Korean Innovation Model, Revisited

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ABSTRACT

Over the last decade, some Korean enterprises have emerged to become global players in their specialized products. How have they achieved such tremendous technological progress in a short period of time? This paper explores that question by examining the characteristics of technological innovation activities at major Korean enterprises.

The paper begins with a brief review of the stages of economic growth and science and technology development in Korea. Then, the existing literature, explaining the Korean innovation model, is analyzed in order to establish a new framework for the Korean innovation model. Specifically, Korean firms have experienced three sequential phases, and thus, the Korean model, at the firm level, can be coined as "path-following," "path-revealing," and "path-creating." Then, the stylized facts in the first phase (path-following) and the second phase (path-revealing) are discussed, in the context of empirical evidence from the areas of memory chips, automobiles, shipbuilding, and steel.

In terms of technology development, the Korean model has evolved as "collective learning" in the first phase, "collective recombination" of existing knowledge and technology in the second phase, and is assumed as "collective creativity" in the third phase. Ultimately, all three can be classified as "collective creation".

Korean firms now face a transition in the modes of technological innovation in order to efficiently implement the third phase. To achieve remarkable progress again, as they did in the past, and to sustain the growth momentum, Korean firms should challenge new dimensions such as creative technological ideas, distinctive technological capabilities, and unique innovation systems -- all of which connote 'uniqueness'. Finally, some lessons from the Korean technological innovation experience are addressed.

KEYWORDS: Korean innovation model, dynamic capabilities, catch up, path-revealing, collective creation

1. IN SEARCH OF A NEW ANALYTIC FRAMEWORK

Korean enterprises have aggressively developed their technology and recently closed the gap with world leaders in the West and Japan. How can they shift from imitation status to innovation? What are their critical technology strategies and major modes of technology development? What kinds of evolutionary processes they have developed during the past four decades? Now is the right time to thoroughly investigate their practice and paths of technological progress. This paper tries to clarify the firm dynamics of technological innovation activities as it relates to the major Korean enterprises.

During the last four decades, Korea has been successful in transforming from a developing nation to that of an advanced one. The Korean case provides a particularly good example for many developing economies of a nation that has drastically upgraded its technological capability. However, due to the limited availability of materials, only the overall sketch of the evolutionary processes of technological development activities is briefly touched upon in the paper. Therefore, in-detail analyses and discussions on the subject are left for another occasion.

This paper, thus, aims to explore the possibility of establishing a new framework in the Korean innovation models at the firm level. This paper also examines the key features of new innovation patterns (from the mid-nineties) that Korea is now facing.

As a background for this new framework, the overall economic growth and growth of R&D sector in Korea are reviewed in sections two and three. Then, in section four, some critical literature about the Korean innovation models is discussed. The crux of the paper, a new framework on the evolutionary phases of the Korean innovation models at the firm level and some typical stylized facts of technological innovation activities are consecutively analyzed in sections five and six. And in the final section, some crucial theoretical debates and policy implications from the Korean experience are articulated

2. ECONOMIC GROWTH

During the past four decades, Korea has been cited as an ideal example of a fast growing economy. Table 1 shows a few perspectives of this remarkable economic performance, including GDP per capita, which sharply increased from USD 79 in 1960 to USD 20,045 in 2007. A great leap is also seen in the export volume, from a mere USD 33 million in 1960 to USD 371 billion in 2007.

TABLE 1. Major Economic Indicators

	1960	1970	1980	1990	2000	2007
Population (1000)	25,012	32,241	38,124	42,869	47,008	48,456
GDP (US$, Billion)	2.0	8.1	63.8	263.7	511.8	969.9
Gross Rate of GDP (%)	1.2	8.8	-1.5	9.2	8.5	5.0
GDP per capita (US$)	79	254	1,645	6,147	10,841	20,045
Trade Balance (US$, Million)	-311	-1,149	-4,787	-4,828	11,786	14,643
Exports (US$, Million)	33	835	17,505	65,016	172,268	371,489
Imports (US$, Million)	344	1,984	22,292	69,844	160,481	356,846

Source: The Statistics Korea (2008)

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During this period, Korea has undergone a drastic transformation in its industrial structure, migrating from light industries to heavy/chemical industries, and then, to high-tech industries (OECD, 1996). Broken down into decades, the ultimate objective in the sixties was to lay the foundation for industrialization through the development of industries that would transform the import-oriented market structure to the export-oriented light industries, such as textiles and clothing. Meanwhile, the expansion of labor-intensive industries created a huge demand for machinery, raw materials, and components, which were mainly imported. To cope with this, the Korean government adopted a series of sectoral promotion policies, during the seventies, to facilitate the growth of local machineries, chemicals, metal products, and basic metal industries.

In the eighties, Korea realized the importance of promoting so-called high-tech industries in its effort to join the ranks of the advanced countries. To this end, industrial transformation to high-tech areas, including information technology, biotechnology, and new materials emerged as an urgent task, during the eighties, for both the government and the private sector. Promotion of high-tech industries continued to serve as one of the key items on the agenda, going into the nineties. Many Korean firms put forth their best efforts to strengthen in-house technological capabilities, and they succeeded in emerging as the world market leader in high-tech areas, including memory chips, cellular phones, and flat panel displays. As private firms started to play a greater role and emerge the major national economic driver, after the mid-eighties, the government began to adopt a functional industrial policy that was quite different from the sectoral promotion policies in the sixties and seventies. That is to say, the role of the government has shifted toward establishing sound infrastructure and promoting R&D activities, and away from its previous position of providing direct financial support.

Table 2 summarizes the rapid industrial transformation that took place in Korea over the past four decades. Overall, Korea successfully embraced and skillfully managed the drastic and dynamic changes in its industrial structure. First, starting out from the light industries in the sixties, Korea moved into the heavy and chemical industries in the seventies and eighties, and then shifted to high-tech industries in the nineties and early 21st century.

From another aspect, Korea has been very successful in continuous introduction of new, pivotal sources for economic growth, as shown in Figure 1. The key element of economic growth was labor (light industry) during the sixties, capital (heavy and chemical industry) during the seventies, internationalization (international trade) during the eighties, technology (high-tech industry) during the nineties, and knowledge, information and innovation (high-tech industry and knowledge industry) since 2000. From the technology side, key elements for economic growth were the technique and technicians in the sixties, operation technology in imported capital goods in the seventies, production technology for world-class quality products in the global market in the eighties, and technological innovation and knowledge creation after nineties.

FIGURE 1. PIVOTAL SOURCES OF ECONOMIC GROWTH IN KOREA

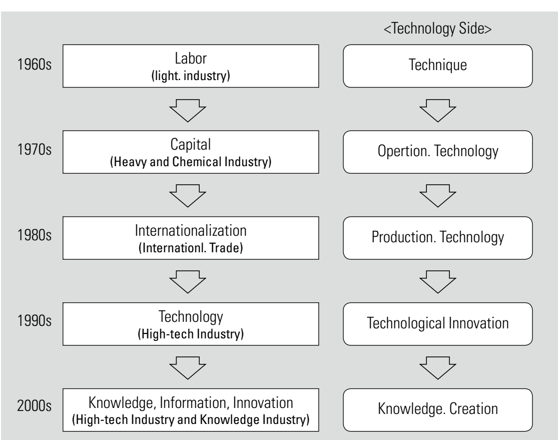

TABLE 2. Top Ten Export Items (1960-2007)

1960			1970		
Item		%	Item		%
1	Iron Ore	13.0	1	Textiles	40.8
2	Tungsten Ore	12.6	2	Plywood	11.0
3	Raw Silk	6.7	3	Wig	10.8
4	Anthracite	5.8	4	Iron Ore	5.9
5	Cuttlefish	5.5	5	Electronics	3.5
6	Live Fish	4.5	6	Fruits & Vegetable	2.3
7	Natural Graphite	4.2	7	Footwear	2.1
8	Plywood	3.3	8	Tobacco	1.6
9	Rice	3.3	9	Iron & Steel Prod.	1.5
10	Bristles	3.0	10	Metal Prod.	1.5

1980			1990		
Item		%	Item		%
1	Textiles	28.8	1	Textile Prod.	11.7
2	Electronics	11.4	2	Semiconductor	7.2
3	Iron & Steel Prod.	9.0	3	Footwear	4.6
4	Footwear	5.2	4	Ships	4.3
5	Ships	3.5	5	TV/VTR	4.1
6	Synthetic Fibers	3.3	6	Iron & Steel Prod.	3.8
7	Metal Prod.	2.3	7	Textile Fabrics	3.6
8	Plywood	2.0	8	Computers	3.3
9	Fish	2.0	9	Audio	3.0
10	Electrical Goods	1.9	10	Automobile	3.0

2000			2007		
Item		%	Item		%
1	Semiconductor	15.1	1	Semiconductor	10.5
2	Computers	8.4	2	Automobile	10.0
3	Automobile	7.7	3	Wireless Telecomm. Equip.	8.2
4	Petrochemical Prod.	5.5	4	Ships	7.5
5	Wireless Telecomm. Equip	4.8	5	Petrochemical Prod.	6.4
6	Ships	4.7	6	Flat Panel Display	4.6
7	Iron & Steel Prod.	2.8	7	Computers	3.7
8	Textile Prod	2.7	8	Synthetic Fibers	3.5
9	Textile Fabrics	2.1	9	Automobile Parts	3.4
10	Electronics Goods/Parts	2.1	10	Iron & Steel Prod.	3.3

Source: KITA, Each Year

3. GROWTH OF THE RESEARCH AND DEVELOPMENT SECTOR

Korea's impressive progress in research and development (R&D) over the last four decades can be largely attributable to the rapid growth in R&D investment and human resources (Choi et al. 1997). Korean total R&D expenditure was USD 31 billion, and the government portion of gross expenditure on R&D (GERD) was recorded as 27% in 2008, as shown in Table 3. The R&D intensity (GERD/GDP) was 3.37% in 2008, which is far beyond the average (GERD/GDP) of advanced countries. The total number of researchers in 2008 was 236,137, which is close to the number of researchers in U. K. and France.

TABLE 3. Major R&D Statistics

	1963	1970	1980	1990	2000	2008
GERD(US$ M)	4	32	321	4,676	12,249	31,288
Gov't vs. Private	97:3	71:29	64:36	19:81	28:72	27:73
R&D/GDP(%)	0.24*	0.39*	0.56*	1.72	2.39	3.37
Researcher(FTE)	1,750**	5,628**	18,434**	70,503**	108,370	236,137

*R&D/GNP
** Head Count (Persons)

Source: MEST, Each Year

TABLE 4. Evolution of R&D System ((%)

	1970	1980	1990	2000	2008
Public Institute (GRIs)	84 (25)	49 (27	22 (16)	15 (11)	14 (10)
University	4	12	7	11	11
Company	13	38	71	74	75

Source: MEST, Each Year

TABLE 5. International Academic Papers (SCI)

	1997	2000	2001	2005	2006	2007	2008
Number	7,852	12,316	14,733	15,705	23,286	25,494	35,569
Share (%)	0.96	1.39	1.61	2.02	2.05	2.17	2.42
Rank	18	16	15	14	13	12	12

Source: MEST, Each Year

TABLE 6. Overseas Patents (U.S.A., Registration)

	1990	1995	2000	2003	2004	2004	2006	2007
Number	219	1,181	3,352	3,980	4,518	4,388	5,990	6,295
Rank	18	9	9	6	5	5	5	4

Source: MEST, Each Year

Korea's R&D structure went through a drastic evolution during the last forty years (MOST, 2008). As evident from the Table 4, the concentration of labs housed in public research institutes rapidly shrunk from 84% in 1970 to 14% in 2008. In contrast, 75% of research labs belonged to the private sector in 2008, marking a remarkable surge from 13% in 1970. Currently, the major performers of Korean R&D are private enterprises. In particular, a small number of Korean global companies in high-tech industries, such as Samsung Electronics, LG Electronics, and Hyundai Motors, comprise the core of private R&D activities. In 2008, the top 5 companies accounted for 39% of the private R&D expenditures. Yet, government-supported research institutes (GRIs) and universities are also very powerful players in Korea.

In addition, Korea has recently achieved outstanding outputs in R&D activities. Thus, the S&T knowledge capacity has rapidly expanded. For example, Korea ranked 12th in terms of international academic papers published in 2008, as seen in Table 5. Overseas patents have also increased drastically. Korea ranked 4th in 2007, in the number of patents registered in the U.S.A., as seen in the Table 6.

The nature of the Korean research system cannot be separately described without, first, considering the characteristics of Korean economic development. During the sixties and seventies, the labor-intensive light industries for export expansion and the capital-intensive heavy industries for import substitution were developed. This development resulted in generating huge demand for technologies, which were not available from domestic sources. Thus, the Korea's science, technology and innovation (STI) policies started promoting the inward transfer of technologies from foreign sources and developing the domestic capacity to assimilate and improve the transferred technologies. The Korean government took a restrictive stance toward direct foreign investment, and relied upon long-term foreign loans to finance the selected industrial investment. This led to massive importation of foreign capital goods and turnkey plants. Industries acquired appropriate technologies and increased technological capabilities through reverse engineering.

Since the nineteen eighties, the Korean economic development has required more sophisticated technologies, while foreign sources have become increasingly reluctant to transfer technologies to Korean industries. The Korean government responded to these challenges by developing national R&D programs and promoting private industrial R&D activities through fiscal and financial incentives. A national R&D program for promoting target areas was launched in 1982 by the Ministry of Science and Technology. Following the national program, a series of national R&D programs have been promoted by many other ministries. Ultimately, since the mid-eighties, the R&D investment of the private sector has rapidly increased, and private enterprises have emerged as the major force of R&D activities.

The characteristics of the Korean research system originate from the fact that the Korean economy has pursued export-oriented growth, which resulted in strong demand and pressure for enhanced technological capabilities. The Korean innovation system clearly shows the powerful dynamism of a highly motivated private sector that is led by global high-tech conglomerates, with strong government support for indigenous technological capability building (Choi et al. 1986). This support includes, GRIs, public R&D programs and high tax/fiscal incentives for private R&D investments. During the course of enhancing technological capabilities, the rich pool of S&T human resources has played the decisive role.

4. EXISTING LITERATURE ON THE KOREAN INNOVATION MODELS

Technological development of developing economies has been extensively studied. However, only the few stage models of technological innovation that relate to the key theme of this paper will be discussed. As shown in Table 7, the following examples are typical stage models that have strongly impacted the establishment of the Korean innovation models, until now.

The stage model of Utterback and Abernathy (1975), based on the perspective of product life cycle, has provided a basic framework for other analytic models of technological innovation activities in Korea. Kim (1980) applied this framework in analyzing the early period of technology develop-

TABLE 7. Stage Models of Technological Innovation

	Stages of Technological Innovation	Analysis Unit
Utterback and Abernathy (1975)	fluid→transition→specific	productive segment
Kim (1980)	acquisition→assimilation→improvement	industry
Dahlman et al. (1987)	production capability→investment capability→innovation capability	firm
Lee et al. (1988)	initiation→internalization→generation	from unit tech. to global
Kim (1999)	duplicative imitation→creative imitation→innovation	firm

ment in Korea and concluded that Korea followed the framework in a reverse direction. Specifically, Korea started from the acquisition stage, which can be matched with the specific stage in advanced countries, and then shifted into the assimilation and improvement stages, but in a reverse way. Lee et al. (1988) also applied the framework with a reverse direction and similarly concluded that Korea moved along the ladder toward the global level of fundamental technologies. Later on, Kim (1999) summarized the evolutionary stages of technological innovation activities in Korea, until that point in time, and confirmed that the Korean enterprises transitioned into the innovation stage.

However, in spite of these valuable studies, there are some critical views on the existing literature. Those major studies do not reflect new trends of technological innovation activities in Korea, especially after the mid-nineties. These new trends are completely different from the previous modes and, more importantly, are creating Korea's independent technologies and products, which can be competitive in the world market. For example, Kim (1997) wonderfully explained the transition processes from imitation to innovation in major Korean enterprises, but did little to address new trends in technological innovation activities, from that time to the present. Another criticism is that the insider's view, at the firm level, should receive much more attention than the outsider's observation of firm technological innovation activities, as the former view has been neglected in the past. For example, from the insider's view, problem solving and problem defining are the most urgent and critical issues in innovation studies, but have not been dealt with in the past. Until now, only a few in-depth analyses on inside innovation activities at the firm level have been conducted. The third criticism is that technological learning activities are very important factors for technological capability building, but there are other factors, such as technology strategies and efficient technology management that should be considered, as well. In the past, technological learning in studying technological innovation in development economies received too much attention and was treated as if it were a kind of panacea.

Thus, a new trend emerges to explain the patterns of technological innovation in Korea. This new trend can be found in Lee and Lim (2001). It provides empirical evidence in which Korean industries achieved three types of catching-up development, coined as path-creating, path-skipping and path-following. Hobday et al. (2004) articulated that Korea is approaching the global frontier and stressed that, based on the latecomer firm's perspective, Korea is facing a transition from catch-up to technological leadership. Song et al. (2007) clarified that Korea is shifting into a post catch-up period and, at the firm level, there are three patterns in this trend: deepening of accumulated technologies, architectural innovation through recombination of existing technologies, and science-based technological innovation. Lee et al. (2008) also recognized the importance of path-creating capability of leading industries in Korea. This study emphasized the need for three capabilities: the capability to manage core competencies, the capability to integrate internal and external knowledge sources, and the capability to pursue innovation policy and strategy. These studies notwithstanding, in order to further develop this new framework, more in-depth studies on inside innovation activities at the firm level are needed.

5. PHASES OF TECHNOLOGICAL INNOVATION

Private enterprises have also made aggressive efforts to build up in-house R&D capabilities and succeeded in establishing a strong R&D base. As a consequence of massive in-house technological ef-

TABLE 8. Performances of Korean Enterprises

• Memory Chip	World market leader since 1998 (50%, 2008)
• CDMA	World market leader since 1998 (38%, 2008)
• TFT-LCD	World market leader since 2001 (46%, 2008)
• Shipbuilding	World market leader in 1999 (37%, 2008)
• Automobile	Global market share (5%, 2008)
• Steel	Global market share (4%, 2008)

Source: MKE (2009)

forts of private firms, several Korean products have emerged as market leaders in the world, as seen in Table 8. In the area of memory chips, Korean players have held the largest market share since they secured this post for the first time in 1998, and their market share remained at 50%, in 2008. In particular, Samsung has continuously been ranked as the leading company in the world market, since 1992. In the CDMA (Code Division Multiple Access) front, Korean firms held the world's largest market share at 57 % in 1998, and that market share was 38% in 2008. In the case of TFT-LCD (Thin-film Transistor Liquid Crystal Display), Korean firms posted 46% of market share in 2008, sustaining their market leadership since 2001, and Samsung has been the largest provider since 1998. After Korean companies achieved the top market share in the shipbuilding sector in 1999 with 41%, they continued to maintain their top position, with 37% in 2008. Korea's market share in the steel industry in 2008 was 4%, and 5% in the automotive industry in 2008, with Hyundai as the largest provider since 1983.

The technological innovation of private enterprises can be broken down into three phases (Choi et al 2008). The first phase can be named as the 'Path-Following', in which the most technological knowledge and production know-how was transferred from more advanced foreign firms. The role of the Korean companies in this phase was mainly confined to absorb and acquire imported technologies by technology learning and localization, as well as to make small modifications to fit to the local production environment. In that sense, the focus of technological innovation activities was to set up countermeasures regarding imitation issues. As noted in Table 9, by this phase, the development path of products and means to develop products, were known to individual firms, making them competitive in the world market. Typical products in this phase are 64K DRAM (dynamic random access memory), 4M DRAM, analog cellular phone, tanker, bulk carrier, standard automobile, and general steel as noted in Table 10.

The second phase can be classified as 'Path-Revealing'. Korean enterprises have succeeded in generating new frontier products with their in-house technological innovations, but the underlying original ideas and core knowledge were borrowed from external parties, and the technological path of progress were known to many. Thus, it lacked technological originality. Instead, the focus of technological innovation was the problem solving for innovation. In addition, the development path of products was known, but the means to develop competitive products in the world market was unknown to individual firms, as noted in Table 9. Typical examples in this category include

TABLE 9 Phases of Technological Innovation

	Phase I : Path-Following	Phase II : Path-Revealing	Phases III : Path-Creating
Focus	problem-solving for imitation	problem-solving for innovation	problem-defining for innovation
Development path	known (available)	known (available)	unknown
Means to achieve	known (available)	unknown	unknown
Fundamental tech.	foreign	foreign+ in-house	In-house+ outsourcing
Critical element	reverse engineering	process technology	architecture & new process technology
Core mode	collective learning	collective recombination	collective creativity

Source: Choi et al. (2008).

TABLE 10. Typical Products by Phase

	Phase I	Phase II	Phase III
Memory Chip (Samsung)	• 64K, … , 4M / 16M DRAM	• 256M, 1G, 4G DRAM • Flash Memory • Multi Chip Package	• Memory + Logic • PRAM
Mobile Phone (Samsung)	• Analog Cellular phone	• Anycall • WiBro • DMB	• 4th Generation
Shipbuilding (Hyundai)	• VLCC • Tanker • Bulk Carrier • Container Ship	• LNG Carrier • On-Ground Building Method • Cruise Ship* • Yacht* • Super Liner*	• Eco ship • New Concept Ship: Ultra speed / Super large
Automobile (Hyundai)	• Pony • Excel • Sonata • Alpha Engine	• Accent • Theta Engine • Hybrid Electric Vehicle* • Fuel Cell Vehicle*	• Intelligent Vehicle • Hydrogen Vehicle
Steel (POSCO)	• Mass Production of General Steel • Top-rate Operational Technologies	• High Value-added Steel • Advanced Mill: Kwangyang Mill • FINEX Process • MMIM*	• HIPERS (Super Steel)

* Targets to challenge in the second phase

Source: Choi et al. (2008).

256M DRAM, NAND (not AND) flash, mobile handset, On-Ground Building Method in shipbuilding, Theta Engine in automobile, FINEX (fine iron ore reduction) process in steel, and so on (Table 10). For the time being, these types of technological innovation activities have been quite prevailing in many Korean enterprises.

The third phase can be noted as ‘Path-Creating’. This is a phase in which new products are developed solely with in-house innovative capabilities, and the original ideas and technological novelties were derived from their own proprietary R&D efforts. In the phase, it is possible to have a certain level of technological input from external sources, but the initiative and the overall management of the development lies under the control of in-house members. What distinguishes this phase from the previous one is the ability to acquire its own set of new product architecture from internal resources and innovation activities. Thus, the focus of technological innovation was problem defining for innovation, including problem solving for innovation in the next stage. In addition, the development path of products and the means to develop products, which are competitive in the world market, were unknown to individual firms (Table 9). At present, it seems that there are only a few examples that apply to Korean firms in the third phase, but the candidate products with high potential, include memory with logic, PRAM, 4th generation mobile handsets, eco-ships, new concept ships, intelligent vehicles, hydrogen vehicles, and super steel (Table 10).

One thing to note, in particular, is that the core mode of technological development activities in the Korean enterprises can be expressed as “Collective Creation”. As shown seen from the successful cases, key features in creating path-breaking new products or technologies include formulation of task force team (TFT) by direct involvement of CEO, mobilization of best in-house manpower for target technologies, team approach for common targets by division of labor among members, TFT member's all-out, day and night efforts to achieve the tasks within given time frame, and the provision of best research conditions given by the CEO. During the course, those TFT members are forced to focus more on achieving given target goals through the application of their expertise and knowledge instead of deepening their specialty knowledge. As shown in Table 9, this type of collective creation has been materialized by "collective learning" in the first phase, "collective recombination" in the second phase, and in the third phase, "collective creativity" is the central factor that leads to success.

In summary, Korea has been assessed to be quite successful in the first and the second phases of technological innovation, as described by 'best practices' within Korean context. However, now the challenge is the successful transition to the third phase of technological innovation, which is certainly going to be the more advantageous approach for the 21st century. Some of the key elements of this new phase are creative technological ideas, distinctive technological capabilities, and a unique development system – all of which connote 'uniqueness'. In other words, acquiring salient assets in technological innovation would be the key aspect for Korea's success in the 21st century. To efficiently achieve such a goal, Korea needs to develop new elements. They are, to name a few, architecture and platform technology, creative human resources, fundamental technology, fusion technology, sophisticated parts and components, software and service, networking among innovation actors, and path-navigating innovation. Moreover, to transform successfully into the third phase of technological innovation, Korea should acquire a sufficient level of knowledge and systems to solve the 'unknowns' in development paths and means to develop competitive products in the world market. These might not be easy tasks for Korean firms to handle with their current capacity and potential.

6. STYLIZED FACTS OF TECHNOLOGICAL INNOVATION

Those products developed in the first phase of technological innovation have different types of technological innovation activities according to the nature of the product, level of in-house technological capability, and maturity of the world market. However, common characteristics do exist.

First, products developed by Korean firms are based on technological knowledge or processing technologies imported from other advanced countries. This technology, import through both formal and informal channels of technology transfer, has served as an important part of technological progress. Moreover, the aggressive technological learning activities were also vital to building and enhancing technological capability.

Second, due to the lack of in-house R&D capabilities, Korean firms have focussed on the so-called standardized items, with their strength lying in the mass production system. This indirectly illustrates Korean companies' inclination toward technological development paths with lower technological uncertainties. The target goal was the acquisition of production and process technologies, and technological novelty was not the main concern, particularly at the earlier stages. Tremendous emphasis was placed on in-house engineers to internalize and match outside technological sources, and this was what enabled and drove such a rapid increase in technological capability. Local engineers were equipped with strong commitments to catch up with the leading companies as early as possible, despite the presence of high technological entry barriers.

Third, the key concern of Korean firms was to catch up with leading firms in a short period of time. The major Korean firms had a strong will to establish an independent brand from the beginning. They carried out aggressive investments, even in hard times, and also took initiatives to develop new products by focusing on critical technologies that were two-steps ahead. Parallel product development through concurrent engineering was other crucial instrument for Korean firms.

Fourth, Korean firms set their targets to mostly focus on the export market rather than the domestic market. Their level of standard was to produce world-class quality products that were competitive in world market. Exporting products enabled domestic engineers to obtain opportunities to learn the latest technologies. In that sense, "learning-by-using" contributed to the technological progress of Korean firms. In addition, tough and rapid changes in international market conditions demanded that Korean firms improve the quality of their products, increase productivity in the production process, and sustain a high level of investment for technological learning.

Fifth, Korean firms have relied on a certain level of prior experience in terms of a technological base or business activity in related areas when they entered a new market. In addition, while making technological progress, Korean firms undergo a very tough and critical period of technological core formulation process, and only firms that overcame that challenging period of acquiring core technologies have succeeded in providing competitive products to the world market.

Another factor shared among many cases was the presence of a pioneering top management with long-term vision, as well as technological insight who were ready to make long-term commitments to the targeted item. Their direct involvement in the technology development process has been of paramount importance. These pioneers have shown strength in techno-management capability, i.e. the ability to combine technology and business know-how, and the courage to give up on technological novelty that seems to hold no business prospects.

Those common elements of stylized facts in the second phase of leading Korean enterprises can be summarized as long-term commitment and hard working in developing new products, exploiting accumulated knowledge and experience, developing own new ideas and unique systems, active search for outside sources and cooperative partners, strengths in mass production, market-oriented R&D, internally trained local talents leading the efforts, and limited technical assistance for production technologies from local institutes. It is very meaningful to scrutinize those stylized facts in the second phase of technological innovation at Korean enterprises. The frontline for Korean enterprises is the second phase of technological innovation.

Here, the four typical cases in the first and the second phase of technological innovation at the major Korean enterprises are briefly discussed. The cases described in this section are summarized from Song et al. (2007), Lee et al. (2008), and Choi et al. (2008).

Memory Chips: Samsung Electronics Co. ❙❙ The stages of technological capability building in the Memory Chip Sector of Samsung Electronics Co. can be divided into the stage of introduction (1977-1982), the stage of assimilation (1983- 1992), and the stage of self-generating (1992-present). The Memory Chip sector emerged as the world market leader since early 1990s, and, since that time, it has enjoyed the market leadership position in the world.

Choi (1996) analyzed the technology development activities in the early stage of Memory Chip sector. Technology importation was the key source of technology development in the early stages. Design technologies were imported from an American company and process technologies from a Japanese company. Following the initial technology import, a series of technology imports were carried out. But there was no large-scale, foreign direct investment, joint venture, or original equipment manufacturing in the beginning. Also, there was no large-scale technology import after 1M DRAM. However, heavy reliance on equipment and materials from foreign suppliers had been established for a long time.

Aggressive technological outsourcing has also been carried out. Massive technological training and education programs were conducted in both an American company and a Japanese company. In addition, learning from consulting was a very important measure, mostly for problem solving. Samsung excellently utilized consultants, and the purchase of patents was actively implemented to prevent patent conflicts.

There were also active technological learning activities, such as apprenticeship and on-the-job training, which were used as key means to accumulate production know-how. Hard work was also another key element. For example, the 'eleven meeting', implemented during the initial stages, which meant that team members meet at 11: 00 P. M. to review the day's work and also to set up plans for the next day's work. Other learning activities included, aggressive operation of concurrent engineering, rigorous management of TFTs, direct involvement of top management on in-detail technology matters, excellent choices for technology paths.

The key success factors (KSFs) of Samsung were as follows: very capable human resources, excellent infrastructure and incentives, critical mass of core manpower; long-term investment and commitments; top management leadership, high risk-taking, economy of speed, open system, resource concentration, flexible adjustments, and a competitive environment.

NAND Flash : A Best Practice in the Path-revealing Phase ❙❙ In the memory chip sector, NAND Flash emerged as the next most promising item, followed by DRAM, and Samsung decided to put all its efforts into those technologies, in early 1990s. Samsung developed a series of consecutive products, mainly relying on in-house manpower and accumulated experience. To become a technological leader in this area, Samsung mobilized a huge amount of financial resources to R&D activities and production facilities. It is interesting that Samsung refused the cooperative partnerships offered by Toshiba at the development of its early version of the product, instead aiming for the top spot as the future technological leader in the field.

Early 1990s, after three years of development, Samsung was the second company in the world to develop the 16M NAND Flash, followed by Toshiba. The mass production of 16M NAND Flash started from 1994, and Samsung has kept the highest market share of NAND Flash in world market since 2002. Samsung consecutively developed the 32M NAND Flash in 1995, 64M in 1997, 128M in 1998, 256M in 1999, 1Gb in 1999, 90nm 2Gb in 2002, 60nm 8Gb and 40nm 32Gb in 2006, and 30nm 64Gb in 2007. Thus, Samsung has achieved the technological leadership as well as the market leader in this area. In addition, Samsung has kept its technological leadership position in new architecture of multi-chips as OneNAND, OneDRAM, and FlexOneNAND. Recently, Samsung succeeded in achieving world-class technological novelties in 30nm 64 GB such as CFT (Charge Trap Flash) and SaDPT (Self-aligned Double Patterning Technology). The CTF is a breakthrough technology, surpassing the existing 'floating gate flash' which has been in use for the past 35 years.

NAND utilized those technological base and production knowledge that was accumulated during DRAM area. Production processes in both areas are mutually applicable and exchangeable. The most critical element in NAND is the process technologies and NAND's process technologies were indebted to the competitive edge of DRAM's process technologies and accumulated experience. NAND adopted those superior strengths and systems in DRAM area as concurrent engineering, creating a close connection between R&D and production.

Automobile: Hyundai Motor Company ❙❙ The stages of technological capability building in the Hyundai Motor Company can be divided into the stage of assembly manufacturing (1967-1974), the stage of establishing independent brand (1975- 1990), and the stage of self-generating (1990-present).

Technology importation was the key source of technology development in the early stages. And it has evolved as following stages: 1) Operation technology such as after sales service, material management manuals, and parts drawings; 2) Element technologies from diversified sources such as design, engine, manufacturing; 3) Technological alliance with technology service companies in the field of test, decoration, exhaust control; and 4) Academic research for fundamental technologies.

Aggressive technological outsourcing was carried out as follows: Training and education from finished car makers; Technical advice and consulting from foreign experts; Training and education from technology service companies; Recruitment of high caliber manpower with master degree and Ph.D. degrees; Joint R&D activities with outside research institutes.

There have also been active technological learning activities such as aggressive on-the-job training for production know-how, expert engineers being assigned as foremen, deepening of technological capabilities for target technologies through powerful technological division of labor, introduction of advanced design and production technologies like CAD, CAM, 3D design and simulation, and the establishment of R&D institutes.

The KSFs of Hyundai Motor Company were economies of scale with strengths in mass production and CEO leadership to overcome several difficulties in its growth paths. The major driving forces of technological competitiveness were strong desire to establish its independent brand from the beginning, effective 'constructed crisis' management to boost up the fast internal learning of key technologies, and strong supports from top management in providing favorable R&D infrastructure.

Theta Engine: A Best Practice in the Path-revealing Phase ❙❙ Hyundai succeeded in developing the Alpha Engine in 1991 as its first independent engine. Since then, Hyundai has developed ten gasoline engines. Along the way, Hyundai developed a new engine for high performance, fuel efficiency improvement, durability, quietness, and environmental friendliness to meet the enforced environmental restrictions. This Theta Engine was mounted on the NF Sonata platform in September 2004, after four years of development efforts from 2000-2004.

Its functionality is considered to be at the same level as the engines of Toyoda Camry and Honda Accord. The key features are aluminum alloy, metal timing belt, variable valve timing, and balance shaft. It was developed through a joint effort with DaimlerChrysler and Mitsubishi, with Hyundai receiving a royalty of USD 57 million from them. DaimlerChrysler and Mitsubishi adopted the engine in 2005. During the development processes of the engine, 70 local and overseas patents were acquired. The engine is known to have the largest production capacity as a single engine of 2 million units per year, around the world.

Shipbuilding: Hyundai Heavy Industries ❙❙ The stages of technological capability building in the Hyundai Heavy Industries can be divided into the stage of imitation and improvement of production technologies during the 1970s, the stage of diversification and deepening of its products and design technology during the 1980s, and the stage of self-generating from the 1990s to now.

Technology importation evolved as follows: All shipbuilding-related technologies such as design drawings, production technologies, production technologies, design technologies, core technologies for high value-added and specialty vessels, and academic research for fundamental technologies. Furthermore, the major modes of technological outsourcing were as follows: hiring of foreign engineers, massive overseas training and education, technological alliances with and consultations from its counterparts.

Active technological learning was performed as follows, aggressive on-the-job-training, technological learning and education by hired foreign engineers, expert engineers being assigned as field engineers, recruitment of capable technicians from other Hyundai companies, establishment of in-house training center to cultivate technical manpower, and establishment of a series of R&D institutes.

The KSFs of Hyundai Heavy Industries were economies of scale with strengths in mass production, top class design manpower and skilled technicians, and stable local supply chains of materials and components particularly steel materials and shipbuilding engines. The major driving forces of technological competitiveness were all-out efforts to foster its own technological manpower, active import of technologies, utilization of foreign engineers and overseas technical training, and introduction of advanced production technologies such as CAM, CAM, and 3D technology.

On-Ground Building Method: A Best Practice in the Path-revealing Phase ❙❙ Hyundai developed a new method, building its commercial ships on the ground instead of in a dry dock. Hyundai broke the conventional concept that a 'ship is constructed in dry dock', and opened up a new era in shipbuilding history. Hyundai was unable to meet the increasing demand for shipbuilding, due to fully booked dry dock schedule. Thus, it tried to find a new solution to overcome the limitations from the conventional dry dock method. The so-called "On-Ground Building" method had already been verified through the construction of drilling rigs and other huge offshore structures. But, for the first time in the world, Hyundai adopted this method for building ships in October 2004.

It took Hyundai numerous tries, over one and half years, to develop the method. Key features of the method are as follows: the ship is constructed on the ground by using huge crane, loaded out transversely to quayside and on to double barge unit by skidding system of air-pad & skid rail. Then, the double barge unit of semi-submersible is towed, using tugboat, to a pre-determined site and ballasted down to float-off the ship from the double barge unit. Hyundai achieved the same productivity, in the same construction period, as the conventional dry dock method. Furthermore, other methods such as 'floating dock' at sea, was also developed by another Korean company.

Steel: POSCO ❙❙ The stages of technological capability building of POSCO can be divided into the stage of imitation of imported technology during the 1970s, the stage of improvement of imported technology during the 1980s, and the stage of self-generating from the 1990s to the present (Bae et al. 2002).

Technology importation evolved as follows: introduction of performance-proved superior facilities, advanced production systems and quality products, state-of–the-art equipments and components, literature survey on core technologies, and academic research for fundamental technologies.

The major modes of technological outsourcing were as follows: massive overseas training and education for operation technologies, technological advice and consulting by foreign experts, mainly by Japanese, invitation of foreign experts for core technologies, and overseas training and education for fundamental technologies.

Massive technological learning were carried out as follows, aggressive on-the-job training for operation technologies and production know-how, top class engineers assigned as foremen in charge of factory operation, Saint Technician System i.e., special treatment to top quality technicians, joint problem-solving with and informal learning from foreign engineers, efforts for technological improvement of equipments and production systems, and establishment of R&D institutes.

The KSFs of POSCO were economies of scale with strengths in mass production, the government's active supports in early stage including sufficient supply of infrastructure, and adoption of the latest production facilities. The major driving forces of technological competitiveness were securing of long-experienced company engineers and technicians with powerful internal promotion system, active technological learning through in-house and overseas training, acquiring of world class operation technologies by skilled engineers in production sites, and active internal R&D activities to internalize the next generation of technologies.

FINEX: A Best Practice in the Path-revealing Phase ❙❙ POSCO became the first company in the world having the 1.5 M TPY (ton per year) scale plant of FINEX in May 2007, which could compete with large-scale blast furnace plants. FINEX is a type of the smelting reduction method, an alternative way to make virgin iron in the integrated steel mill. Many companies have tried to develop new iron making processes, from 1970s, in order to overcome fundamental limitations of the blast furnace process (the dominant design in iron making for more than 100 years), yet none succeeded in developing a new process with mass production.

POSCO was a latecomer in the steel industry, but rapidly increased its capability to produce a high quality product and develop process technologies. Consequently, POSCO became competitive in mass production of general steel and top-rate operational technologies. However, its capability for basic research and new process development remained poor.

As a technological latecomer in developing this new iron-making process, from 1990 to 2007, long-term commitment and hard work was coupled with large-scale investments and long-term project teams. Also, huge amount of effort was put into making thoughtful technology choices. In-house manpower in R&D, engineering, and operation became a strong base. In addition, long-term, close collaborations with a capable partner, Siemens VAI, became another critical factor in POSCO's success. POSCO has plans to replace the first and second blast furnaces in Pohang Mill with this process in the future. POSCO also is trying to establish large-scale plants of FINEX process in India.

Patterns of Technological Innovation

The first pattern of technological innovation begins with sophistication and deepening of technologies that were accumulated during the path-revealing and path-creating phases. Typical examples, in Korea, are the NAND Flash in Samsung Electronics, the Theta Engine in Hyundai Motor Company, and the On-Ground Building Method in Hyundai Heavy Industries. The second pattern is the technological innovation within given paths achieved by recombining those accumulated technologies with fundamental technologies outsourced. Typical examples, in Korea, are the CDMA in Samsung Electronics, the FINEX in POSCO, and the Factive (the first Korean drug approved by FDA in U. S. A.) in LG Chemicals. Those two patterns belong to the second phase of path-revealing in the Korean enterprises.

The third pattern would be the technological innovation opening new paths by restructuring those existing technologies, whether in-house or outside. A typical example is the I-pod for Apple.

The fourth pattern would be technological innovation opening new paths by science-based knowledge. A typical example would be customer-centric treatments based on stem cells. Anyway, the third and fourth patterns belong to the third phase of path-creating in the Korean enterprises, but there is no empirical evidence that has materialized in Korea.

7. LESSONS FROM THE KOREAN EXPERIENCE

It would be worthwhile to look at some of the implications, regarding technological innovation activities, identified from the Korean enterprises. First of all, strong production capability opens the door to become a world market leader, even without novel, world-class technological and technological breakthroughs. Secondly, technological learning and absorptive capacity are important elements, but to be a technological forerunner, agile strategies and effective systems for technological capability building are equally critical. Thirdly, strong willingness of the top management (i.e., 'genes' in evolutionary perspective) is a very essential factor for rapid corporate growth. Fourth, dynamic firm capabilities are desire able, even up to the environment-creation stage. Fifth, technologically-known paths are uncertain and risky to individual firms (i.e., in-house knowledge base is very important), but the ability to internalize production activities is more valuable. In essence, the most important lesson learned from the Korean experience seems to boil down to this phrase; "Everyone can get the same technology. But, that doesn't mean they can make an advanced product", which is Samsung's perspective on technological innovation, cited from Business Week, June 16, 2003.

From a different aspect, the internal dynamics of major Korean enterprises can be summarized as the following three dimensions. The first dimension is the economy of scale, which encompasses strong mass production system in highly standardized items; large-scale and massive in-house technological learning; production of world class products focusing on global markets than domestic; and maintaining high productivity by efficient production management system. The second dimension is the economy of speed which includes factors such as module-type development and strong integration ability of production processes, concurrent engineering and parallel product development system, close interface between R&D and production departments, and active import and outsourcing of technological knowledge. The third dimension is the dynamic firm capability. This includes high risk-taking, in terms of technology and market, long-term commitment to technology development made possible through the 'Chaebol' system, top management leadership with long-term vision as well as technological insight, and benchmarking of global standard from the beginning. Furthermore, one other critical factor to be noted is that the real power behind these Korean enterprises comes from their ability to achieve all three dimensions simultaneously, when for many, even one isn't easy.

On the other hand, the role of government has been very crucial as well. The Korean government has, in many ways, been successful in building the basic structure of the national innovation system in a very short period of time. The government has managed to cultivate R&D actors as GRIs, private sector R&D institutes, and university research labs. Second, the government has been committed to mobilizing the necessary resources including human resource development. The third success factor employed by the government has been building infrastructure including, Daeduk Science Park, equipments and facilities, and supporting institutions. In sum, the government-led system contributed to a rapid growth of the science and technology sector in the early stages, but private firms became a major driving force later on. It is particularly worthwhile to note that the Korean government has not pursued a dominant position in science and technology development. Instead, the government sought to promote a private-led system in technological innovation from the beginning.

Overall, the most important issue in Korea's preparation for the 21st century is to what extent Korea has sown new seeds of Korean technological innovation, developed unique technological ideas, and built an advanced technology development system. Korea has only recently started down this path and has a long way to go. In this regard, it would be meaningful to examine the chances of establishing a Korean innovation model as noted above. But it is not yet robust enough to become a more concrete framework. In other words, Korea is at a midpoint of her journey and has another half to go. Thus, additional empirical evidence is required to build a complete set of Korean innovation models.

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