Sources of Innovation in Developing Economies: Reflections on the Asian Experience

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This article is concerned with the remarkable development of technological and economic capabilities by Korean and Taiwanese firms, particularly in electronics, and Indian firms in software and a few other fields. While the cases differ in many aspects, they all involve active learning, in some cases through reverse engineering, requiring a considerable amount to technical and economic sophistication. All of them also involved selling on sophisticated markets which provided both feedback and pressure to learn rapidly and well. The cases teach us a lot about the mechanisms involved in successful technological and economic catch up.

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I. Introduction

The very term "technology transfer" makes the process sound deceptively easy. This has had the unfortunate effect, for many years, of leading to a neglect of the difficulties, often subtle and complex, associated with introducing an old technology into a context that was substantially different from the economic and social context in which it originally developed. These transfers in fact involve substantial doses of entrepreneurship and therefore risk. I use the term "entrepreneurship" here in

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order to emphasize that such transfers have been full of uncertainties. These uncertainties are typically ignored in current approaches by economists of a neoclassical persuasion who treat the entire world as if everyone had equal access to all points on some pre-existing international production function. While there has indeed been a growing awareness, in recent years, of the difficulties attached to such an approach, it is also true that many of the technologies that are now undergoing transfer are far more complicated than those that were being transferred 30 or 40 years ago. One of the reasons for this is a very gratifying one: that several countries, mainly in east and southeast Asia, have achieved considerable success in industrial development and have thus moved well up on the scale of technological sophistication.

These remarks already call attention to the dangers of sweeping generalizations. In discussing technology transfer it is essential to understand that technologies are enormously diverse from one sector of the economy to another, and changes in the patterns of industrial organization, including particularly changes in the division of labor among firms, may open up opportunities that did not previously exist. Indeed, the possibility of new economic opportunities thrown up by new international divisions of labor will be one of my central concerns. But the overriding concern of my paper is to enlarge the framework within which we think about technology transfer. Most especially, I am trying to identify new doorways through which LDCs (late developing countries) can obtain access to the benefits that can be made to flow from new technologies.

I intend to focus on 3 countries that have had distinctly different experiences with the introduction of new technologies into their economies. Some of the contrasts between South Korea and Taiwan, on the one hand, and India on the other, are surely blatantly obvious. But it should also be said, at the outset, that although Korea and Taiwan have been outstanding success stories, some of their successes have been attained by travelling along distinctly different paths from one another. With respect to India, I have been driven by 2 very different concerns. First of all, India's huge size simply commands attention. The population of India passed the one billion mark not long ago; indeed, India has two states (Uttar Pradesh and Bihar) each of whose populations vastly exceed the combined populations of Korea and Taiwan. Moreover, a distressingly large percentage of the world's poorest people live in India. But, secondly, recent experiences on the Indian subcontinent suggest that the country may be in a position to make much more extensive utilization of technologies — technologies that may not be new to the world, but may hold out great promise in the changing Indian context.

II. Korea and Taiwan

A useful perspective for analyzing the poor performance of many less-developed economies is to say that their efforts to accelerate the technological learning process have suffered from an excessive preoccupation with the manipulation of supply side variables. This was very obviously the case in establishing and financing public agencies that were expected to provide the country with research and development findings of economic value. Moreover, given the genuine weakness of incentives for private firms to undertake research, as well as the ideological glamour that was once attached to central planning and the control over the "commanding heights" of the economy in the years of decolonization, it seemed natural for governments to place such research in the public sector. Far less attention was devoted to policies that might have expressed themselves by working via demand side variables, by strengthening the incentives of profit-seeking firms to upgrade their own technological-learning activities.

Against this background, a strategic feature of the successful east Asian economies, most especially Korea and Taiwan, is that they adopted policies that powerfully strengthened the demand side of the equation. I am not, of course, suggesting that Korea and Taiwan ignored the supply side — far from it — but rather that they also devoted much greater attention to policies that had large impacts on the demand side. As is well known, Korea and Taiwan introduced policies that strongly rewarded an export orientation and an eventual shifting from lower-value-added to higher-value-added products. Pursuit of these overlapping objectives at the level of the individual firm inevitably required an expanded commitment to internal technological learning — *i.e.*, internal to the firm. In effect, the strong export-oriented policies of Korea and Taiwan provided a powerful feedback mechanism, emanating from the demand side and impinging directly upon profit-making firms. It must be stressed that it is at the level of the individual firm that the new technological capabilities must be mastered — at least in the cases of the electronic and mechanical products that loomed so large in the exports of Korea and Taiwan. Producing for more affluent overseas markets required growing commitments to improvements in manufacturing technologies and, later, to more formalized R&D investments in order to master (and in some cases to eventually improve upon) the imported technologies that were essential in catering to the demand of those overseas markets for sophisticated consumer goods.

Not only were Korea and Taiwan highly successful, but it is important to note that their remarkable economic achievements were built upon strikingly different industrial structures — a handful of huge chaebols in the Korean case and a vast expanse of small and medium-sized enterprises in the Taiwanese case. Nevertheless, their export-oriented and higher-value-added policies served, in both cases, to powerfully raise the demand for technological learning inside the firm. The predominance of large-scale conglomerates in Korean industry was central to that country's spectacular growth in private sector spending on R&D. In the middle of the 1970s, Korean R&D spending amounted to a mere 0.5 percent of GNP, a share roughly comparable at the time to Brazil, Mexico and India. Moreover, 80 percent of Korea's R&D budgets in the 1970s were publicly financed, and most of the R&D was actually performed in government laboratories. By 1990, however, there had taken place a five-fold increase in the share of R&D in GNP, and the share that was financed by government had fallen to 20 percent (Dahlman and Nelson 1993). Here again, however, the Taiwanese case offers a sharp contrast with the situation in Korea. More than half of Taiwan's R&D expenditures in the early 1990s were provided by the government, reflecting an economy dominated by small and medium-sized enterprises. Taiwan had established a government-financed Industrial Technology Research Institute (ITRI), which certainly made contributions to technology transfer in specific categories. But Hobday, and others, have concluded that it was primarily the entrepreneurial initiatives, and the ability of small and medium-sized firms to improve upon foreign technology, that accounted for Taiwan's impressive economic achievements in the electronics sector (Hobday 1995)

Much of the economic literature on Korea and Taiwan has focused upon their respective achievements in mastering sophisticated electronics technologies. Their accomplishments within this realm have indeed been most impressive. In the Korean case, Samsung Electronics has become the world's largest producer of memory chips; in recent years, Korea has been ranked first or second in the world as a producer of cellular phones; and most recently it has laid claim to world leadership in the development of wireless Internet services. But beside these achievements at the technological frontier, Korea now has the largest ship-building industry in the world and is also home to the world's largest facility for the production of iron and steel — Pohang Iron and Steel Ltd. (POSCO). Korea is also now the third largest producer of iron and steel in the world. Clearly, these are only indirect measures of technological performance that may not directly translate into measures of economic performance if, for example, such firms have simply remained heavily dependent upon government subsidies. This, however, has not been the case. But my primary concern at present is with the transfer of technological capabilities, and with respect to that criterion these rankings are, I believe, most revealing. For the record, however, World Bank data on per capita gross national income (GNI) [$US, PPP] show Korea approaching European standards at $17,340 for the year 2000. Comparable figures for other countries are as follows (World Bank 2002): China, $3940; Russia, $8030; Japan, $26460; US, $34260.

The Taiwanese case has been especially impressive because, among other things, it challenges a widely-held view that export growth in electronics and elsewhere necessarily required firms that operated on a large scale. But in fact, as Hobday has observed, "... in consumer electronics, computing, clothing, footware, bicycles and other important export sectors small firms in Taiwan matched or exceeded the performance of the chaebol in export value" (Hobday 1995). Taiwan's predominantly small firms possessed an impressive capacity to change direction and to respond quickly to altered specifications, a capability that was of great commercial value in industrial sectors that experienced rapid technological changes or sudden alterations in consumer preferences.

In fact, in spite of the chaebol successes in organizing many of its modernization efforts, it may be argued that Korea's heavy reliance on large firms was not an unqualified success. Whereas the chaebols improved their manufacturing and design capabilities by drawing on foreign sources, Korea's dynamic small firms, at least in the early stages of its industrial development, achieved similar goals through the reverse engineering of foreign technologies and other measures internal to the firm, as well as through a more extensive reliance on local Korean universities. A central strategy of these firms was to reverse engineer, so much so that Linsu Kim has concluded: "The Korean experience indicates that most of the information required to solve technical problems **in the early years of industrialization** can be obtained free of charge through non-market-mediated informal mechanisms if catching-up firms have the local ability to undertake reverse engineering tasks" (Kim 1997). In the later stages of its rapid industrial development, Korea relied heavily upon the purchasing and licensing of capital goods from abroad. Additionally, as Enos and Park have observed., "... Korea has not relied upon direct foreign investment as a source of foreign technologie" (Enos and Park 1998).[1]

When placed within the matrix of international trade, the early growth of the east Asian industrial firms has to be understood in terms of their ability to respond to the demand-pull provided by multinational firms. These multinationals welcomed the low cost versions of products, or labor inputs, that Asian firms were able to supply. Thus, the east Asian industrial firm was confronted with a potentially vastly enlarged demand for products or components that could be delivered cheaply, by global standards, and that required no search or research devoted to product innovation. The product already existed, having been innovated abroad. However, knowledge of how best to produce these products did not yet exist within the firms. In these cases, a successful strategy for acquiring this knowledge involved tapping the skills of trained engineers and technicians to reverse engineer the product. These are activities associated with the creation of "internally-new" knowledge, but knowledge that was not new to the world. Without minimizing an array of difficulties in "learning to imitate," or "learning to learn," many of which are not readily classifiable within the usual subcategories or R&D in OECD countries, what was required was, mainly, the skills of trained engineers and technicians. Engineers and technicians in east Asian firms, then, were able to gain initial entry into world markets by devising new process technologies, or making other adaptations, that would allow their firms to become suppliers to large multinational firms that sold their products in more affluent world markets (Patel and Pavitt 1994).[2]

[1] Enos and Park (1998) provides a careful, technologically-sophisticated examination of Korea's technology transfer experiences in petrochemicals, synthetic fibres, machinery and iron and steel. The authors regard "lower costs of acquisition and speedier transmission of know-how" as "the two main accomplishments of the Koreans in their negotiations with foreign suppliers of technology," whereas they regard the Koreans as having been least successful "in the next stage of the process of incorporating foreign technologies — learning how to design facilities and the constituent equipment."

[2] Patel and Pavitt (1994) argue for the continuing pervasive importance of mechanical engineering capabilities in spite of the growth of highly visible, science-based technologies in the realms of the chemical and electrical industries. "Science-based technologies are those that in general are growing most rapidly and they are dominated by large firms, but this is only part (about a half) of the story. Nearly 40% is made up of improvements in mechanical instrumentation and process technologies, development of which is hidden in

Hence, one key reason why the concept of R&D is of only limited use in the present context is precisely because the process of technology transfer in the east Asian case involved recourse to a diversity of organizational arrangements, some of them new, some of them old but utilized on a much larger scale. For the countries that could make the transition, their firms were able to enter world markets through the new divisions of labor that were made possible by these mechanisms. These arrangements included subcontracting, original equipment manufacture (OEM), purchase of foreign capital goods, reverse engineering, joint ventures, foreign direct investment, licensing of patented technologies, as well as overseas training and the return of nationals with overseas education or experience, *etc*. (Hobday 2000).[3]

As east Asia entered into new relationships with overseas firms (subcontractor, OEM, FDI), the technological learning achieved by the ldc firms came to be shaped increasingly by feedbacks from the design, distribution and marketing stages of foreign firms in the industrial world, rather than from feedbacks originating in the marketing and distribution activities of their own domestic markets. These feedbacks included meeting higher standards of quality and performance, introducing drastic changes in design to accommodate different tastes, or niche markets, frequent changes in the composition of demand in affluent markets, as well as different tradeoffs between quality and cost. In terms of the primary activities involved, a common pattern was movement upward from the supplying of labor-intensive assembly services to the eventual export of more sophisticated final products, especially electronic products, to foreign markets (Kim 1997).[4]

There is an important point to be made here that is usually overlooked. That is, as east Asian firms became increasingly dependent upon multinational firms for their marketing and distribution services, these same multinationals, **ipso facto**, acquired strong financial incentives to

the published data on large companies' R&D activities and dispersed amongst small firms whose technological activities are only very imperfectly and incompletely recorded."

[3] Hobday has defined the OEM system as follows: "OEM is a specific form of subcontracting that evolved out of the joint operations of TNC buyers and NIE suppliers. Under OEM, the finished product is made to the precise specification of a particular buyer (or TNC) who then markets the product under its own brand name, through its own distribution channels."

[4] Linsu Kim has documented the global efforts of Korean chaebol to monitor research in advanced countries at the technological frontiers by purchasing firms and setting up subsidiaries abroad.

improve the technological capabilities of their east Asian suppliers. Obviously, the multinationals were not anxious to create new overseas competitors, and this concern was often a source of considerable friction — for example, when ldc suppliers attempted to move up to the higher product quality ranges and, eventually, to introduce their own brand names. Nevertheless, when a Korean or Taiwanese firm acted as a supplier of products or components that were destined to be sold under a well-known overseas brand name or distribution channel, the multinational inevitably acquired an incentive to assure that its supplier firm met minimal standards of quality, performance and cost and, not least, delivered the inputs within an agreed-upon time schedule. These were, by no means, trivial things to learn.

By the late 1980s the OEM relationship accounted, by one estimate, for 60 to 70 percent of Korea's total electronics exports a sector dominated by the large chaebols (Jun and Kim 1990) In Taiwan, under organizational arrangements that were drastically different from those that prevailed in Korea, hundreds of small electronics firms emerged under various kinds of sub-contracting and OEM arrangements. Taiwan's electronics firms derived huge economic benefits from these arrangements. As Hobday has observed: "Under the early OEM deals, the foreign corporations frequently supplied training, technical specifications and advice on engineering and capital goods. The OEM system proved an enduring technological training school for latecomers in the NIEs, enabling hundreds of small firms to overcome barriers to entry. By the early 1990s a significant proportion of electronics output was still sold under OEM and similar sub-contracting arrangements" (Hobday 1995). The OEM, in its various forms, unquestionably deserves to be regarded as an organizational innovation of major importance.

By 1993, Taiwan was a major player in the world computer market, dominating that market for a number of component products. These included: 83% of the world market share of motherboards; 51% of the monitors, 55% of image scanners, 80% of the mouses, and 49% of the keyboards (Pack 2000). The small Taiwanese firms possessed none of the benefits of scale or huge financial resources that eventually accrued to the Korean chaebols; nevertheless, they exhibited formidable entrepreneurial skills including, most especially, the ability to carefully analyze trends in specialized niche markets and to mobilize rapid responses to these emerging opportunities, often in the face of very high levels of risk. In many cases, as suggested by the numbers just cited, the niches sometimes proved to be capable of almost indefinite enlargement.

This has been a considerable accomplishment in view of the inherent features of some of these high tech markets where there are rapid changes in product specification. As Howard Pack has observed: "... it is precisely in high-tech areas that it is very difficult to achieve a self-sustaining niche in world markets ... There are few high-income elasticity markets with static unchanging demands for standardized commodities such as steel and television sets. Rather, many of the markets with high-income elasticity change with extraordinary rapidity, and their evolution, even over six months, is often unpredictable (2000)."

The Korean and Taiwanese achievements were based on extreme differences in industrial organization and structure, and relied on a variety of organizational channels through which each was able to acquire new skills at progressively higher levels of technological sophistication. Much of the learning, it should be emphasized, was organizational and managerial, including especially the acquisition of specific knowledge and skills that were essential in selling products in overseas markets. The access to knowledge concerning the determinants of demand side forces in these affluent overseas markets provided, in turn, indispensable feedbacks that shaped the technological learning processes in east Asia. The essential point about such feedbacks is that they provide guidance to technological improvements and design change. In the industrial sectors in which Korea and Taiwan competed in international markets (*i.e.*, in the electronics and mechanical sectors), feedbacks are the essential aspect of learning, as opposed to, say, the chemical and pharmaceutical sectors, where such feedbacks have been far less influential.

Of course, the very success of the technology transfer process on the part of an late developing countries (LDC) was also likely to encounter certain inherent limitations. As the LDC firms moved up the ladder of technological sophistication, rising wages reduced the economic attractiveness of the country as a source of relatively cheap labor. Indeed, for the last couple decades a conspicuous major trend in east Asia has been the continuous shifting of the outsourcing activities of Japanese and American multinational firms to other Asian countries in which labor markets have not yet been visited by the rising wages generated by technology transfer mechanisms.

It is interesting to note that the successful tigers in east Asia are already extensively committed to the transfer of productive activities to neighboring countries where labor costs are still very low. The current favorite is, of course, China, and China's status in this respect is likely to continue for a long time. The London **Economist** has reported that more than half of Taiwan's production of information technologies has already been moved to the Chinese mainland, and it adds, succinctly: "Acer, Taiwan's best-known computer brand, looks increasingly like a mainland company with a head office in Taipei."[5] (Economist 2000)

There has also been another, opposite side to this coin of successful technology transfer. Although the marketing, distribution and design capabilities of multinational firms provided the portals through which Korean and Taiwanese firms entered into new international markets, the mutually-beneficial nature of these relationships eventually encountered certain limits. These limits were likely to be encountered when LDC firms wished to move out of the shadows as invisible suppliers of components or finished products, in order to establish their own identity with their own brand names, products and distribution systems — thus becoming a competitor rather than a supplier to the multinational firm. In the bicycle markets of America and Europe, for example, which have been absorbing massive imports of Asian products, Asian manufacturers who are searching for greater brand name awareness have discovered that the fastest way to achieve such awareness may be simply to purchase (often moribund) western bicycle firms in order to exploit their names as well as their distribution networks.[6]

Korea eventually introduced another organizational mechanism that has played a role of increasing significance in acquiring advanced technological knowledge; It has established R&D facilities in the US — of which it had no less than 32 by 1996, including 10 in semiconductors and 7 in computers (National Science Board 1998).

III. India

So far our examination of technology transfer has drawn primarily on the experiences of two countries that have been highly successful at this activity. It may now be useful to ask whether some additional insights can be drawn from the experiences of a country that has had very different background conditions and that, until recently, has had a dismally poor record in introducing new technologies, most particularly when measured against the high achievers, Korea and Taiwan. Some recent Indian experiences raise intriguing possibilities concerning the potential role of innovations — both technological and organizational —

[5] From a report in Economist Magazine in page 59 of the April 27 2000 issue.
[6] From a report in Economist Magazine in page 62 of the June 1 2002 issue.

in the country's future. What are the opportunities that might lie ahead?

It is not necessary to rehearse the broad contours of the Indian situation in any detail. For forty years or so after its independence the Indian economy was dominated by a dedication to a policy of autarky, with an industrial sector solidly protected against the competition of imports, and an overall economic policy whose primary concern was with ensuring national self-sufficiency. In its most extreme formulation, one needs only to recall Nehru's extraordinary dictum that "It is better to have a second-rate thing made in one's own country than a first-rate thing one has to import." Key features were extensive government regulation, dominated by requirements that firms seek permission, usually in the form of a license issued by the government bureaucracy, for a bewildering array of what would, in more market-oriented economies, be regarded as normal, prosaic, day-to-day business transactions. The central figure in all this was the notorious "license raj." Moreover, a very large swath of economic activity fell within the public sphere including, notably for our present purposes, the quite substantial resources committed to scientific and technological research. Many sectors of the economy were reserved for small-scale firms by such simple expedients as legal restrictions on the freedom of firms to expand their share of domestic markets (Kim and Nelson 2000).[7] Clearly, the regulatory regime under which the Indian economy suppressed competitive forces for several decades was an environment that also suppressed the incentives for technological change.[8]

In 1991 a policy of extensive liberalization was introduced, which included a sharp reduction in a variety of licensing controls and a general

[7] In some cases, at least, the Indian government actually discouraged competitive efforts that would lead to changes in the share of Indian firms in the domestic market. In discussing the textile industry, Pack has observed: "Until the reforms of 1991, individual firms faced legal restrictions on their ability to expand their share of the domestic market. Simultaneously, the foreign trade regime discouraged exports. Thus, even with superb researchers and excellent institutional structure, there was no payoff to either education or R&D in the Indian textile sector."

[8] DeLong (2001) asserts, using IMF data, that India experienced an acceleration of annual real GDP growth, and annual real GDP growth per capita, during the 1980s. Although India's rate of growth continued to accelerate during the 1990s, that acceleration was nowhere nearly as great as the acceleration of the previous decade. De Long observes further that "... Since the late 1980s India ... has been one of the fastest-growing economies in the world." He identifies India's true turning point as 1984, pegging it to a liberalization movement that was started in that year under Rajiv Gandhi.

opening up of a previously largely closed economy, involving especially a lifting of some import restrictions on capital goods and foreign investment and a decline in the (still large) public sector. The effects of these relaxations are still reverberating through the economy, but what is already clear is that many sectors have been exposed, for the first time, to competitive forces, especially competition from abroad. In the most general sense, the existence of increased competition called into play an active search for better technologies — not necessarily new technologies — that could enhance a firm's market position vis-a-vis existing or potential competitors. These competitive forces impacted upon the introduction of new technologies in various ways. Obviously, foreign firms could now enter Indian markets far more freely than was previously possible, bringing with them new consumer products, along with capital goods, that were previously excluded from entry. Indian manufacturers of a wide range of products, from automobiles to tooth brushes, found themselves shaken out of a long period of somnolence during which they had been able to sell products to the Indian middle classes that would have been regarded as hilariously obsolete in most other countries of the world. And, not least, India's pool of potential entrepreneurs discovered that, with access to foreign technologies that were not previously importable, they could now enter and possibly compete successfully in delivering services and goods, not only to Indian markets, but also to overseas markets — something they had not previously considered as even remotely possible (Forbes 2000).

I wish to call attention to some striking developments in the country's acquisition of new technological capabilities, which are deserving of further examination. The first one, India's entry into the world market as a major exporter of software, is by now well-known, although some possible implications of that entry need further consideration. The second, India's acquisition of a large domestic capability in the technologically-sophisticated realm of chemical process plants, is not widely-known, but deserves to be. I will deal with the latter case first.

It is worth pointing out, to begin with, that the share of non-industrial countries in the total world production and export of chemicals has increased drastically since the 1950s. Eichengreen (1998) shows that industrial countries accounted for 86 percent of world chemical production in 1954 and 62 percent in 1994. But the increase in the share of the non-industrial countries in world exports was spectacular: Those countries accounted for a trivial 0.2 percent of chemical exports in 1959 but fully one-third (33.4 percent) in 1993. For the specific case of India, much of its growth was in the intermediate goods sectors. In the second half of the 1990s its chemical sector was growing at the rapid annual rate of 10 percent, while its high tech petrochemical sector was growing at an annual rate of between 15 and 20 percent. India's overall industrial growth rate was 8 percent (Eichengreen 1998).[9]

A strategic consideration for India's future (as well as for other ldcs) is that there now exists a more extensive division of labor within the world chemical industry. This involves the activities of specialized engineering firms, as well as other sellers of chemical technologies, that may facilitate many of the critical aspects of technology transfers in chemicals to a less developed economy. For example, LDCs can now contract with specialized engineering firms to design and to install a chemical process plant with specified output capabilities. These are skills that are, typically, very difficult, and very expensive, to generate internally in LDCs, but in the presence of a well-functioning market for technology design and engineering services, this may now be unnecessary (Arora, Fisfuri and A. Gambardella 2001).

Thus, the turnkey plant, long derided in the development literature, has become more feasible, although the feasibility remains subject to certain qualifications. The recipient firm is not absolved of all responsibility in the sense that the term "turnkey plant" might suggest. The recipient firm must have, or at least must be able to develop, some inhouse capability to "trouble-shoot" and to perform maintenance and repair work, which will involve periodically bringing the operation of the plant to a halt and later starting it up again. Here too, the specialized engineering firm can be contracted with to "de-bottleneck" the plant, if necessary. However, if these capabilities are not quickly achieved by the recipient, prospects for future commercial viability of the plant will remain distinctly poor. An important inference from the recent Indian experience, however, is that entry into certain higher technology sectors of economic activity has become, at the least, very much cheaper than before.

These observations raise some profoundly important questions: will the new division of labor in world markets now permit firms in certain sectors of LDCs to move up the ladder of technological sophistication with a smaller "endowment" of their own technological capabilities than was previously the case? How much smaller? And which specific sectors?

[9] Mani (2002, Chapter 7) reports that "very nearly 70% of India's high-tech exports is composed of pharmaceutical and inorganic chemical products."

I will have something to say about chemical processing plants — a sector of huge importance — but I am really most interested in the more generic issue: are new international divisions of labor reducing the level of technological skills that once had to exist in the recipient LDC firms in order to achieve a successful transfer of technology? Clearly, some minimal technological capabilities must reside inside the industrial firm, but recent experience also suggests that the ability to manage the contracting firms that will design and install the new technologies, will often be a crucial skill. Does the experience of the chemical industry suggest that there are further new opportunities that have been emerging in world markets, along with new international divisions of labor, the future significance of which is far from being fully appreciated? What other variables shape these possibilities? In particular, to what extent can improved managerial skills serve as a substitute for limited technological skills in facilitating technology transfers? In the Indian context, is it the case that there is such a thing as a core competence in large project management expertise? Some recent experience in India suggests that this competence may be real.

Consider the experience of Reliance Industries Ltd. Reliance is a very large Indian firm that had its origins in the textile industry and then integrated "upstream" into intermediates (purified terephthalic acid for polyesters), and then into refining and the production of feed stocks. Reliance engaged several large contracting firms, including Bechtel and Stone and Webster, from whom they also licensed technologies, who successfully built the world's largest "grassroots" refinery and downstream plants, in Gujarat. This facility, which came on line six months ahead of schedule, costing $US 6 billion, now accounts for 25 percent of India's refining capacity.[10] But it is important to add that this firm, which had never set up a refinery, and which had only limited technological skills, also demonstrated a considerable managerial sophistication. This sophistication applied, not only with respect to the man-

[10] Reliance also employed about 2000 of its own engineers who worked alongside the Bechtel engineers. These engineers learned from Bechtel, who were then enabled, later on, to take greater responsibility for an expansion that was launched while the first phase of the project was being completed. Reliance has recently moved in the direction of becoming a conglomerate, as a result of its entry into power, telecommunications, IT, insurance and biotechnology. It should also be noted that Reliance's expansion into petrochemical products such as polyesters, polyester intermediates and plastics has been facilitated by high levels of import duties on such products.

agement of several large contractors, but also in entering into a number of complex contractual relationships that stabilized the reliability of its crude oil procurement and thereby insulated the firm from a number of the other, unavoidable vagaries of the oil business. These were considerable achievements. It should be noted that Reliance appears also to have had considerable political influence.

The Reliance experience, of entering the oil refinery business with no capacity for either designing or constructing such a facility, suggests that much technology may now be acquired through the marketplace by firms that have the appropriate, in-house managerial skills, but not the in-house capability to design and construct a large refinery. But this encouraging possibility, in turn, calls attention to issues that require further exploration at the sectoral level.

After all, in all advanced industrial economies there have long existed capital goods firms that design and manufacture capital equipment that could not be designed or manufactured by the eventual users of such equipment. In this sense, Reliance's dependence upon a number of specialized contractors is hardly unique. But why, then, should Reliance's accomplishments in refining be treated as so remarkable in the Indian case? An answer that readily suggests itself is that the managerial expertise of the kind that was exercised by Reliance remains very scarce, not only on the Indian subcontinent, but in much of the less-developed world as well. But of course the possibility exists that the apparent scarcity of managerial and entrepreneurial skills may, in turn, simply be a reflection of an over-regulated economy where such potential talents have, in the past, been deflected into rent-seeking activities.

In the case of the rising share of the LDCs in the chemical industry, conditioning factors in the past half century were the growth in demand, the decline in transportation costs, and better access to sources of raw materials. Underlying the growth in demand, in turn, was the huge growth in the petrochemical industries after the Second World War, a growth that required a vastly enlarged capacity for the production of the intermediate inputs for plastics, synthetic fibres, *etc*. A powerful facilitating factor in the less-developed world after 1970, when chemical processing plants (including, of course, oil refineries) began to become important outside of the industrial world, was the specialized engineering firms (a specialization that was largely of American origin) that had already come to play a major role in the diffusion of chemical processing plants in industrial countries. Many SEFs provide construction services and have therefore served as providers of "turnkey plants." They have also often served as licensing agents for chemical firms and, by inducing these firms to license their technologies, they have speeded up the process of diffusion and have helped to create, in effect, a market for technology.

As Arora *et al.* (2001) have shown in their valuable and extensive study, in the decade of the 1980s SEFs accounted for nearly three quarters of world construction of chemical processing plants. Going back to the years immediately after the Second World War, these SEFs, through long cumulative learning and experience, acquired a comparative advantage in the delivery of chemical engineering services. Competition among these SEFs for First World markets brought about substantial cost red'uctions leading, in turn, to lower technology transfer costs for markets in less-developed countries. It is at least a plausible conjecture that the expansion of ldcs in the production and export of chemicals since the 1950s, to which Eichengreen has called our attention, was heavily shaped by the increasing competitiveness and cost reductions in which the SEFs played such a significant role.

As Arora *et al.* (2001) have argued, this new international division of labor, generated initially in the First World, brought with it a substantial reduction in the cost of chemical processing plants in the Third World. "Simply put, the growth of the chemical industry in the first world created an upstream sector, which later spurred the growth of the chemical industry in the developing countries" (Arora, Fosfuri and Gambardella 2001). I do not wish to prejudge the extent of the effectiveness of similar market mechanisms in achieving technology transfers elsewhere. I do, however, suggest that a high priority ought to be attached to an exploration of the changes in organizational and regulatory mechanisms that might lead to further improvements in the effectiveness of markets for technology (Arora and Gambardella 1998).

I turn now to a very different sector. One of the most remarkable technological transfers in post-independence India (or, for that matter, in the entire LDC world) has been the sudden efflorescence of the computer software industry in the past two decades. The Indian software industry achieved annual growth rates of almost 50 percent during the 1990s. India's software exports reached $6 billion in the year ending March 2001, compared to just $150 million a decade earlier[11] (New York Times 2002).

[11] See A. Arora, R. Landau and N. Rosenberg (1998). 13 14 From a report in New York Times (section C3, 18 March, 2002).

According to one estimate, India in the mid-90s accounted for 16 percent of the world market in customized software, and 185 of the Fortune 500 firms have engaged in outsourcing to India (Arora *et al.* 1998). India's rising share of world trade during the 1990s, after four decades of decline, owed much to the spectacular performance of the country's software sector — admittedly in large part because India had long been such a feeble exporter. It is also important to emphasize that India's software achievements could hardly have been realized had the country's software firms been required to rely upon domestically-produced computers and software tools. India's unexpected but welcome achievements owed very much to the sharp decline in transmission costs that flowed from major innovations overseas in the realm of information and communication technologies.

One of the distinctive features of this sudden emergence, most unusual, perhaps even unprecedented, in the Indian context, is that it was an export-driven phenomenon — a phenomenon based on low-value-added services combined with the transfer of recently-developed ICTs. It was driven by the export demand for the products of the computer software capabilities that were made possible by India's abundance of low wage, English-speaking workers (Software development is still highly labor-intensive). Additionally, and less obviously, it owed something to a sizeable phalanx of talented Indians who "exported" their software development and programming skills by migrating overseas, mostly to the US. A number of these migrants eventually returned to India where they contributed not only their technological skills, but also their entrepreneurial/managerial and organizational skills, some of which were acquired, or at least "polished" abroad, to the further growth of the Indian software industry (Saxenian 1999).[12] But the significance of "returning immigrants" to the Indian software industry appears to have been far less influential than was the case for Taiwan. The Indian diaspora played a far more important role as, in effect, brokers who helped to establish connections, in the US and UK, between clients (typically in

[12] Saxenian found in her interviews that many Indian and Chinese immigrants working in Silicon Valley believed that there was a form of racial discrimination, a "glass ceiling," limiting the rise of Indian and Chinese software engineers into the higher echelons of management in well-established firms. Many Indians interviewed by Saxenian attributed their decision to engage in some form of entrepreneurial activity to the persistence of that belief. At the same time, Saxenian cites income data that fail to provide support for the existence of a glass ceiling.

large firms) and vendors (typically Indian software services suppliers).

The Indian software industry benefitted substantially, as did so many other sectors of the economy, from the liberalisation changes that took place in 1991. But the establishment of Software Technology Parks in the late 1980s had already provided favorable tax treatment and other special privileges to export-oriented software firms, even before the general policy of liberalisation had taken place. For example, firms in the STPs "... were allowed to import all equipment without duty or import license, and 100 percent foreign ownership was permitted in exchange for a sizeable export obligation" (Saxenian 1999).[13]

India's surprising success as a software exporter raises many questions, the answers to which may have potentially valuable implications, not just for India, but for other LDCs as well. For example:

1) What have been the essential ingredients of the Indian success, aside from the 2 rather obvious ones: *i.e.*, a large pool of educated people with excellent English language skills, plus their availability at salaries that are very low by international standards?
2) Closely connected, just how professionally sophisticated do the software people need to be in order to build this industry and, eventually, to provide the leadership for moving into higher-value-added activities?
3) In what ways will the firms need to change in order to move from their present status as suppliers of low-value-added services to suppliers of higher-value-added services?[14]
4) What is the best strategy for acquiring these necessary skills for

[13] The difficulties imposed by India's heavy-handed and uninformed bureaucracy in the 1980s (*e.g.*, customs officials who didn't understand how the satellite datalink worked) is recounted by the experiences of Radha Basu, an Indian immigrant to Silicon Valley who had a long career at Hewlett-Packard and who later spent four years in Bangalore setting up H-P's software center there. She later reported in an interview that she "... could not convince Indian customs agents that it was possible to export software without material evidence. For five years she was thus forced to dump all of the H-P systems data onto tapes and ship them physically to customers in the United States so that they could be registered and recorded as exports.

[14] A number of Indian software firms are currently attempting to make this transition. One Indian firm, Wipro, which built its earlier reputation in low-margin activities, is moving into several higher-margin operations, including a joint venture with General Electric. The firm, Wipro GE Medical Systems, is already an exporter of sophisticated medical equipment. Reported in Wall Street Journal: section A15 in 4 January 2001.

upgrading? What, in particular, are the implications for changes in higher education, technical training and research?

If one compares Asian countries in terms of their supplies of engineers, presumably a critical input into the software industry, an intriguing fact quickly emerges. That is, India fails to share the general Asian "bias" in favor of the engineering disciplines. In 1990, India was the only Asian country in which university enrollment in the natural sciences exceeded enrollment in engineering — and it was fully 4 times larger. India's ratio of enrollment of engineers to that of scientists was, by far, the lowest among Asian countries (Lall 2000).[15]

How to explain, then, how India has managed to do so well in software with its apparent paucity of engineering skills?[16] First of all, it is important to keep absolute numbers in mind, and India's population is many times larger than that of any Asian country other than China. Still, it is notable that South Korea, with a population less than 5 percent of that of India, has far more enrolled engineers (2000). Arora *et al.* argue that "... the bulk of the work is relatively non-technical and requires mostly logical and methodical work and a familiarity with software development tools and languages (Arora *et al.* 1998). Given the large number of science and arts graduates, and the widespread availability of private training institutions, the pool of potential software developers is much larger than merely graduates from engineering colleges (Arora *et al.* 1998). Elsewhere, Arora has stated that what the industry requires is "creative people familiar with software development tools... The simple point is that one does not need to know thermodynamics, or for that matter, about the details of the operating system, to develop business applications which will run on top of a standard platform such as Oracle or SAP (a German software company). Instead, one needs to know Oracle and SAP and be familiar with tools to develop business applications." Indeed, many engineering graduates have not been taught even the entry-level skills required for the software industry which, in any case, are subject to frequent change.

Inevitably, this raises questions concerning the qualitative dimensions of the available labor force. India has already established itself as a

[15] Interestingly, India has long had a modest but globally competitive engineering consultancy industry.

[16] And also the fact that a non-trivial percentage of India's best software talent has responded to the lure of far higher salaries abroad?

major player in the global market by drawing upon an educated, English-speaking labor force (the largest English-speaking, scientific labor population in the world) that has been available at a low wage by comparison with overseas competitors. But how long can India's recent software growth rates, based on exports of standard coding and programming services to overseas clients, continue? How far up the value-added ladder can the country go with its initial advantages alone? To what extent can India draw upon the international division of labor, thus making use of complementary, high-powered skills that are not available at home, in sufficient amounts to support such an upward climb? And what specific sorts of skills are necessary? Finally, it may be simplistic to focus purely on technical training and technology transfer when the crucial inputs may be organizational and managerial, as appears to be at least partly the case in other sectors of the economy.

A huge imponderable with respect to the future is, to what extent can India exploit her present advantages in computer software and telecommunications as a platform for new specializations in the service sectors? The recent convergence of several technologies — computers, satellites, fiber optics and telecommunications generally — has created a new set of opportunities: possible new patterns of international specialization that are still, very probably, in the early stages of development. Low labor cost countries now have a number of options for, literally, "plugging in" to distant markets once the necessary IT infrastructure has become available. India, it should be emphasized, is still seriously under-equipped in terms of its telecommunication infrastructure — electric power supply, bandwidth, Internet access, and telephone.[17] China, the present location of choice for low cost manufacturing activities, has currently begun to show a considerable interest in software — lacking, of course, the linguistic advantages of India. Nevertheless, delegations of officials from the Chinese Ministry of Education have begun to show up at Infosys Technologies, India's best-known Information Technology company, reportedly asking a wide range of detailed questions and taking extensive notes.

Can India establish itself as a "good place" to perform certain kinds of R&D? At the private sector level, the Indian press has recently reported that Oracle has 2000 R&D employees in India, with an announced plan

[17] India has just 5.1 internet users per 10,000 inhabitants, compared to 14.5 for Indonesia, 20.6 for the Philippines, 367.8 for Malasia and 1373 for Taiwan. Based on a report in Economist magazine, in p. 399 of 22 July 2000 issue.

to raise that number to 4000.[18] The Hindu Business Line According to this report, what was taking place included a “perceptible drift” on the part of Indian software developers from their well-established focus upon services development and maintenance work, to an expansion in the outsourcing of product R&D. Perhaps significantly, these numbers were announced at a time of deep recession in overseas dotcom markets.

One possible implication for longer term trends is that the resulting increasing tightness in R&D budgets has pointed even more forcefully to the competitive advantages that may be offered by India as a low cost center for the performance of higher-value-added R&D work as well as for more traditional services. There are many straws that may be detected, other than Oracle, in this wind: General Electric’s research center in Bangalore, for example, employs 1700 scientists and engineers, making it GE’s largest research center outside the US. Mr. Ramesh Emani, Chief Technology Officer of Wipro, the largest publicly-traded software services company in India, has reported: “In Wipro we are seeing a good amount of interest from product companies in the areas of consumer electronics, automotive electronics, industrial automation, medical electronics, *etc.*, in addition to the traditional outsourcers in IT and Telecomm.” Veritas Software, a global software company with 14 storage centers all over the world, now has its second largest center in Pune (the largest is in the US), and expects to have invested $15 to 16 million in its Pune center in calendar year 2002. The company reports that 20 of its patents in 2001 were filed by its Pune subsidiary[19] (The Hindu Business Line 2002).

Closely connected is a large group of outsourcing firms (so-called “call centers” or “back offices”) providing more mundane but indispensable telephone and data entry services to airlines, insurance companies (including claims processing), car rental firms, credit card agencies, *etc*. Aside from providing information, some of which is also being shifted to recorded messages, backroom activities may deal with inventory management, payrolls, billing, credit card approvals, medical transcriptions, etc. But India is by no means the only LDC backroom. Handwritten tickets issued for violations of New York City’s environmental code are currently typed up into a searchable data base in Accra, Ghana by women working under contract for Data Management Internationale for less than $70/month — 3 times the Ghanain minimum wage. They are

[18] Reported in The Hindu Business Line in 19 June 2002 issue.

[19] Reported in The Hindu Business Line in 19 June 2002 issue.

then transmitted back to New York where they are stored electronically and subsequently used to generate payment notices.[20]

It would, however, be a mistake to classify backroom activity as uniformly involving low skill levels. Some will involve education of the sort received in MBA programs; elsewhere, as in the realm of bioinformatics, Indian Ph.D. graduate students currently prepare overnight delivery of data for American biotechnology firms while the American research workers sleep.

At the high tech end of the spectrum, it should be noted that India has a considerable generic drugs industry, with a growth rate of 8 to 9 percent per year, with recent annual sales of about $4 billion, much of it exported. Since it has been estimated that pharmaceutical products worth over $40 billion are to go off patent by 2005, Indian companies may be in a strong position to take some advantage of this market.

Most of the industry's research effort in this sector in the past has been to use its in-house capability to reverse engineer ways of producing an existing drug more cheaply (process patents are allowed in India). These new processing techniques, involving the ability to produce low cost intermediates for the pharmaceutical industry, have then been sold to American pharmaceutical firms. It has been such arrangements that the **Financial Times** presumably had in mind when it characterized the Indian drug industry as "copy a drug and then produce it 70-80 percent cheaper" (8 June 2002). While this may well be an accurate description, efforts at large cost reductions of pharmaceutical products in an extremely poor country hardly deserve to be treated with such ill-concealed disdain. The parallels should also be noted with India's software industry: employing the country's low-cost, educated human capital to produce products (in this case intermediate goods) for export primarily to the US.

In fact, there is recent evidence that the Indian pharmaceutical industry is taking steps to move up the value-added ladder by devoting an increasing effort to drug discovery. Indeed, some of India's best-known pharmaceutical companies such as Ranbaxy and Dr. Reddy's Laboratories, have recently entered into licensing arrangements in which Indian innovations have been made available to western companies (*i.e.*, "licensing out" rather than the traditional "licensing in."). Ranbaxy has entered into a licensing agreement with the German firm, Schwarz Pharma involving a new chemical entity for the treatment of benign

[20] From a report in New York Times (section C3, 18 March, 2002).

prostate hyperplasia (enlarged prostate, a very common, chronic condition in older men). Under this agreement, Schwarz Pharma obtained the exclusive right to develop, market and distribute the product in the US, Japan and Europe, while Ranbaxy retained the rights in all other markets. In the event that the product were to be developed successfully, Schwarz Pharma agreed to pay Ranbaxy $42 million over the next five to six years, including an "up front" payment of $6.3 million, to be followed by royalties on commercialization. These are substantial sums of money in the context of the Indian economy[21] (The Hindu Business Line 2002).

Dr. Reddy's Laboratory has had more extensive connections with prominent European pharmaceutical firms. It has licensed one of its research molecules to Novartis, the Swiss pharmaceutical giant, for the treatment of diabetes, and another to the same firm for worldwide exclusive rights for the development and commercialization of an insulin sensitiser. Dr. Reddy's Lab will receive up to $55 million up front and "milestone payments for specific clinical and regulatory endpoints as well as royalties."[22] On an earlier occasion Dr. Reddy's licensed two of its molecules to Novo Nordisk. These molecules, at the time of the writing of the article providing this information, were in the second phase of clinical trials.

Although these are obviously modest beginnings in the context of the immense world pharmaceutical industry, they show a competence for high tech R&D in which India may learn to play a prominent role, especially given the large pool of qualified Indian scientists who are seriously underemployed. Furthermore, an enlarged competence in this field will surely strengthen the prospects for extensive participation in the future growth of biotechnology, an industry that is certain to experience great expansion in the course of the 21st century. But there is another particular aspect that deserves attention. That is, India's first, tentative steps in the world pharmaceutical industry have drawn directly on the property rights attached to its pharmaceutical products. In the ongoing expansion of international markets for technology, intellectual property rights may well come to serve as a force for strengthening "licensing out" rather than "licensing in" for less developed economies. Such licensing out, of course, will serve to strengthen Indian incentives to expand investment in R&D (Arora *et al.* 2004).

[21] Reported in The Hindu Business Line in 19 June 2002 issue.
[22] Dr. Reddy's: Right Prescription. pt http://content.icicidirect.com/ULF/UploadFile 2002316153328.asp.

Finally, not yet extensively explored (so far as I know) is the additional potential that might be made to flow from India's elite, higher education institutions. This potential refers particularly to the premier Indian Institutes of Technology and the Indian Institutes of Science, but also to the high quality of its trained scientists and engineers working in the country's national laboratories — the Council of Scientific and Industrial Research (CSIR). These labs have, in the past, maintained an arms length relationship with private industry, although they have recently been instructed to earn 30 to 50 percent of their operating budgets by playing a direct role, along with the private sector, in the commercialization of indigenously developed technologies. Some progress is being reported in this direction.[23] This policy should certainly be applauded and encouraged. At the same time, India's considerable R&D capabilities, combined with the global information networks that have been created by vastly improved telecommunications facilities, raise new opportunities in international markets that deserve to be explored. Sadly there is, so far, little evidence of a growth of R&D spending on the part of private industry.

IV. Closing Observations

Most of the technology transfer activities that have been discussed here have involved making uses of international markets, but in a variety of different and, in some respects, novel ways. These ways typically had the consequence of tapping new sources of demand in overseas markets for electronic products. In the case of the most successful new activities for Korea and Taiwan, entry was initially achieved through various kinds of contractual relationships with multinational firms. The

[23] The National Chemical Laboratory, established in 1950, has been widely considered to be the most distinguished of the 40 CSIR labs. According to Mani (2002), "the NCL is internationally known for its excellence in scientific research in chemistry and chemical engineering, and for its outstanding track record of industrial research. Approximately 50 per cent of its receipts emanate from the industry." Mani points out that much of the recent improvement in the CSIR's patenting record is attributable to the NCL. With respect to the Institutes of Indian Technology as a whole, he observes that "About 30 per cent of the graduates ... emigrate to the United States. Further information about the operations at NCL, including extensive information concerning their patenting activity (*e.g.*, their extensive patenting activity in the realm of catalysis, as measured by their US patents in this field) may be found at http://www.ncl-India.org/aboutus/patcat.htmi.

feedbacks flowing from these relationships were central to the growing technological sophistication of Korean and Taiwanese labor forces and to the latent entrepreneurial capabilities in both countries.

In some important ways the Indian experience, which is much more recent than that of Korea and Taiwan, is far more portentious for the future. India's recent experience in introducing sophisticated technologies in the chemical sector suggests that new patterns of international specialization may now offer greatly expanded opportunities for technology transfer through market-mediated relationships. So far the most promising developments (Reliance) have catered primarily to the growing needs of India's domestic markets. However, there is no obvious reason why the acquisition of such new technological skills could not eventually be directed at international markets, especially regional markets. India's pharmaceutical sector has already achieved a number of modest successes, including in exports, and it is a field in which the country's much-underutilized, scientific labor force could become part of a future enlarged high-tech success story. It would also be more than a little ironic if India's pharmaceutical success were to be at least partially reinforced by an expanding global system of protection for intellectual property! Finally, India's quite unexpected achievement in the world software industry is now part of a vast platform on which the country may be able to build. The existing global network provided by information and communication technologies offers vast opportunities for specialized roles played by well-trained science graduates whose research findings can now, at least in principle, be instantly transferred anywhere in the world. This would require a continuation of India's market-liberalizing policies of the 1990s and its further integration into the international economy. In this respect, all economic policies are also technology policies, whether or not they are intended to be.

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