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The Dynamics of Technological Learning in Industrialisation

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THE DYNAMICS OF TECHNOLOGICAL LEARNING IN INDUSTRIALISATION1

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ABSTRACT

This paper presents an analytical framework on how industrialization takes place through the development of technological capability in interactions with the evolution of market competition, government policy, corporate strategy, and social culture in the context of developing countries. This framework is applied to Korea to describe the dynamics of technological learning in the industrialization process. The Korean experience suggests a set of implications for other developing countries.

Biographical Note

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INTRODUCTION

In most advanced countries, industrialization has been a process of transformation from a traditional to a modern society. Science and technology have played a crucial role in that process. Many studies show that more than 50 percent of economic growth in advanced countries stems from technological innovation (Grossman, 1991). That is, industrial development is the process of building technological capabilities through learning and translating them into product and process innovations in the course of continuous technological change (Pack and Westphal, 1986).

Technological capability refers to the ability to make effective use of technological knowledge in production, engineering, and innovation in order to sustain competitiveness in price and quality. Such capability enables a firm to assimilate, use, adapt, and change existing technologies. It also enables a firm to create new technologies and to develop new products and processes in response to the changing economic environment. Technological learning is the process of building and accumulating technological capability. To increase competitiveness, both governments and firms should be concerned with capability building. Those activities take place largely at firms, but the government’s public policy can establish important infrastructure that facilitates such activities.

In advanced countries, technological capability is accumulated largely through "learning by research," which expands the technological frontier. In developing countries, in contrast, technological capability is built primarily in the process of imitative "learning by doing." A few newly industrializing economies (NIEs) have made a rapid transition from "learning by doing" to "learning by research." Korea, Taiwan, and Singapore are good examples (Hobday, 1995).

The following analytical framework helps explain the dynamics of technological learning in the process of industrialization. The framework is used to examine Korea’s industrialization experience as a case in point. The Korean experience suggests a set of implications for other developing countries.

ANALYTICAL FRAMEWORK

From an in-depth study of the automobile industry in Korea, Kim (1998) developed an integrative framework for understanding the dynamics of technological learning at the firm level (see Figure 1). It shows that expeditious technological learning takes place through the conversion between explicit and tacit knowledge. Explicit knowledge refers to knowledge that is codified and transmittable in formal, systematic language. In contrast, tacit knowledge is so deeply rooted in the human mind and body that it is difficult to codify and communicate and can be expressed only through action, commitment, and involvement in a specific context. Learning and knowledge creation through the interaction between explicit and tacit knowledge will become larger in scale in an upward spiral progression from the individual to the organizational level (Nonaka and Takeuchi, 1995).

Figure 1 also shows that many variables affect directly or indirectly the spiral process of technological learning. Learning orientation is one of them. In the early stage of industrialization, firms in developing countries undertake the duplicative imitation of existing foreign mature products through reverse engineering. Most second and third tier developing countries are at this stage. Then, as industrialization progresses, they shift their focus from duplicative imitation to creative imitation, producing imitative products with new performance features. Most first tier NIEs are at this stage. When a developing country catches up with advanced countries and reaches the technological frontier, major emphasis shifts from imitation to original innovation. Japan may be the only country that has reached this stage since World War II. Differences in learning orientation affect the speed and nature of the learning process, as they require different kinds and qualities of both explicit and tacit knowledge. For instance, at the duplicative imitation stage, knowledge conversion is easy and fast, requiring few trials and errors, because mature knowledge is generally available and reverse engineering and "learning by doing" are relatively easy to undertake (Kim, 1997a). In contrast, at the creative imitation stage, knowledge conversion is increasingly difficult and requires many trials and errors because the assimilation of available knowledge becomes increasingly difficult. At the innovation stage, it becomes extremely difficult to generate new knowledge through learning and to apply it creatively to produce competitive products and services.

Table 1: Research and Development Expenditures, 1965-1998

	1965	1970	1975	1980	1985	1990	1995	1998
R&D expenditure	2.1	10.5	42.7	282.5	1,237.1	3,349.9	9,440.6	11,336.6
Government	1.9	9.2	30.3	180.0	306.8	651.0	1,780.9	3,051.8
Private Sector	0.2	1.3	12.3	102.5	930.3	2,698.9	7,659.7	8,276.4
Government vs. Private	61:39	97:03	71:29	64:36	25:75	19:81	19:81	27:73
R&D/GNP	0.26	0.38	0.42	0.77	1.58	1.95	2.51	2.52
Manufacturing Sector								
R&D expenditure	NA	NA	16.7[a]	76.0	688.6	2,134.7	5,809.9	6,439.2
Percent of Sales	NA	NA	0.36[a]	0.50	1.51	1.96	2.72	2.64
Number of Researchers (total)[b]	2,135	5,628	10,275	18,434	41,473	70,503	128,315	129,767
Govt Research Inst.	1,671	2,458	3,086	4,598	7,542	10,434	15,007	12,587
Universities	352	2,011	4,534	8,695	14,935	21,332	44,683	51,162
Private Sector	112	1,159	2,655	5,141	18,996	38,737	68,625	66,018
R&D expenditure per researcher (W 1000)	967	1,874	4,152	15,325	27,853	47,514	73,574	87,361
Researcher per 10,000 Population	0.7	1.7	2.9	4.8	10.1	16.4	28.6	27.9
Number of Corporate R&D Centers	0	1[c]	12	54	183	966	2,270	3,760

NOTES: a: for 1976.
b: The figures does not include research assistants, technicians, and other supporting personnel.
c: for 1971.

Source: Ministry of Science and Technology

The learning process is also affected by absorptive capacity, which has two important elements: existing knowledge base and intensity of effort (Cohen and Levinthal, 1990). Existing knowledge base is an essential platform in technological learning, as knowledge today influences learning processes and the nature of learning to create increased knowledge tomorrow. Intensity of effort refers to the amount of energy expended by organizational members to solve problems. Merely exposing firms to relevant external knowledge is insufficient if no effort is made to internalise it. Hence, the greater the existing knowledge base and intensity of effort, the faster and deeper is the spiral process of technological learning.

How can firms increase their existing knowledge base? Technology transfer from foreign firms in advanced countries can be a very important source of new knowledge for firms in developing countries. Technology transfer may be transacted formally through market mediation. Foreign direct investment (FDI), foreign licensing (FL), and turnkey plans are major formal mechanisms. Technology may be transferred informally without market mediation. Original equipment manufacturing (OEM), literature, and human mobility are major informal mechanisms. New knowledge creation through the spiral process of technological learning may also raise the existing knowledge base.

How should firms manage the intensity of effort? Cumulative technological learning can take place under normal circumstances. However, discontinuous learning may take place when a crisis is perceived in market competition and a strategy is implemented to remedy the situation. Just as the term "crisis" in Chinese (*weiji*,) is a combination of two characters (threat and opportunity), some firms use a crisis as an opportunity to intensify their effort and transform technological capabilities in a discontinuous way through expeditious technological learning. Thus, a crisis may be creative rather than destructive (Kim, 1998).

A crisis may be evoked externally when the firm loses its competitive standing in the market or created proactively when top management evokes a sense of crisis by imposing challenging goals. An externally evoked crisis may be a crisis for top management, but not necessarily for lower organizational echelons, who may refuse to recognize the crisis as being real. In contrast, a crisis created when top management proactively imposes ambitious goals on a team generates strong pressure to intensify technological learning efforts and thus make the crisis creative.

The government can use an array of policy instruments to influence the dynamic process of technological learning at the firm level. It can invest for developing human resources, who undertake technological activities. It can also use industrial and R&D policy instruments to create demand for technological learning and strengthen the supply of technological capability. Financial and tax incentives lubricate the interactive process between the demand and supply sides of technological learning (Kim and Dahlman, 1992).

DYNAMICS OF TECHNOLOGICAL LEARNING: A CASE

Most developing countries have tried to industrialize their economies, but the majority of them have made little progress. Korea, one of only a few that has managed to make significant strides has transformed itself from a subsistent agrarian economy into a newly industrialized one during the past four decades. Beginning in 1962, the Korean economy grew at an average annual rate of almost 8 percent, raising GNP per capita in current prices from $87 in 1962 to $10,550 in 1997. Although Korea experienced its worst economic crisis in 1997, its economy bounced back with an impressive growth rate of 10 percent in 1999 and is expected to grow by more than 8 percent in 2000.

Exports increased from a mere $40 million in 1962 to $143 billion by 1999 with significant structural changes. For instance, in the mid-1960s, Korea began exporting textiles, apparels, toys, wigs, plywood, and other labour-intensive mature products. Ten years later, ships, steel, consumer electronics, and construction services from Korea challenged established suppliers from the industrially advanced countries. By the mid-1980s, computers, semiconductor memory chips, videocassette recorders, electronic switching systems, automobiles, industrial plants and other technology-intensive products were added to Korea's list of major export items. Korea began exporting such next-generation products as multi-media electronics, high-density television, and cellular telecommunications systems.

How did Korea achieve such phenomenal growth in technological capability in only four decades? The analytical framework can be applied to the Korean experience to illustrate the dynamic process of technological learning in industrialization. Variables that directly affect the spiral process of technological learning -- learning orientation and absorptive capacity – are the main structural elements of the following discussion. Indirect variables such as technology transfer and crisis construction, as introduced in the analytical framework, also are considered.

Duplicative Imitation Stage

In Korea, duplicative imitation began in such light industries as textiles, toys, plywood, and consumer electronics in the 1960s and in such heavy industries as automobiles, steel, shipbuilding, and machinery in the 1970s.

How did Korean firms acquire the *existing knowledge base* to expedite technological learning in those industries? The three most important knowledge-building mechanisms for Korea in the duplicative imitation stage were education, foreign technology transfer, the deliberate creation of *chaebols* (large family-owned conglomerates), and the mobility of experienced technical people. First, education to develop human resources was one of Korea's most conspicuous efforts in industrialization. Several other developing countries matched Korea's rapid growth rate in elementary education, but Korea was unique in achieving well-balanced expansion at all levels of education early enough to support its economic development. Using data from the late 1950s for 73 developing countries, Harbison and Myers (1964) found three nations – Korea, Taiwan, and Yugoslavia – with levels of educational achievement far above what would be expected, given their levels of economic development. Those are the countries that made remarkable strides in industrialization in the subsequent decades. The data reflect the high commitment to education within Korean society. The expansion of education outpaced economic progress in the early years, creating a severe unemployment problem for the educated. However, the formation of educated human resources laid an important tacit knowledge base for the subsequent development of the economy, which soon absorbed the surplus.

Second, lacking technological capability at the outset, Korean firms relied heavily on foreign sources for both explicit and tacit knowledge. Most of the important or crucial tacit and explicit knowledge needed to solve technical problems in the duplicative imitation stage could be obtained through such informal mechanisms as literature, reverse engineering, and technical assistance associated with OEM manufacturing. That mode of technology transfer clearly prevailed in innovative small firms. Large Korean firms resorted to such formal mechanisms as turnkey plant transfer or technical licensing agreements with foreign suppliers. However, informal technology transfer has been most significant in further broadening the capabilities of both large and small firms (Kim, 1997a).

Third, the government deliberately created and nurtured *chaebols* as engines for rapid economic development. The *chaebols* were the major source of Korean industrialization. They recruited the best-qualified entrants to the workforce, had technical and financial resources to purchase foreign technologies, achieved in rapid diffusion of technological capabilities across subsidiaries by applying experiences gained in one field of business to another, and spearheaded the drastic expansion, deepening, and globalisation of industrial R&D in Korea.

Fourth, the mobility of experienced technical people afforded one of the most effective ways for late entrants to acquire the necessary knowledge base. For instance, the majority of consumer electronics producers in the 1970s entered the industry by poaching experienced managerial and technical people from existing firms. Large state-owned chemical and machinery companies in the 1950s and 1960s relied completely on turnkey transplant and foreign engineers for the initial knowledge base, but engineers who accumulated modern production experience in those firms eventually joined private enterprises to provide the crucial knowledge base there.

How did the Korean government and corporate top management raise the *intensity of effort*? Four major means were export promotion, the hasty creation of heavy and chemical industries (HCIs), technology transfer strategy, and crisis construction. First, given the small domestic market, the government used export promotion as a major instrument for achieving economic growth goals. The export promotion policy created business opportunities and concurrently imposed externally evoked crises as firms engaged in "a life or death" struggle in the competitive international market. To survive the crises and maximize the utilization of capacity in excess of local market size, Korean firms in turn created internal crises to accelerate technological learning by reverse engineering, importing, and rapidly assimilating production technology from abroad.

Second, the Korean government imposed an externally evoked crisis on firms by the hasty creation of HCIs without adequate preparation in technological capability. The Korean government launched the HCI program ahead of its schedule at a much greater intensity and in a much shorter time than previously envisioned. The hasty move was motivated more by the need to build a self-reliant national defence capability after the withdrawal of U.S. forces from Korea than by economic concerns. Such hasty promotion led to a rapid increase in foreign debt, misallocation of resources, inflation, and further concentration of economic powers in the several *chaebols* involved in HCIs. The most significant result of the hasty HCI promotion, however, was expeditious technological learning. Lacking capability, the *chaebols* had to rely almost entirely on foreign sources for technology. Tasks required to assimilate imported technology were so far beyond the capability available at the firms that the HCI program imposed a major crisis in setting up and starting up plants, let alone mastering production technology. Firms were forced to assimilate technology very rapidly by expediting learning as in Figure 1 and in turn upgrade capacity utilization by strengthening competitiveness in order to survive. As a result, it took only 15 years for the ratio of value added in light industries over HCI to fall from four to one in Korea; whereas the same shift took 25 years in Japan and 50 years in the United States (Watanabe, 1985).

Third, government policy and firms' strategy on foreign technology transfer also strengthened the intensity of effort. In the 1960s, the Korean government restricted foreign direct investment (FDI) but promoted instead technology transfer through other means such as capital goods imports. As a result, in contrast to its influence in other developing countries, FDI had a minimal effect on the Korean economy. Such policy forced Korean firms to maintain their management independence from foreign multinationals. Even if some equity participation was allowed for some reasons, management independence was maintained. Hyundai Motors is a good example (Kim, 1998). The policy created a crisis, coercing Korean firms to invest aggressively for technological learning and, consequently, accumulate technological capability.

Unlike foreign subsidiaries that can depend on parent firms to supply technologies, the independent Korean firms had to take initiatives and a central role in acquiring, assimilating, and improving mature foreign technology for duplicative imitation.

Fourth, many Korean firms constructed crises proactively either in response to or in the absence of externally evoked crises by setting ambitious goals as a means to expedite technological learning. Constructed crises increase the intensity of effort at the individual and organizational levels in the search for alternative courses of action to make the crises creative rather than destructive. Crisis construction and expeditious learning were widespread in Korean manufacturing. Firms in the automobiles, shipbuilding, steel, electronics, and machinery industries underwent similar processes of crisis construction and expeditious learning in the duplicative imitation stage.

Creative Imitation Stage

Eroded competitiveness in low-wage-based mature technology industries forced Korean firms in the 1980s to shift their learning orientation from duplicative imitation to creative imitation. The firms needed a significantly higher level of existing knowledge base than that in the preceding stage to bring about creative imitation.

What did the government and corporate top management do to raise *existing knowledge base*? The five major sources of knowledge in the creative imitation stage were formal technology transfer, reverse brain drain, corporate R&D, universities, and government research institutes (GRIs). First, foreign technology transfer continued to be a major means of building the existing knowledge base in Korean firms. Although mature technologies were readily available and could be obtained free of charge through informal mechanisms, sophisticated technologies could be obtained only through formal mechanisms. Obtaining necessary knowledge became increasingly expensive for Korean firms, as is evident from statistics: FDI increased from $218 million in 1967-1971 to $1.76 billion in 1982-1986, whereas FL royalties increased from $16.3 million to $1.18 billion during the same period.

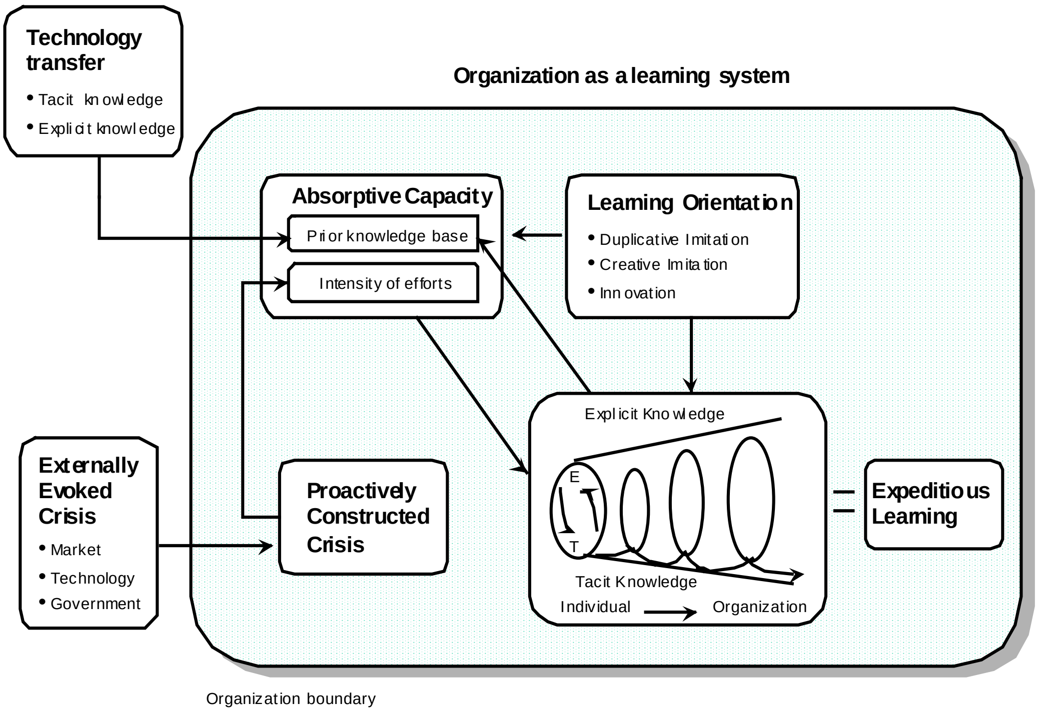
Second, another important source of external knowledge was the reverse brain drain of the high-calibre Korean manpower pool abroad. The Korean government took a relatively liberal policy with regard to the brain drain at the duplicative imitation stage. As of 1967, 96.7 percent of Korean scientists and 87.7 percent of engineers educated abroad remained there, mainly in the United States, in contrast to 35 and 30.2 percent, respectively, for all countries (Hentges, 1975). When industrialization progressed rapidly in the 1970s, the Korean government made systematic efforts to repatriate Korean scientists and engineers from abroad. The state-led reverse brain drain program was quite successful, as few repatriates went back to advanced countries. The program became a model for the private sector, which began assertive recruitment of high calibre-scientists and engineers in the 1980s. Those individuals played a pivotal role in both emerging GRIs and corporate R&D centres.

Third, the emergence and surge of corporate R&D activities was one of the most remarkable characteristics in the creative imitation stage, giving rise to bargaining power in formal technology transfer, assimilation of imported technologies, and generation of new knowledge through knowledge conversion and by research. As shown in Table 1, the number of corporate R&D laboratories increased from one in 1970 to 966 by 1990, reflecting the seriousness with which Korean firms were pursuing intermediate technology development. The total R&D investment increased from W10.6 billion (US$28.6 million) to W3.35 trillion (US$4.68 billion) and the share of R&D in GNP (R&D/GNP) increased from 0.32 percent to 1.95 during the same period. The growth rate was the highest in the world. The private sector accounted for only 2 percent of the nation's total R&D expenditure in 1963 but 81 percent by 1990.

Fourth, the creative imitation stage required universities to produce well-trained scientists and engineers and to have more sophisticated basic capabilities than ever before. However, the poor quality of university education and research was a major impediment to the building of Korea's knowledge base. Frustrated in its efforts to reform the teaching-oriented undergraduate universities, the government founded the Korea Advanced Institute of Science and Technology (KAIST), a research-oriented graduate institution specializing in science and engineering. Nevertheless, one institution could not produce enough graduates to increase the level of firms' knowledge base.

Fifth, in the absence of university research, the government took the initiative in establishing several GRIs by recruiting overseas-trained Korean scientists and engineers. The GRIs were industry-oriented, focusing on such sectors as chemicals, machinery, electronics, ocean science, standardization, nuclear energy, biotechnology, system engineering, and aerospace to serve the growing needs of the private sector. Many experienced researchers produced by the GRIs joined corporate R&D centres.

Figure 1 Integrative Model



What did the government and corporate top management do to strengthen the *intensity of effort*? As in the preceding stage, export promotion and crisis construction continued to be important in the creative imitation stage. First, as Korea undertook structural adjustments from mature technology industries to intermediate technology industries, its competition in the export market shifted from that against other developing countries to that against advanced countries. As a result, the continued emphasis on export promotion made competing more difficult for Korean firms, creating a formidable crisis in the international market. The tougher competition in more technology-intensive industries and the reluctance of the advanced countries to share sophisticated technologies forced Korean firms to intensify their R&D efforts so as to enhance "learning by research."

Second, although creative imitation requires much more ingenuity than duplicative imitation, crisis construction continued to be a useful strategic means of intensifying technological learning effort. The usefulness of crisis construction, however, is related inversely to the degree of creativity required in technological effort.

Innovation Stage

Having mastered intermediate technologies for creative imitation, some Korean *chaebols* began to challenge emerging technologies for innovation. For instance, in semiconductors, Samsung developed the 256 mega and 1 giga dynamic random access memory (DRAM) chips ahead of Japan (Kim 1997b). Although a core patent was licensed from the United States, Korea was the first country to succeed in commercialising code division multiple access (CDMA) mobile telephone technology.

How did Korea reach the innovation stage in terms of the *existing knowledge base*? What problems does it face now? In the preceding two stages, relevant knowledge was readily available elsewhere and Korean firms could copy or purchase it for their own knowledge base. In the innovation stage, however, Korean firms must generate it. Five mechanisms – basic research in universities, mission-oriented applied research at GRIs, intense corporate R&D activities, globalisation of R&D, and the recruitment of high-calibre personnel from abroad – have been used successfully.

First, recognizing the importance of basic research at universities, the Korean government began to transform a dozen or so universities into research-oriented graduate schools. As a result, the number of university researchers more than doubled from 21,332 in 1990 to 51,162 by 1998. In addition, emulating the U.S. experience, the government introduced in 1989 a scheme to establish Science Research Centres (SRCs) and Engineering Research Centres (ERCs) in the nation's leading universities. The number of SRCs and ERCs increased from 13 in 1990 to 35 in

1995. Most Korean universities, however, still are not equipped to provide adequate support for Korea’s economy and industry. Building a strong modern university system will require enormous investment and cultural change and will take at least a decade, if not longer.

Second, in parallel with the increased investment in university research, GRIs played a role in developing some of the significant research results (such as 4M DRAM memory chips, electronics switching system, and CDMA mobile telephone system), which subsequently were passed on to the private sector. In 1992, the government introduced the Highly Advanced National R&D (HAN) Project, also known as the G-7 Project, aimed at lifting Korea’s technological capability to the level of the G-7 countries by the year 2020. A total of US$5.7 billion is to be invested jointly by the government, universities, and industries, about half of which will come from the private sector. Nevertheless, because of the rapid expansion of private R&D activities and increasing intensity of university R&D, reform of GRIs to redefine their roles has been discussed for some time. Organizational inertia and the labour union in GRIs, however, have made it difficult to implement the reforms.

Third, in light of increasing difficulty in obtaining technology from abroad and the growing importance of innovation capability in sustaining Korea’s international competitiveness in recent years, the private sector drastically stepped up its R&D efforts, from W2.37 trillion ($3.36 billion) in 1990 to W.8.27 trillion ($7.52 billion) in 1998. After the Asian crisis, the government greatly increased its R&D investment, but the private sector maintained its proportion of the nation’s total R&D at 73 percent in 1998 (see Table 1). That level is one of the highest among both advanced and newly industrialized countries. The table also shows that the number of corporate R&D centres increased from 966 in 1990 to 3,760 in 1998, reflecting the importance attached to R&D by private firms in recent years.

Fourth, although investment for university and GRI research has increased significantly, Korean firms find it essential to devise other alternatives to build their existing knowledge base for emerging technologies in the face of the rising reluctance of foreign technology suppliers. One alternative is globalisation of R&D, which includes establishment of R&D outposts, merger and acquisition (M&A) of foreign high-tech firms, and strategic alliances with leading multinational firms. C*haebols* established R&D outposts in the United States, Japan, and Europe to monitor technological change and undertake frontier R&D. Samsung’s leapfrogging into semiconductors is a good example of how Korean firms used outposts to acquire the necessary knowledge base (see Kim, 1997b). Korean firms are also acquiring the necessary knowledge base through M&A of R&D-intensive foreign venture firms. However, the globalisation of R&D is so new to Korean firms that they experience a series of trials and errors in managing acquired foreign firms.

A few leading *chaebols* at the innovation stage have begun to form strategic alliances with leading foreign firms to develop future technologies, but the triad of Japan, the United States, and Europe accounts for 95.6 percent of the total number of such ties. Strategic alliances with NIEs, including Korea, account for only 2.3 percent of the total (Freeman and Hagedoorn, 1993). Korea must develop its own technologies to share with rival firms in order to expand its global technology network. Through that process, Samsung Electronics, for instance, emerged in 1999 as the fourth in the world after IBM, NEC, and Canon in number of U.S. patent registrations, which is often used as a surrogate measure of international competitiveness.

Fifth, reverse brain drain became even more important in the 1990s as a way for Korean *chaebols* to upgrade their existing knowledge base and "leapfrog" into state-of-the-art technologies. Many *chaebols* in such industries as automobiles, electronics, and semiconductors lured away some of the best Korean-American scientists and engineers. Korean *chaebols* gave them challenging jobs and attractive compensation packages with considerable independence. Government statistics show that the number of scientists and engineers recruited by corporate R&D centres from abroad was 427 in 1992 alone.

As Korean firms approach the technological frontier, managing the *intensity of effort* is increasingly difficult for them. Four points, however, are apparent. First, continued heightening of market competition is a major source of stimulus for Korean firms. In addition to export-orientation, import liberalization became a new source of stimulus under the World Trade Organization regime. It forced Korean firms to compete against multinational firms not only in the export market but also in the domestic market, creating an externally evoked crisis that caused Korean firms to intensify their effort.

Second, crisis construction is an effective means of expediting technological learning in catching-up, but not in pioneering. Learning goals may be more specific and clearer in catching-up than in pioneering. Catching-up firms can acquire existing knowledge through literature review, poaching of personnel, observation tours, and technology licensing. In contrast, pioneering firms must work with a strategic ambiguity that provides only broad direction (Nonaka, 1988). They have difficulty identifying external sources or relevant knowledge. Consequently, learning in pioneering may be creative but not necessarily expeditious.

Third, Koreans are no longer as hard working as they were in past decades. Democratisation and the labour movement have resulted in significant changes in social and organizational climates; workers became much less submissive than they were previously. The new generation brought up in affluence is less willing to work hard than the older generation, making it increasingly difficult even for catching-up firms to use crisis construction as a means of intensifying learning effort.

Fourth, the Asian crisis of 1997 appears to have created significant dynamisms in the market. To improve short-term liquidity, large *chaebols* reduced their R&D activities by about 13 percent during the year following the crisis (Kim, 1999). The result was a major surge of technology-based small firms in Korea. Well-trained scientists and engineers who had been laid off by *chaebols* formed a large number of technology-based small firms, increasing the number of venture firms from about 100 right after the crisis in early 1998 to more than 7,000 by June 2000. Contrary to general expectations, the number of corporate R&D laboratories increased from 3,060 at the time of the crisis in Korea to 5,200 two years later. SMEs accounted for 95% of that increase.

IMPLICATIONS FOR OTHER DEVELOPING COUNTRIES

Korea's phenomenal growth in building technological capability over the past four decades has many implications for other developing countries. First, export promotion is an effective public policy instrument that creates competitive stimulus for firms to expedite technological learning. It forced Korean firms in export-oriented industries to learn significantly more rapidly and grow faster than firms in import-substituting industries. Likewise, countries with export-oriented industrialization (EOI) grew faster than countries with import-substituting industrialization (ISI). The EOI-oriented NIEs in East Asia grew faster than ISI-oriented counterparts in Latin America.

Second, expanding and improving the quality of education at all levels are among the most fundamental and effective measures governments can take to help firms build an adequate existing knowledge base. Rapid expansion of education at the duplicative imitation stage enabled Korean firms to have an adequate existing knowledge base for technological learning. However, under-investment in upgrading the quality of education in the subsequent stages severely hindered technological learning. Many studies conclude that the quantity and quality of education in an economy are major determinants of whether the economy is catching up rapidly to narrow the gap with advanced countries (Baumol, Blackman, and Wolff, 1991).

Third, a liberal policy on brain drain in the early stage of industrialization can benefit developing countries over the long run. If scarce scientists and engineers are not allowed to migrate to advanced countries before or in the early industrialization stage, many of them will not find suitable jobs at home to advance their technical competence. Brain drain was a problem for Korea through the 1960s, but Korean scientists and engineers eventually returned home and played the pivotal role in cracking intermediate and emerging technologies.

Fourth, a high tacit knowledge base is an important prerequisite to effective technological learning. Three major ways to build it are: (1) recruitment of high-calibre human resources, (2) foreign technology transfer, and (3) learning by research through in-house R&D. The Korean experience shows that those three elements are complementary rather than substitutive. The introduction of higher tacit knowledge through the recruitment of high-calibre scientists enables a firm to challenge more sophisticated technologies in in-house R&D and, in turn, strengthen bargaining power in negotiating technology transfer.

Fifth, technology transfer strategy should evolve over time, as industrialization progresses. When technology is mature and simple, local firms can reverse-engineer foreign products.

When technology is beyond the capacity of local firms, they can rely on foreign licensing and attempt to assimilate the imported technology in the shortest possible time. When the technology is at the intermediate stage, local firms can intensify in-house R&D to strengthen bargaining power in technology transfer negotiations. When technology is at the emerging stage, they can establish R&D outposts in advanced countries and use M&As and strategic alliances to gain access to frontier technologies.

Sixth, intensity of effort is another prerequisite to building technological capability for industrialization. The Korean experience shows that constructing crises by setting ambitious goals is one of the most effective ways to intensify effort at the individual and organizational levels. The goal-focused, high-intensity effort to resolve crises prompts firm members to search actively for information for new ways of responding to them and to expedite knowledge conversion and accumulation at the individual level. That process also intensifies interactions among firm members, giving rise to knowledge conversion and accumulation at the organizational level.

Seventh, public technology policies must evolve over time in response to changes in the market and technology environment. For instance, Korea's national innovation system functioned effectively in the duplicative imitation stage but became problematic in the subsequent stages because the government failed to modernize the nation's educational system and readjust industrial structure in response to changes in the economic environment (Kim, 1993; Kim, 2000).

Eighth, the Korean experience indicates that the role of GRIs should evolve over time. In the early years of industrialization, GRIs should provide technical assistance with the private sector to strengthen its bargaining power in technology transfer and enable it to assimilate and adapt imported technology rapidly. They should also generate many experienced researchers, who could later play a pivotal role in industrial R&D in the private sector. In other words, GRIs should not be evaluated in terms of the number of patents or significant research results generated and transferred to the private sector. Rather, they should be evaluated in terms of their role in helping the private sector to transfer foreign technology economically and to assimilate and improve it effectively. Then, as industrialization progresses to the innovation stage, the role of GRIs can become narrower in the face of rapid expansion of university research and corporate R&D activities.

Some of the Korean experience may be difficult for other developing countries to emulate because of radical changes in the international economic environment. First, the new order of international trade under the World Trade Organization (WTO) will make it difficult for developing countries to protect the domestic market for infant industry learning. Furthermore, because of new pressure under the WTO regime to liberalize the domestic market for products, services, and investments, becoming independent of multinationals will be more difficult for developing countries than it was for Korea.

Second, intellectual property rights protection will pre-empt duplicative imitation of foreign technologies. Reverse-engineering of foreign products for duplicative imitation will be more difficult and costly for developing countries than it was for Korea in the 1960s and 1970s. China, for instance, faces enormous pressure from the United States to honour intellectual property rights, which Japan, Korea, and Taiwan did not face in their early industrialization stage.

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