver preparation, dyeing and finishing are continuous processes. Training inputs have been moderate, at best. Quality is delivered though better technology and not necessarily through better quality systems or through the process capability route. Arvind has a classic scale intensive & supplier dominated technology with most of new improvements in processes being procured from machinery suppliers. Product obsolescence is medium to high and process obsolescence is relatively low and process adaptations have been used to deliver new product features. Its entry into value added garmenting business for exports makes supply chain co-ordination extremely critical. However, what distinctive competence it has built other than low cost, is not quite clear.

Tata Engineering and Locomotive Works Limited (Telco)

Telco is one of the largest public limited company in the country. It is part of the Tata Group of Companies with a turnover of Rs 100 billion. It produces a wide range of automobiles (e.g., trucks, buses, pick-up, troop carriers, passenger vehicles etc.) and construction equipments. Its key business strategy has been to produce new products for different segments and to enter new markets. Its market share in the highly competitive light commercial vehicles segment is around 74 per cent (and 70 per cent in the heavy commercial vehicles segment). It is about launch a new passenger car in the small car segment where it currently has a market share of 2.5 per cent.

Telco could be categorized as an engineering driven company. Its technological developments draw heavily upon knowledge embodied in product, process and practice technologies. Telco's technology strategy has been to develop indigenous products through internal R&D with the help of best equipment producers globally. Telco entered into licensing arrangements with many equipment producers and JVs with others. It insists that foreign equipment suppliers provide design drawings along with their machines and that they permit Telco's production engineers to visit the plants (Lall, 1987). In each of these cases, Telco has been able to modify the equipment to its need and develop variants for its own usage. India's policy regime of pre '91 period had prevented Telco from exploiting its excellent equipment design & fabrication capabilities by not giving it the appropriate licenses. Telco, unlike other firms, has followed a trajectory of high degree of 'self reliance', internal adaptation & modifications to suit future technology needs. This was also partly induced by the policy regime which made imports of foreign technology (embodied as well as dis-embodied) difficult.

Telco's approach has been to learn from collaborators (who have always been the best in the class). Recently, for the design of the body of its new small passenger car, Indica, it has sought assistance of IDAE of Italy. It purchased a second hand plant of NISSAN from Australia, got their engine designed in Austria (Chaudhuri, 1998) and did all engineering and manufacturing activities (including most of the dies and other toolings) in their own plant in Pune. Telco has entered into a JV with a Japanese firm to produce spot and arc welding robots for auto assembly. It has 12 JVs and technical collaborations with some of the leading engineering companies of the world. Thus, Telco has emerged as a technologically strong and strategically networked firm in the region. Other than procuring ISO certifications of quality processes for their plants, Telco has been learning through exports (which started as early as 1960s) and JVs abroad. It exports its products (especially trucks) to a range of countries though the designs (which were earlier considered robust in several markets) have taken a beating at the hands of Japanese producers. In Indian, however, these same firms have not been able to compete with low cost (although outdated designs) of Telco's truck. In the light commercial vehicle segments, its new designs have been quite successful as compared to Japanese models. It also has JV's in Malaysia and Bangladesh to assemble Telco trucks for local markets. In 1972, at the insistence of the Prime Minister of Singapore, Telco set up a state-of-art engineering training centre in Singapore which is one of the best centres in Asia. It also established a manufacturing facility in Singapore to produce miniature tools for the electronics industry -- most of the output from this plant is exported globally (Chaudhuri, 1998). These two locations have also provided Telco engineers & technicians in India a window to the world of global technology and learning. However, the license regime in India had prevented Telco from establishing such facilities for Indian firms!!

R&D investments at Telco have been around 2.5% of sales. There exists a stand alone Engineering Research Centre (set up in 1967) employing about some 1200 engineers and scientists. It is a modern facility comprising styling studios, CAD/CAM centre, sophisticated testing facilities etc. which allow Telco to design, develop and proto-type vehicles conforming to international standards (Bowonder and Yugandhar, 1997).

Telco's technology strategy is a example of capability building via the follow process: indigenization & development of in-house capabilities (rapid indigenization, vertical integration and technology driven solutions); choice of critical areas for capability building, e.g., in engines and gear box; strategic alliances (often time bound) to achieve the above capabilities; development of internal complementary assets (e.g. Engineering Research Centre, Machine Tool Division, Foundry etc.) that could facilitate learning for above; standardization of components and product platforms and use of computer networks to disseminate the same; and extensive training of its employees (at all levels).

Manufacturing strategy has always been co-terminus with technology strategy at Telco, recent efforts have focused on competing through excellence in manufacturing. Telco has a strong potential to emerge as a low cost, high quality producer of well engineered vehicles. Currently, it produces at three different locations with large volumes. Each of these factories is focused. Telco used to procure components from a very large number of vendors and most value addition took place within its own plants. As an important step towards tierization of its component base, Telco has set up a new company that is partnering alliances between MNCs and Indian auto component firm. It promises to change the subcontracting practices and quality of components produced in the Indian auto component sector. Telco's Machine Tool Division produces special purpose machines; automated transfer lines, CNC etc. for its use and for sale to other users. Similarly, its Foundry Division is completely automated and produces high precision castings (Iron & Aluminium) for use at its plants. Various other initiatives (like SMED, SPC etc.) have also been put in place to enhance shopfloor productivity. Similarly, it is in the process of developing strong third party logistics ties for effective procurement of sub-components and distribution of its vehicles. Training, at Telco has been an integral part of conscious technology strategy. It provides two types of apprenticeship program (ranging from one to four years depending on past diploma) in order to prepare technicians for its plants and other firms in the country. In addition, it has a two year Graduate Trainee Engineers program for fresh engineers who have been hired by Telco. The two pillars of this capability building process have been the Design-Engineering Interface and Manufacturing Process Management.

As a scale intensive & specialized supplier category firm, Telco has developed a reputation of being a technology driven and sound engineering firm. It has slowly been trying to develop manufacturing nimbleness and design saviness. It is due to introduce its first small passenger car, Indica (though it has developed larger multi-utility passenger vehicles earlier) thereby bringing it into a different league of technology development and new product introduction based competition. Its ability to design & introduce new products rapidly for mass markets will depend on how it is able to leverage its own capabilities and those of its new network partners.

V TECHNOLOGY STRATEGIES OF INDIAN FIRMS: SOME COMMON THEMES

The six companies under study represent a diverse industrial environment in terms of size, industry groups, technology strategies and accumulated learning. Manufacturing as the key complementary asset has played different roles in different firms. Table 2 shows four levels of manufacturing capabilities and the strategic role that it plays in any organization. The first stage represents a passive role of manufacturing in the competitiveness of a firm while the last stage characterizes those firms where manufacturing is the basis of competitive advantage. Obviously, these are not water tight compartments and the categories only represent a broad classification.

While placing firms in specific categories is difficult, a broad trend can be discerned. Telco is classical Stage 3 firm which expects manufacturing to support and strengthen the firm's competitive position. It has a well defined manufacturing strategy but still remains a follower in terms of new manufacturing practices globally. This may also be partly a result of "inward looking" corporate strategies induced by industrial policies of import substitution, export pessimism etc. Similarly, Arvind can be categorized as a representative Stage 2 firm. Manufacturing at Arvind has been driven by industry standards. As suggested earlier, manufacturing capability building at Amtrex followed their technology strategy. However, several efforts have been made recently to enhance shop floor competitiveness. In this sense, the firm can bee seen as a Stage 2 firm seeking entry into the next stage. Torrent has been traditionally a Stage 1 firm. However, recently it has started to revamp its manufacturing facilities to comply with multiple country standards like USFDA, MCA, WHO etc. Soon it should become an active Stage 2 firm. SBL, like Torrent, has been a Stage 1 firm where manufacturing's responsibility was to meet capacity requirements for marketing. It has now setup a new facility (and closed the old one), acquired new equipment and employees with new skills thereby graduating to Stage 2. PBW is slightly difficult to categorize because of the heterogeneity of process types (e.g., job shop like structure in older plants and continuous process at the new one). However, strategically they have always emphasized process improvements at the shop floor for competitive advantage. Its reflects all the Stage 2 characteristics. In fact, amongst al the other Stage 2 firms studied here, PBW would have the strongest manufacturing culture of continuous improvement though systems are yet to take roots. It appears that most firms are in the process of acquiring industry standards in terms of machinery but have yet to change manufacturing or work related practices (often tacit in nature and not transferred along with equipment or licensing) that will enhance the effectiveness of the acquired technology. It appears that the firms have not recognized the importance of the linkages among products, process and practices in order to reap full benefit of new technologies.

As suggested earlier, inter-firm linkages can be formed on the basis of firm's input and output linkages. It is not necessary, however, that firms with such linkages will always utilize them for developing technologies. Utilizing these linkages to develop technologies, therefore, is an explicit element of a firm's technology strategy. Obviously, the levels of vertical integration will determine the extent to which these technology supply chains are internal to the firm. In the case of Telco, for example, this chain comprised product development & styling, foundries, machine tool production, robot fabrication, PLCs and other electronics manufacturing, engines & die designing and production etc. most of which are internal to the firm. Despite this, it has unbundled technologies to identify technology inputs to be sourced from outside. This was usually arms-length licensing and in some cases JVs. Arvind, on the other hand, has innovated through equipment producers (like air-jet loom producers) who are external to the firm. SBL has purchased technology in embodied and dis-embodied form and its linkages with innovators in their technology chain are extremely weak. PBW, on the other hand, has combined purchase of embodied technology with in-house product imitation and process development but linkage across the technology chain are almost missing. Amtrex is a successful example of utilizing technology supply chain for innovation on the basis of in-house technology unbundling. Such unbundling facilitated identification of areas where the firm did not have adequate capabilities and needed to access them externally. Till very recently, there were practically no instance of seeking to innovate through innovation agents external to the firm at Torrent. All innovation was located within the organization and external linkages were of arms-length variety. Lately, it has developed relations with national laboratories to perform specific R&D.

In the changing environment, the challenge for firms like Telco would be to find ways to "gracefully disintegrate" and exploit the full potential of innovation across the technology supply chain. PBW being specialized suppliers will need to build strong R&D linkages with user firms to exploit technology opportunities arising out of the technology chain. Similar links with users will also be critical for SBL to fully benefit from the manufacturing facilities have created. New technologies are creating several opportunities for networking and gradual disintegration for new drug development (Economist, 1998) Torrent will need to take account of this technology led global restructuring while formulating its future technology strategies. Arvind has already increased the scope of the firm by integrating forward into apparel manufacturing. Its links with cotton production may need a boost to ensure good quality raw material. Opportunities for innovation in designs will need to be exploited either through developing such capabilities in-house or networking with other competent firms. Amtrex's networking for technology development with outside firms along the supply chain was induced by the licensor's unwillingness to share the tacit knowledge (know-how as well as know-why) embodied in the blueprints etc. licensed by them. The licensor has now become a JV partner. The firm may need to review its earlier technology strategy as many of the capabilities being thus far acquired through networking may now be available in-house. It may, therefore, see some vertical integration in the near future.

VI CONCLUSION: SOME HYPOTHESES

What implications does this study have for the Indian corporate sector? Of course, a lot will depend on the firm, technology and industry characteristics. Besides, the technology strategy 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. Typically, this has been the route taken by successful late industrializing countries. Our analysis in the last two sections suggest the following hypotheses for the Indian environment:

Hypothesis 1: Inter-firm networks for technology development are weak in Indian firms. This has been a result of the past policy regime and lack of trust among industrial firms in India. Indian firms find it difficult to operate in an environment of "shared vulnerability and growth". "Networking economies" have typically been reaped through vertical integration by successful firms.

Hypothesis 2: Firms that have unbundled technology have been able to develop innovative networks.

Hypothesis 3: Key routes to successful capability building have been conformance to standards (e.g., ISO certification etc.), internal equipment design & fabrication and exports. However, the potential of utilizing such conformance to put robust quality systems in place has been adequately exploited.

Hypothesis 4: Firms, typically, have not paid adequate attention to training of its employees.

Hypothesis 5: Embodied and dis-embodied technology is seen as the key source of competitiveness. Firms have not yet made "manufacturing excellence" as an important competitive strategy. Those that have developed the discipline for continuous improvement have been successful.

The potential for exploiting technology supply chains to continuously develop new technologies has not been fully utilized by Indian firms. In the post liberalization environment, competition in the domestic markets have increased as have foreign technology flows. As mentioned, both embodied and dis-embodied technology flows from foreign firms have increased in recent years. All the firms in our study had acquired technology from abroad. Typically, acquisition of technology has been seen as the key element of technology to become competitive. However, *indigenous R&D to assimilate foreign technology and exploit technology spillovers along with access to complementary assets (especially competing manufacturing) to appropriate benefits* appear to be missing. Once, we explicitly recognize the three domains of technology, namely, product, process and practices, the relevance of focusing on both technology supply chains and complementary assets *simultaneously* becomes obvious. Wherever innovation related linkages of this kind need strengthening, policy initiatives to promote the interface of innovative agents, their cooperation on a common project and the reduction of related investment costs will be required.

Table 1: Some Aspects Related to Technology Strategies of Indian Firms

	Amtrex	PBW	SBL	Torrent Pharma	Arvind	Telco
Product	Airconditioners	Bimetal/trimetal bearings	Automotive & industrial batteries	Pharmaceuticals, cosmetics	Textiles, garments	Automobiles (HCV, LCV, Passenger)
Structure	Part of conglomerate	Stand alone	Part of conglomerate	Part of conglomerate	Part of conglomerate	Part of conglomerate
Size (Rupees)	Medium;1 billion	Small;150 million	Medium;1.07 billion	Medium; 4 billion	Medium; 10 billion	Large; 100 billion
Business Strategy	Leader in tropical AC/low cost; new sizes & applications	Diversification into automotive segment new to PBW; new applications	Old product, new customers; requirements of new auto entrants	New products to the firm, new customers, first in India	Existing product, new markets; new garment segments; low cost	New products for different segments; new markets
Technology Strategy						
Selection, Specialization & Embodiment	Design (of product); blueprints	Process technology; equipment;	Product technology; blueprints, machines	Product technology; product formulations; process technology	Process technology; machinery	Product, Process & Practice technology
Sources of Technology	Licensing from Foreign Firms	Product imitation Indigenous process; development & Foreign machinery	Licensing from Foreign Firm	Purchase of Product technology from Foreign firms; JV with foreign firm; indigenous process development	Indigenous R&D and linkage with machinery manufacturer	Indigenous product R&D; Licensing, JVs with equipment manufacturers & internal adaptation; recently global sourcing for car design
Capability Building	Mainly Internal; Unbundling of technology	Internal,Consultants Exports	Mainly External; process & testing support from licensor	Mainly Internal (mostly process; recently product)	Mix of Internal & External	Mostly Internal
International Conformance	ISO; product quality approvals from international agencies; exports	ISO; suppliers to international machine producers; exports; critical applications	ISO & QS9000 certifications	Seeking USFDA approvals; export	ISO; exports	ISO; exports

	Amtrex	PBW	SBL	Torrent Pharma	Arvind	Telco
Innovation Networks	Domestic & Int. vendors; Design & Machine Tool Institutes	Equipment supplier; specialized vendors & customers	Not significant	Research Sub-contracting (including international)	Equipment manufacturer	Specialized Suppliers;equipment suppliers
R&D Investment	Low; design & testing centre	Low; testing	Moderate; mostly product testing & some improvements	Significant; new R&D centre	Significant; testing & process	Significant; design, testing & process development; machinery design & manufacturing
R&D Organization	Separate design centre (small)	None	Separate R&D facility	Separate R&D facility	Separate R&D facility	Separate R&D facilities (large)
Manufacturing Strategy						
Links with Corporate/Technology Strategy	Followed Technology Strategy with a time lag	Co-terminus with Technology Strategy	Followed Corporate Strategy	Independent (not significant until recently)	Co-terminus	Co-terminus
Location	Two plants involved	Multiple plants; old-cellular; new-focused	Single plant; few lines	Single plant; multiple lines	Multiple plants; focused; vertically integrated	Multiple plants; focused; vertically integrated
Capacity	Small	Small/large (sintering)	Medium	Medium	Large	Large
Practices	Outsourcing limited; 100%OK;Kaizen, Kanban	Outsourcing of low precision jobs; weak quality systems; excellent housekeeping	Outsourcing very limited; sampling; weak program in place	Monitoring of suppliers practices; GMP/USFDA requirements	Off-line quality control; quality & productivity through equipment;	Tierization of vendors; kanbans, SMED; process capability; SPC systems;CAD-CAM; standards; 3P logistics; automations
Process	Batch/assembly	Batch/continuous	Batch/assembly	Batch/assembly	Batch/continuous	Batch/assembly

	Amtrex	PBW	SBL	Torrent Pharma	Arvind	Telco
Training	Moderate; shop floor managerial practices	Low; mostly on the job -manufacturing related	Moderate, mostly on the job-manufactur-ing related	Low - machine & GMP related	Moderate - process related	High - design, engineering & manufacturing
Likely Trajectory						
Technology Characterization	Scale Intensive/ Limited Science Based (Core Stable)	Specialized Suppliers (Core Stable)	Scale Intensive (Stable)	Combination of Science Based & Scale Intensive	Scale Intensive & Supplier Dominated (Core Stable)	Scale Intensive & Specialized Supplier (Core Stable)
Product Obsolescence	Low	Medium	Low	High	Medium	Low
Process Obsolescence	Low	Low	Low	Medium/High	Low	Low/Medium
Firm Trajectory	Blue-print manufacturing/ imitation to Passive assembler ?	Blue-print manufacturer; imitation & development	Blue-print manufacturer	Imitation & development (recent)	Limited development	Product Development & Process Capability
Strategic Technological Challenges	Low costs-core tech.; supply chain (SC) crucial; vertical disintegration; exploit product opportunitie; develop tacit design & engineering. skills; fusion with emerging technologies (e.g., electronics)	Stable, new niches; lower costs; SC relevant; metallurgical skills; absorb user experience; align technological opportunities with user needs; tacit design & engineering. capabilities; exploit cumulative tacit skills	Assimilation of technology; lower costs; learning by doing; focus on production engineering.; exploit manufacturing related complementary assets through cumulative learning	Assimilation; lower costs; quick introduction of new molecules; SC focus on distribution; integration to exploit synergies (including flexible bulk drug facilities); international conformance for manufacturing	Lower costs; process learning; adapt for new features; entry into value added products; SC very crucial; align technological opportunities with user needs	Lower costs; product & process learning; introduction of new models on existing platforms; vertical disintegration & development of networks; exploit tacit design and manufacturing skills

Table 2: Stages in Manufacturing's Strategic Role

Stage 1	Minimize manufacturing's negative potential: "internally neutral"	Outside experts are called to make decisions about strategic manufacturing issues Internal, detailed, management control systems are the primary means for monitoring manufacturing performance. Manufacturing is kept flexible and reactive.
Stage 2	Achieve parity with competitors: "externally neutral"	"Industry practice" is followed. The planning horizon for manufacturing investment decisions is extended to incorporate a single-business cycle. Capital investment is the primary means for catching up with competition or achieving competitive edge.
Stage 3	Provide credible support to the business strategy: "internally supportive"	Manufacturing investments are screened for consistency with the business strategy. A manufacturing strategy is formulated and pursued. Longer-term manufacturing developments and trends are addressed systematically.
Stage 4	Pursue a manufacturing-based competitive advantage: "externally supportive"	Efforts are made to anticipate the potential of new manufacturing practices and technologies. Manufacturing is involved "up front" in major marketing and engineering decisions (and vice versa). Long-range programs are pursued in order to acquire capabilities in advance of needs.

Source: Wheelwright and Hayes (1985)

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