Innovation, Competitiveness, and Growth: Korean Experiences

SUNGCHUL CHUNG

Science, technology, and innovation have been cited as one of the key factors behind the economic success of the Republic of Korea. By making continuous and massive investments in research and development and in innovation, Korea has succeeded in building a unique innovation system that supports sustainable growth of the Korean economy. The factors that have influenced the Korean innovation system the most are (1) outward-looking development strategy, (2) large firm–oriented industrial policy, and (3) human resources, among many others. These are the sources of both the strength and the weakness of the system. This paper reviews the developments of science and technology in Korea, evaluates their impacts on industrial development, and attempts to derive from the discussions some lessons that may be applicable to latecomers.

Over the course of four decades, the Republic of Korea has transformed itself from a stagnant agrarian society into one of the world's most dynamic industrial economies. In the early 1960s, when Korea first launched its industrialization efforts, it was a typical developing country with a poor base of resources and production, a small domestic market, and a large population. Korea's gross national product (GNP) in 1962 was only $2.3 billion (in 1980 prices) or $87 per capita, which came mainly from the primary sectors.[1] The manufacturing sector's share of GNP remained at a mere 15 percent. International trade was also at a very infant stage: in 1962 the volume of exports was only $55 million, and the volume of imports was $390 million. But Korea is now the thirteenth largest economy and one

Sungchul Chung is a research fellow emeritus at the Science and Technology Policy Institute (STEPI).

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of the major trading countries in the world. It has achieved world prominence in areas such as semiconductors, liquid crystal displays, telecommunications equipment, automobiles, shipbuilding, and so on. Indeed, it is one of the key players in the global economy.

Korea has achieved in four decades what it took more than a century for the Western industrial countries to accomplish. A rich literature on Korean growth attributes Korea's success to an assortment of factors, but there is broad agreement that the Korean government's "outward-looking development strategy," well-educated and well-disciplined workforce, and technological innovation have combined to bring about what is called the "Korean miracle."

Of the three factors, this paper focuses on the role of technological innovation. What stimulated and facilitated Korean industries to engage so actively in research and development (R&D) and innovation? What has been the role of government in the process? And, to what extent has technological innovation improved the competitiveness of Korean industries and supported economic growth? The paper discusses these issues, with a view to drawing some lessons from the Korean development experience. The paper starts by reviewing what Korea has done to learn and acquire technologies for industrialization and how Korea has promoted R&D and innovation and built up technological capability. It then analyzes the contribution of R&D and innovation to industrial competitiveness and economic growth in Korea. Finally, it draws some lessons for latecomers.

How Korea Learned and Acquired Technologies for Industrialization

In the 1960s Korea was barren in the fields of science and technology. There were only two public institutes for scientific research and technological development: the National Defense R&D Institute, which was created right after the end of the Korean War, and the Korea Atomic Energy Research Institute, which was founded in 1959; there were fewer than 5,000 research scientists and engineers in the public and private sectors combined.[2] In 1963 R&D expenditures remained at $9.5 million.

Fortunately, Korea had a well-educated workforce relative to other developing countries. The Korean workforce had an average of 4.98 years of schooling in 1960, and the elementary school enrollment rate reached 100 percent as early as 1970. Korea's educational attainment in the 1960s stood fairly close to the level expected for a country twice as wealthy as Korea (Cohen and Soto 2001). For this, Korea owes much to the Confucian tradition, which holds education and scholarship in high esteem.[3]

In this setting, Korea launched the First Five-Year Economic Development Plan in 1962. Lacking technological capability, Korea had to rely almost totally on foreign sources of technology. Korea's policy strategy was geared to promoting the inward transfer of foreign technologies, while, at the same time, developing domestic capacity to digest, assimilate, and improve upon the transferred technologies.

Korean Strategy for Technology Learning

Foreign direct investment (FDI) is often cited as a key to technological learning and one of the most effective means for latecomers to learn new production skills and acquire managerial expertise. However, the Korean government discouraged FDI by restricting ownership and repatriation of profits and imposing requirements on technology transfer and exports. Such a restrictive policy was inevitable because the public viewed multinationals as perpetuating the country's economic and technological dependence and as reinforcing the asymmetrical relationship between the industrial and developing countries (Koo 1986; Vernon 1977; Stewart 1978).[4] For this reason, FDI played a less important role in Korea's acquisition of capital and technology than it did in other developing countries.

The purchase of technology through foreign licensing was also of modest importance in Korea because of the government's imposition of foreign exchange controls. Being a typical agrarian economy relying on agriculture for almost three-quarters of national production, Korea in the 1960s simply could not afford to buy technology from foreign sources. It therefore curtailed foreign licensing, which often entails long-term financial commitments.

As an alternative to foreign licensing, Korea financed industrial investments through long-term foreign loans. The Korean government brought in large-scale foreign loans and allocated them to investments in select industries, leading to massive importation of foreign capital goods and turnkey plants (see table 1). Industries later reverse-engineered the imported capital goods for the purpose of acquiring needed technologies. The government selected not only the target industries for investment but also the entrepreneurs who would implement the new investment projects, and some of those entrepreneurs later became the owners of "chaebols" (defined and discussed later in this paper). The FDI policy had much to do with the unique industrial structure of Korea.

How Private Industries Responded

The response of private companies to such restrictive policies varied across industries. In the case of light industries, such as shoes, clothing, textiles, and some intermediate goods for import substitution as well as export, the major sources of technological learning were OEM (original equipment manufacturing) production arrangements.

TABLE 1. Channels for Technology Transfer in Korea, 1962–81

US$ millions

Time period	FDI	Foreign licensing	Capital goods
1962–66	45.4	0.8	316.0
1967–71	218.6	16.3	2,541.0
1972–76	879.4	96.6	8,841.0
1977–81	720.6	451.4	27,978.0

Source: Data from the National Statistical Office.

Korean firms benefited most from such arrangements because they offered opportunities to work with foreign buyers who provided everything from product designs and materials to quality control at the end of the process. This was especially so in the case of garment and electronic industries (Hobday 1995).

In the 1970s Korea's development target shifted to more capital- and technology-intensive industries, and the government implemented massive investment projects to build up machinery and chemical industries. For the development of chemical industries, Korea relied largely on the importation of turnkey plants, which offered technical training programs as part of the package. In the case of heavy machinery, foreign licensing was an important channel for technology acquisition (Chung and Branscomb 1996).

To help industries to adopt new technologies, the government created government R&D institutes in the fields of heavy machinery and chemicals, such as the Korea Institute of Machinery and Metals, the Electronics and Telecommunications Research Institute, the Korea Research Institute of Chemical Technology, the Korea Research Institute of Standards and Science, the Korea Institute for Energy Research, and the Korea Ocean R&D Institute. These institutes worked with private industries to build a technological foundation for industrial development.

As a result, FDI had a minimal impact on the Korean economy, accounting for only 4 percent of Korea's cumulative total long-term foreign capital over the period of 1962–82 ($9 billion). According to a United Nations report, FDI in all developing countries in the early and mid-1970s accounted for 10–20 percent of their total foreign capital inflow (Ahn 1991). Over the period of 1962–71, FDI inflow in Korea remained at $264 million, while imported capital goods reached $2.9 billion.

In short, Korean industries acquired technology more from informal than formal channels. As informal channels involve less market mediation, they are less costly; they also require recipients to have higher capacity, not just in identifying and selecting technologies, but also in absorbing, assimilating, and improving upon the transferred technologies.[5] Korea was able to acquire technologies for industrialization through informal channels as a result of its rich pool of well-educated, motivated people.

Building a Base for R&D and Innovation

While promoting technological learning for industrialization, the government also made efforts to build a base for science and technology (S&T) development during this period. The Science and Technology Promotion Act and the Science Education Act were passed in 1967 as a legal base for S&T development. The Korea Institute of Science and Technology (KIST) was established in 1966, followed in 1967 by the Ministry of Science and Technology (MOST), the central government agency responsible for S&T policy. In 1970 the government enacted the Korea Advanced Institute of Sciences Act, which created the basis for the Korea Advanced Institute of Sciences (KAIS; currently KAIST). KIST was the first organization dedicated strictly to R&D in Korea, while KAIS brought the U.S. graduate education system to Korea. In the 1970s various government research and development institutes were also established to assist industries in absorbing and assimilating technologies. In the early stage of development, these institutions made two important contributions: first, they helped industries to acquire new technologies, and second, they helped to build indigenous R&D capability by repatriating many established scientists and engineers from abroad. In 1974 the government started construction of the Daeduk Science Town, where many public and private R&D institutes, including the government research and development institutes, are now clustered.

Costs and Benefits of the Korean Strategy

The industrialization of Korea in the early phase was a process of learning how to absorb and improve on imported foreign technologies for industrial development. Technological learning, as opposed to indigenous technology development, was at the core of the development strategy. These efforts brought positive results. Around the end of the 1970s, Korea began to export items such as ships, semiconductors, and television sets.

The Korean approach to acquiring technology had both positive and negative effects. On the positive side, this policy enabled Korea to acquire technologies at lower cost and precluded the constraints often imposed by multinationals on the efforts of local firms to develop their own capability. The approach was effective in maintaining independence from the dominance of multinationals. On the negative side, Korea had to give up access to new technologies that might have been available through direct equity links with foreign firms. By restricting FDI, Korea failed to adopt global standards in domestic business operations.[6] The most important lesson here is that had it not been for the well-educated workforce, it would not have been possible for Korea to succeed in acquiring and using technologies through informal modes of technology transfer.

How Korea Has Been Able to Build Up Indigenous R&D Capability

As industrial development continued into the 1980s, the technological requirements of Korean industries became more complex and sophisticated, making it increasingly difficult for Korea to acquire technologies through informal channels. Even though the government eased its restrictions on FDI and liberalized foreign licensing, FDI and foreign licensing did not increase significantly. To sustain development, many saw the need to build indigenous R&D capability.

From Technology Learning to Technology Development: A Policy Shift

The government responded to the changes in the technology environment by launching the National R&D Program in 1982 and taking various policy measures to promote and facilitate private R&D activities, including tax incentives, financial assistance, procurement, and other promotional actions.

First, the government introduced policy incentives that provide private firms with tax exemptions or tax breaks for investments in R&D and human resource development. In 1981 the government revised the Local Tax Law and the National Tax Reduction Law to exempt real estate dedicated to R&D purposes from local taxes and reduce the corporate tax for expenditures on R&D, human resource development, and related facilities. One year after that, the Tariff Law was changed to reduce tariffs on imported materials and instruments for R&D.

Second, in 1981 the government created the Korea Technology Development Corporation, a bank specializing in technology financing, in order to facilitate the development and commercialization of technology. The government reinforced financial supports for technology development by establishing a nonprofit guarantee institution called the Korea Technology Finance Corporation in 1989, whose major function is to help small and medium enterprises (SMEs) to obtain loans for development or commercialization of technology. The government complemented these measures by establishing the Industrial Development Fund (1986), the Science and Technology Promotion Fund (1991), the Information and Telecommunication Technology Fund (1993), and other programs to facilitate commercialization of new technologies. The financial system for technology development in Korea was completed with the opening of KOSDAQ, a technology stock market.

Third, a procurement program was introduced in 1981 to promote demand for new technology products developed by SMEs, followed by many other support programs, such as technical and legal consultancy services, technology information services, technology trade and transfer, and so on.

Fourth, government R&D investments have increased significantly since the early 1980s, when Korea's S&T policy underwent a fundamental shift from technology learning to technology development. The Ministry of Science and Technology launched the National R&D Program in 1982, which was followed by the Industrial Base Technology Development Program of the Ministry of Commerce, Industry, and Energy, the Information and Communication Technology Development Program of the Ministry of Information and Communication, and others. These initiatives promoted industrial R&D by providing private industries with opportunities to cooperate with the public sector and by inducing private R&D investments for commercial purposes.

According to a study conducted by the Science and Technology Policy Institute (STEPI 2005), the Korean government was offering 259 programs in support of industrial R&D and innovation. R&D subsidies accounted for 30 percent of all support programs, technology transfer accounted for 13 percent, and support for human resources development accounted for 11 percent. The government expended \$3.4 billion for loan programs, and \$3.3 billion for R&D subsidy programs. The tax revenue forgone because of the tax incentive programs amounted to \$1.5 billion in 2005. In contrast, human resource development support programs received only 1 percent of the total budget spent that year (see table 2).

Figure 1 describes the R&D support policy of the Korean government. As indicated, Korea's S&T policy focused on promoting learning from foreign sources as well as building up infrastructure for R&D and human resource development before

TABLE 2. Industrial R&D and Innovation Support Programs in Korea, 2005

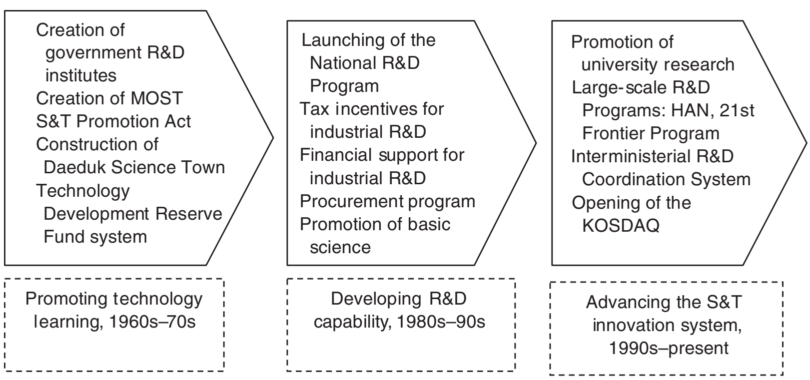
	Programs		Budget	
Category	Number of programs	% of all programs	US$ millions	% of all program budgets
Tax incentives	17	6.6	1,480[a]	15.9
Loans	15	5.8	3,402[b]	36.6
Procurement	2	0.8	394	4.2
Human resources development	29	11.2	106	1.1
R&D subsidies	77	29.7	3,253	35.0
Technology trade	8	3.1	61	0.7
Technology transfer	33	12.7	225	2.4
Technology consultancy	27	10.4	44	0.5
Legal assistance	29	11.2	34	0.4
Technology information	22	8.5	294	3.2
Total	259	100.0	9,296	100.0

Source: Shin and others 2006a.

a. Tax revenues forgone.

b. Amount of loan available.

FIGURE 1.
Development of S&T Policy in Korea



Notes: MOST = Ministry of Science and Technology; HAN = Highly Advanced National R&D Program; KOSDAQ = a technology stock market.

1980. After 1980, it shifted toward nurturing indigenous R&D capability and, at the same time, promoting and facilitating private industrial R&D.

This marked a turning point for the Korean innovation system not only because of the changes in policy orientation but also because of the changes in the role of government in science, technology, and innovation. Before the change, the government set the development target, selected the strategic technologies, and financed the implementation of development programs. So, in the early development process, the government played the role not only of planner and rule setter but also of financier. This was particularly true in the areas of R&D and innovation.[7]

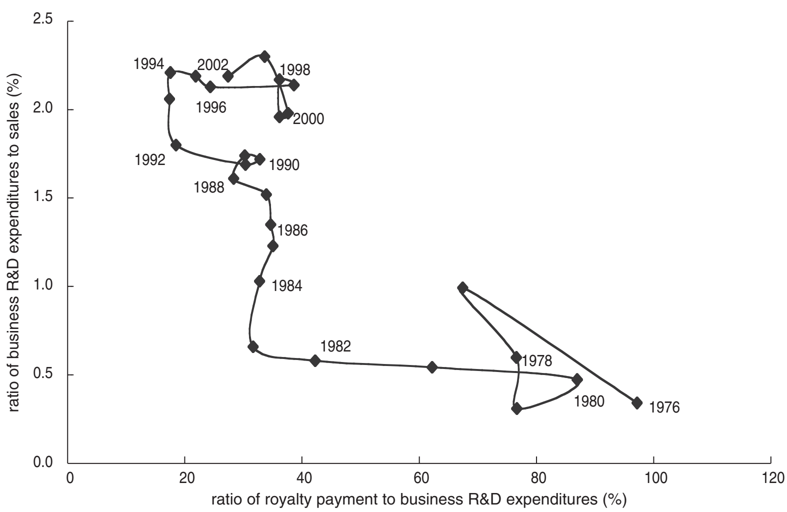
How Industries Responded to the Change

Private industries responded to the changes in policy by investing massive amounts in R&D. Most of all, the number of industrial R&D centers registered at the Korea Industrial Technology Association grew very rapidly: there were 129 industrial R&D centers in 1984, 200 in 1986, 2,000 in 1995, and more than 17,000 in 2009. Consequently, the relationship between technology imports and R&D changed. The ratio of technology imports to business expenditures on R&D declined sharply, from more than 90 percent in 1975 to 30 percent in the mid-1980s.[8]

As figure 2 shows, in the 1970s and early 1980s, the ratio of royalty payments to business expenditures on R&D in Korea was almost 100 percent, which means that Korean industries spent as much money on licensing foreign technologies as on R&D. But the ratio declined to 30 percent in the mid-1980s and to less than 20 percent in the early 1990s. In contrast, the ratio of business expenditures on R&D to sales rose rapidly, from a mere 0.5 percent in the 1970s and the early 1980s to more than 2 percent in the 1990s. By the early 1990s, Korean industries' mode of technology acquisition shifted from borrowing and learning from foreign sources to conducting indigenous R&D.

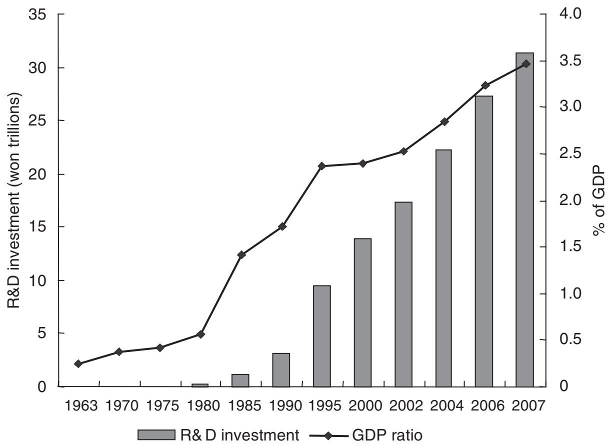
R&D investment has since undergone a quantum leap. Korea's R&D investment, which stood at only W 368.8 billion ($526 million, 0.81 percent GDP) in 1981, rose steadily to reach W 31.3 trillion ($33.7 billion, 3.47 percent of GDP) in 2007. Over a period of 25 years, investment in R&D increased more than 60 times. Korea invests a larger share of its income in R&D than other countries with the same or higher income. Korea now is the sixth largest spender on R&D among Organisation for Economic Co-operation and Development (OECD) countries.

FIGURE 2.
Changing Relationship between R&D and Technology Borrowing in Korea, 1976–2002



Source: Extended from OECD (1996).

FIGURE 3.
Growth of R&D Investment in Korea, 1963–2007



Source: KOITA.

R&D Structure

The rapid growth of R&D in Korea has been led by the private sector. Today, private industries account for about 75 percent of the nation's gross R&D expenditures, which means that private industries are the dominant players in Korea's R&D. Of the total industrial R&D expenditures in 2007, manufacturing industries took up about 90 percent. Manufacturing R&D is largely led by electronic equipment (including office equipment, electronic components, and communications equipment, at 49 percent), automobiles (18 percent), and chemicals (11 percent). Electronic equipment, automobiles, and chemical industries absorb almost 80 percent of manufacturing R&D, suggesting a very high concentration of manufacturing R&D in a few industries.

The average R&D intensity of Korean industries was 2 percent in 2007, and the intensity of manufacturing industries was 3 percent. The industries that invested the largest share of sales in R&D include medical and precision equipment (8 percent), communications equipment (7 percent), and electronic components (6 percent). In contrast, construction, pulp and paper, food and beverages, and textile industries invested less than 1 percent of sales in R&D (see table 3).

Industrial research is highly focused on development (72 percent) and applied research (13 percent), with the remaining 13 percent devoted to basic research. Of the total industrial R&D, 80 percent was for new product development, while only 20 percent was for the improvement or development of processes.

Industrial R&D activities in Korea are highly concentrated in large enterprises. The 20 largest companies account for 56 percent of the total manufacturing R&D, the top 10 companies account for 50 percent, and the top five companies account for 44 percent. In electronic components, the share of the top 20 companies is 91 percent (see table 4). The extremely high concentration of industrial R&D

TABLE 3. Manufacturing R&D, 2007

Industry	R&D expenditures (won billions)	R&D intensity (%)
Total	21,339	2.97
Food	331	0.76
Textiles	146	0.86
Pulp, paper	40	0.71
Chemicals	2,399	1.49
Nonmetal minerals	142	1.20
Basic metals	171	0.63
Fabricated metals	75	1.92
Machinery	1,617	3.56
Office equipment	343	4.29
Electronic components	7,624	6.33
Communications equipment	2,886	6.71
Medical and precision equipment	205	7.50
Automobiles	3,831	3.42
Others	56	1.39

Source: KOITA 2008.

TABLE 4. R&D Concentration in Manufacturing, by Sector and Size of Firm, 2007

percent

Sector	Top 5 firms	Top 10 firms	Top 20 firms
Manufacturing	44.3	50.2	55.7
Chemicals	21.9	32.4	45.9
Electronic components	85.7	89.5	91.4
Communications equipment	64.9	69.4	73.1
Automobiles	67.6	76.4	88.3

Source: KOITA 2008.

reflects the industrial structure of Korea, which is oriented toward large firms. The top five companies in R&D investments are Samsung Electronics, LG Electronics, Hyundai Motors, Hynix, and GM Daewoo Auto and Technology, all of which are "chaebol" companies.

Another unique feature is that foreign funds and institutions have a limited role in R&D and innovation in Korea. Probably due to the once restrictive FDI policy, foreign funds seldom flow into Korea for industrial R&D. The proportion of foreign funds in Korea's industrial R&D expenditures remains at 0.3 percent, while in many of the OECD countries, foreign funds account for more than 10 percent of domestic outlays for industrial R&D (OECD 2008a, 2008b). Given Korea's position as one of the world's major trading countries, it is surprising that the role of international funds and institutions in research and technology remains so low.

The Impact of the 1997 Financial Crisis on R&D and Innovation

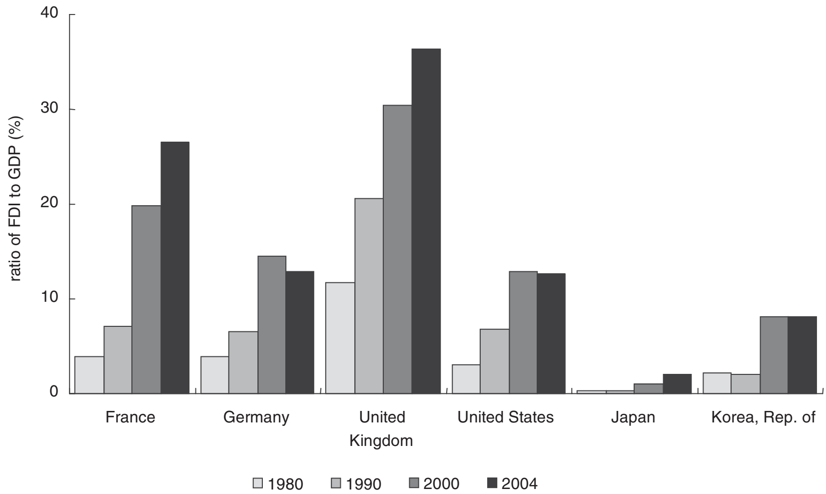
R&D in Korea had been growing rapidly and continuously until Korea was hit by the financial crisis in 1997. R&D was severely damaged by the crisis. Industrial R&D expenditures decreased 10 percent in nominal terms from W 884.4 billion in 1997 to W 797.2 billion in 1998; R&D personnel declined 15 percent from 102,000 in 1997 to 87,000 the following year. This was a serious blow to the Korean innovation system. If the crisis had continued several more years, the Korean innovation system would have collapsed. Fortunately, Korea recovered from the crisis relatively quickly: it took only two years for industrial R&D to recover and surpass the level prior to the financial crisis (see figure 4). Two factors explain this development: one is that the government made up for the decrease in industrial R&D expenditures by increasing government R&D expenditures. The share of government in gross R&D expenditures increased from less than 20 percent before the crisis to 27 percent during the crisis. Government R&D funds flew into private industrial sectors—in particular, small technology-based firms—and helped them to maintain and expand their innovation activities. The other is the promotion of information technology (IT) and IT-related ventures, which led to an IT boom in the early 2000s. The government's commitment to IT development is evident: the share of information technology in government R&D expenditures rose from 13 percent in 1997 to 34 percent in 2002. Such a pro-IT policy fueled innovation in the IT sector, which then spurred innovation activities in other sectors. This policy not only helped the Korean innovation system to recover its former vitality but also promoted Korea's transition to an information society.

The financial crisis brought about two important changes in R&D and innovation in Korea. As firms—in particular large enterprises—downsized their in-house R&D activities, many of the research scientists and engineers who were let go established small-scale, technology-based start-up firms. The number of industrial R&D centers increased despite the reduction in R&D expenditures in the private sector.[9] As a result, the role of SMEs in R&D and innovation became more important than it had been before the crisis.

Second, before the financial crisis, inward FDI had been insignificant for many years and played a minor role in the Korean economy (see figure 4). This was especially true in technology and innovation. In the early stage of development, companies acquired technology largely through informal channels; in the later stage, technology transfer in the private sector was in the form of licensing contracts rather than FDI (OECD 1996).

However, the situation began to change as Korea shifted its policy in the face of the crisis. FDI inflows into Korea increased sharply, as a result of depreciation of the local currency and asset values, the government's deregulation and liberalization of FDI, and the investment opportunities created by corporate restructuring as well as privatization of government-owned companies. FDI companies clearly have played an important role in technology development, as their share in the Korean economy has increased.

FIGURE 4.
Ratio of FDI to GDP in Select Countries, 1980–2004



Source: United Nations 2005.

Factors behind the Rapid Growth in R&D and Innovation

Since it started the drive to develop technology in the early 1980s, Korea has emerged as a major investor in R&D. What made this possible, and, in particular, what motivated private industries to engage so actively in R&D and innovation? Many factors have contributed to the rapid increase in private sector R&D investment, but two are paramount: demand factors and supply factors.

On the demand side, the government's economic development projects generated huge demand for technologies. In addition, international market competition placed tremendous pressure on Korean industries to be technologically competitive. On the supply side, Korean industries were able to meet the increasing demand for R&D and innovation because they were financially able to do so and because their investments were backed by well-trained human resources. The government contributed to this development in several indirect ways, too.

Economic Development Plans Based on an Outward-Looking Development Strategy

In the early stage of development, the government's economic development projects were the major force driving R&D and innovation in Korea. The Five-Year Economic Development Plans implemented during the period of 1961–91 specified strategic targets for industrial development. To attain the targets, companies had to invest heavily in technology acquisition, which included R&D.

Another important factor is the outward-looking development strategy adopted as a means to overcome the constraints on development, such as lack of capital and technology, limited market, and so on. The government's outward-looking development strategy drove domestic industries into the international market, putting them under fierce pressure to compete with foreign companies. In order to survive, companies had to invest heavily in R&D.

Many studies have shown that the more oriented a company is toward international trade, the more it invests in R&D and innovation. A recent study at STEPI has confirmed this relationship using the Korean Innovation Survey data (STEPI 2005).[10] The empirical study shows that companies with higher export intensity (export volume to total sales) tend to invest more in R&D and innovation (Shin and others 2006b). The study also finds a negative relationship between innovation activities and market concentration. In other words, companies operating in a more competitive market invest more in R&D and innovation. International competition motivates companies to invest in innovation. But a reverse relationship may also hold, as more innovative companies are more likely to compete well internationally and sell more in the international markets. In that sense, the two are mutually reinforcing, and so the effects of one on the other are determined simultaneously.

Role of Chaebols

On the supply side, the government's industrial policy favoring large firms gave birth to a unique business organization in Korea: the "chaebol," a conglomerate of businesses that is similar to the prewar "zaibatsu" of Japan. Chaebols, usually controlled by the founding families under a highly centralized structure of ownership, enjoy great financial affluence owing to economies of both scale and scope. But do chaebol companies support innovation? There are two views. One argues that in such a business structure, the major shareholder may pursue his or her private interests at the cost of those of other shareholders, is likely to seek short-term personal benefits rather than long-term company benefits, and may not actively pursue innovation. Another argues that business conglomerates like chaebol may be able to reduce transaction costs and share risks through internal transactions, while, at the same time, pooling financial resources for major investment projects. Furthermore, under the chaebol system, decision making is highly centralized, enabling the company to respond quickly to opportunities.

Only a few studies have directly investigated the differences in innovation behavior between companies belonging to chaebols and independent companies. Recently, a group of researchers at STEPI analyzed this issue using data from the Korea Information Service covering 51,270 observations for the period of 1987–2003 (Shin and others 2006a). Of the total observations, 2,064 are for chaebol companies. The study divided the period into two: before the financial crisis (1987–97) and after the crisis (2000–03), because the government changed the regulations governing the chaebol system during the financial crisis (1997–99). The new regulation bans cross-financing and cross-investment between and among chaebol companies, making the pooling of financial resources and sharing of financial risks between and among chaebol companies impossible. In other words, chaebols in the original sense disappeared toward the end of the 1990s.

TABLE 5. R&D Expenditures and Number of Researchers, by Size of Firm, 1997–2003

	Small and medium enterprises			Large enterprises		
R&D activity	**1997**	**2000**	**2003**	**1997**	**2000**	**2003**
R&D expenditure						
Amount (won billions)	1,090.2	2,106.4	3,425.4	7,755.1	8,148.2	11,084.2
Percentage of sales	2.82	3.14	3.57	2.07	1.81	2.05
Number of researchers						
Total	17,703	36,494	52,332	56,990	57,839	71,698
At the doctoral level	474	1,543	2,291	3,613	3,878	5,562

Source: MOST various years.

The statistical analysis for the pre-crisis period shows that chaebol companies were more able and more likely to invest in R&D than independent companies. But the analysis for the postcrisis period could not find any statistically significant differences in innovation behavior between chaebol companies and independent companies. This supports the argument that chaebol companies, in the original sense, are big international operators, have deeper pockets, are able to engage in risky and expensive R&D projects that are unthinkable for independent companies, and therefore, invest more in R&D and innovation than independent companies. This finding and the high concentration of R&D expenditures in a limited number of large enterprises suggest that chaebols contributed significantly to the growth of R&D and innovation in Korea (see table 5).

Human Resources

Another supply factor relates to human resources. Korean industries have been able to increase R&D investments rapidly, thanks to the abundant pool of well-educated human resources. In both developed and developing countries, R&D investment is constrained more by a lack of human resources than by a lack of financing. Korea prepared itself well for development by investing heavily in education and human resource development.[11] Reflecting the investment in education, the school enrollment rate at the tertiary level in Korea increased from 16 percent in 1980 to 37.7 percent in 1990 and to 52.5 percent in 2000. The number of full-time researchers also grew rapidly from 39,000 in 1985 to 100,000 in 1995 and to 180,000 in 2005. The number of full-time researchers per 1,000 economically active persons in Korea was 9.2 in 2007, which is lower than in Japan (10.7), but higher than in other advanced countries, such as the United Kingdom (6.1 in 2006), France (7.7 in 2006), and Germany (6.7 in 2006; see OECD 2008a).

Government-Support Programs

In order to promote private innovation, the Korean government offers various forms of incentives for industrial R&D and innovation.[12] Overall, Korea employs grants and tax credits as the major instruments to promote industrial R&D; these are complemented by support programs such as procurement, technical consultancy, information, technology transfer, and so on. According to a recent survey, 259 small and large programs support private R&D and innovation (Shin and others 2006a).

How effective have these programs been in promoting industrial R&D? There have been a few attempts to evaluate the effectiveness of the policy programs (for example, Lee and Jang 1998; Shin and others 2006b). Quantitative assessments are especially needed, but full-scale quantitative analysis is not possible due to the lack of data. In 2006 STEPI undertook a survey of private industries to assess the effectiveness of the government incentive programs. The results of the survey and data from the 2005 Korean Innovation Survey formed the basis of STEPI's econometric analysis. Both the survey results and the econometric analysis find that all categories of support programs have been effective in promoting private R&D and innovation, except the procurement program. The econometric analysis finds the tax incentive to be the most effective, followed by the loan program, human resource program, and technical consultancy. This is consistent with the OECD evaluation: "Tax incentives for R&D in Korea are generous and cover every stage: facility investment, R&D outlays, technology transfer" (Baek and Jones 2005).[13]

The STEPI survey also identifies gaps between what private industries want and what the support programs offer. According to the survey, industries demand more government support at earlier stages of innovation. Specifically, industries need more government support at the stages of information gathering and planning (24 percent) and R&D (41 percent), while the current programs are focused on R&D (58 percent), commercialization (13 percent), and marketing (21 percent). In short, the current programs, which place greater emphasis on the later stages of innovation (commercialization and marketing), do not reflect the reality that industries need more assistance at the earlier stage (information gathering and planning).

What Korea Reaped from the Investments

Evaluations of the performance of R&D and innovation activities in Korea are mixed. Korea excels over other countries in R&D inputs, such as human resources and financing, but lags far behind in output. Moreover, R&D results have not been linked effectively to industrial uses.

Despite such criticisms, one cannot deny the positive contributions that the R&D and innovation efforts have made. Rapid growth in R&D investment has led to a remarkable increase in patent registration. The number of patents registered with the Korea Industrial Property Office increased from 1,808 in 1981 to 123,705 in 2007, an increase of almost 70 times in 26 years. Furthermore, Korea ranked fourth in the world in the number of 2007 Patent Cooperation Treaty applications, triadic patents registered in 2006, and U.S. patents registered in 2007. In the production of industrial property, Korea trails only the United States, Japan, and Germany. Of these, U.S. patents are sometimes used as an indicator of a nation's international technological competitiveness. Only five U.S. patents were granted to Koreans in

1969, compared with 1,161 in 1995 and 6,295 in 2007, putting Korea in fourth place in the world (see table 6). According to the U.S. Department of Commerce in the late 1990s, Korea was prominent in technology areas such as information technology, pharmaceuticals, advanced materials, and automotives (Albert 1998).

Another important development is the remarkable increase in the number of scientific publications in internationally recognized academic journals. According to the Science Citation Index, the number of scientific publications written by Koreans increased from a mere 171 in 1980 to 25,494 in 2007. Korea is now the twelfth largest producer of scientific publications in the world (see table 7).

R&D efforts have also contributed to the development of high-tech industries in Korea. Korea's technological competitiveness in semiconductors, displays, cellular phones, computers, telecommunications equipment, and so on is partly the result of the government-industry collaborative R&D.[14]

Even though Korea acquired technological competitiveness in many high-tech products, its reliance on foreign core technology continues. For example, Korea succeeded in commercializing the CDMA (code division multiple access) technology, but the Korean cellular phone manufacturers paid a cumulative royalty of more than W 5 trillion to Qualcomm from 1995 to 2008 (NSTC 2009). Korea's overseas royalty payments are concentrated in the areas where Korea is known to have international competitiveness. Korea's industrial R&D and innovation have been focused too much on commercializing foreign technologies and too little on developing original technologies, such as new materials, components, devices, and designs.

TABLE 6. Number of KIPO Patents Granted and U.S. Patents Granted to Koreans, 1985–2007

Type of patent	1985	1990	1995	2000	2005	2007
Korea Industrial Property Office (KIPO) patents issued	2,687	7,620	12,512	34,956	73,512	123,705
U.S. patents granted to Koreans	41	225	1,161	3,314	4,352	6,295
Korea's world ranking in U.S. patents issued	24	9	8	8	7	4

Source: KOITA and U.S. Patent and Trademark Office.

Note: In 1981, 1,808 KIPO patents were granted.

TABLE 7. Number of Korean Publications in the Science Citation Index, 1980–2007

Indicator	1980	1985	1993	1997	2000	2007
Number of Korean publications	171	1,227	2,997	9,124	12,245	25,494
Rank in the world	—	37	27	17	16	12

Source: Korea Industrial Technology Association.

Note: — = not available.

The Link between Innovation and Industrial Competitiveness

In a neo-Schumpeterian sense, success in forging industrial competitiveness through innovation may imply a sustainable increase in the share in the market or in world trade (Cantwell 2003). Based on this, it is possible to assess the contribution of R&D and innovation to industrial competitiveness by examining how R&D and innovation affect changes in the commodity structure of exports and changes in the share of major export commodities in world trade.

As shown in table 8, in the 1980s Korea was engaged mainly in the trade of medium-low-tech and low-tech commodities and moved gradually toward higher-technology commodities. Now Korea's exports are highly concentrated in high-tech products, such as semiconductors, telecommunications equipment, displays, and so on.[15] The share of high-tech and high-medium-tech products in Korea's exports increased from 14 percent in the 1980s to 43 percent in the 2000s.

The contribution of individual industries to exports changed drastically from 1990 to 2007 (see table 9). The share of primary and light industries in total exports declined dramatically. The share of primary industry declined from 4.9 to 1.5 percent, and the share of textiles declined from 26.7 to 3.7 percent. In contrast, the share of high-tech products rose significantly. In particular, precision machinery, telecommunications equipment, displays, and automobiles account for almost 40 percent of total exports. The highly concentrated export structure of Korea reflects the highly concentrated distribution of Korea's R&D expenditures and patents. Of the Korean patents registered in 2006 (KOITA 2008), electronics and communications accounted for 54 percent and machinery accounted for 15 percent. This is consistent with industrial R&D expenditures, which are concentrated in a few industries such as telecommunications, transportation, and so on. R&D-intensive industries clearly have gained market share, while low-R&D industries have lost market share. This is confirmed by

TABLE 8. Top 10 Export Commodities, 1980–2007

Rank	1980	1990	2000	2007
1	Apparel	Apparel	Semiconductors	Automobiles
2	Iron and steel	Semiconductors	Automobiles	Semiconductors
3	Ships	Shoes	Ships	Telecommunications equipment
4	Synthetic fiber	Ships	Cell phones	Ships
5	Audio	Video equipment	Synthetic fiber	Petroleum products
6	Tire	Iron and steel	Auto parts	Displays
7	Wooden products	Synthetic fiber	Display	Auto parts
8	Miscellaneous goods	Computers	Telecommunications equipment	Computer
9	Semiconductors	Audio equipment	Computers	Visual instruments
10	Video	Automobiles	Color televisions	Electronic parts

Source: Korea International Trade Association.

TABLE 9. Share of Exports, by Industry, 1990–2007

percent of exports

Industry	1990	2007
Declining share in exports		
Primary industries	4.9	1.5
Textiles	22.7	3.7
Shoes	6.6	0.1
Home appliances	11.3	3.7
Maintaining share in exports		
Steel and iron	6.7	6.2
Computers	3.9	3.7
Increasing share in exports		
Petrochemicals	2.0	7.8
Automobiles	3.0	10.1
Precision machineries	2.8	6.9
Telecommunications equipment	0.8	8.3
Semiconductors	7.0	10.6
Flat displays	0.0	4.5
Ships	4.3	6.5

Source: Rearranged from the Korea International Trade Association.

World Trade Organization data, which show that Korea's world market share increased in technology-intensive products, such as office machines, telecommunications equipment, automotive parts, and chemicals. In those areas, R&D investments also increased significantly.[16]

Contribution to Economic Growth

It is hard to estimate how much investments in R&D and innovation have contributed to economic growth, because doing so involves complex data and methodological issues. One widely used method of measuring this was first suggested by Griliches and Lichtenberg (1984), who calculated the growth rate of total factor productivity (TFP) and related this to changes in the stock of R&D. Their estimates of R&D elasticity of TFP ranged between 0.17 and 0.34. Coe and Helpman (1995) conducted the same experiments using data for 22 OECD countries for the period of 1971–90. They found that the elasticity was 0.234 for G-7 countries, but only 0.07 for OECD countries, which suggests that R&D investments of G-7 countries were a lot more efficient than those of OECD countries.

Similar attempts have been made to measure the R&D elasticity of TFP in Korea. Kim (2004) estimates that R&D elasticity of TFP in Korea for the period of 1970–2002 was 0.13, while an earlier study by Shin (1996) finds a higher number, 0.166. More recently, Shin (2006) finds that Japan's R&D is the most efficient of OECD countries

TABLE 10. Sources of Economic Growth, 1971–2006

	1971–80		1981–90		1991–2000		2001–06	
Indicator and input	Growth rate	% of economic growth	Growth rate	% of economic growth	Growth rate	% of economic growth	Growth rate	% of economic growth
Annual growth rate	6.99	100.0	8.37	100.0	5.90	100.0	4.52	100.0
Labor	2.47	35.3	1.95	23.3	1.10	18.6	1.05	23.2
Capital	3.29	47.1	3.08	36.8	2.75	47.0	1.43	31.7
TFP	1.23	17.6	3.34	39.9	2.05	34.8	2.04	45.1
R&D			1.74[a]	22.7[a]			1.61[b]	29.9[b]

Source: Lee 2008.

a. Average for the period 1971–90.

b. Average for the period 1991–2006.

(0.278–0.292), followed by the United States (0.167–0.263) and Korea (0.133–0.199). Korea's R&D elasticity of TFP is almost the same as the average elasticity for all OECD countries (0.188). This suggests that R&D in Korea has performed relatively well in enhancing the productivity of the economy.

A very interesting study by Lee and others (2007) estimates the R&D elasticity in Korea separately for high-tech, high-medium-tech, medium-low-tech, and low-tech industry. They find that R&D elasticity of TFP is 0.32 for high-tech industry and 0.10 for high-medium-tech industry. However, in medium-low-tech and low-tech industries, TFP does not respond to changes in the stock of R&D—that is, R&D does not affect productivity in those industries.

Many economists use the aggregate production function to estimate the contribution of R&D stock to economic growth. The results of estimations vary depending on the periods covered, data, and methods. Lee (2008) estimates that the stock of R&D accounted for 22.7 percent of economic growth in Korea during the period of 1971–90 (see table 10). In addition, the contribution of R&D stock to economic growth has been increasing along with economic development. The share of R&D stock in economic growth during the period 1991–2006 is estimated to be 30 percent. But, sometimes, study results vary too widely to reconcile. For example, according to Hah (2004), R&D stock explains 48 percent of the growth of TFP, while Bae and others (2006) give a figure of 82 percent.

Achievements and Challenges

Korea has made enormous strides in science and technology over the past four decades. By making continuous and massive investments in R&D and innovation, Korea has succeeded in building a unique innovation system that supports sustainable growth of the Korean economy. The factors that have influenced the Korean innovation system the most are (1) outward-looking development strategy, (2) large firm–oriented industrial policy, and (3) human resources, among many others. These are the sources of both the strength and the weakness of the system.

The strength of the Korean innovation system is its dynamism, which is fueled by the strong commitment of the government to "technology-based national development" and private industries' efforts to be competitive. Despite the short history of R&D, Korea has harvested a rich crop of patents, scientific papers, and exports of technology-intensive products, such as semiconductors, cellular phones, liquid crystal displays, automobiles, and others.

Yet there are problems, too. Even though Korea spends a larger share of GDP on R&D than other countries, it still lags far behind advanced industrial countries in the cumulative R&D stock, which is really the determinant of a nation's knowledge power. The challenge is to overcome the disadvantage of being a late starter.

Second, the weakness in basic sciences poses a fundamental problem for the Korean innovation system, because scientific capability determines the technological potential of a nation. Since the Korean R&D efforts have been devoted mainly to technology development, scientific research has been more or less neglected. The lack of a strong scientific base limits technological progress in Korea. The weakness in science results not just from a funding policy that favors technology development but also from weak university research capability. Therefore, strengthening university research poses a major policy challenge.

Third, excessive reliance on private industries for R&D investments has made the innovation system vulnerable in two ways. On the one hand, the system places so much emphasis on applied research and development that it has failed to build up a strong foundation for the long-term development of science and technology. On the other hand, the R&D system is too sensitive to changes in the economic and business environment. For instance, large Korean enterprises responded to the financial crisis of 1997 by cutting their R&D spending about 14 percent, almost destabilizing the R&D system. If the crisis had continued for several more years, the whole system would have collapsed.

Fourth, the Korean innovation system needs to be made more open to the outer world. Korea accounts for about 3 percent of the world R&D activities, which means that 97 percent of the world's R&D activities are taking place outside Korea. In order to access the knowledge, ideas, and technology generated and produced outside the country, Korea needs to open the system more and promote interactions with foreign scientists and institutions. Korea's level of international interaction is the lowest among OECD countries; if not checked, this will constitute a barrier to further growth in the future.

Fifth, the extremely high concentration of R&D activities poses a serious problem. High concentration means that only a few large firms are actively involved in R&D, while others are not. If this persists, Korean industries will be distinguished as either technologically advanced or technologically backward firms and sectors, which will make interfirm and interindustry interactions—the key elements of innovation—unlikely. This is particularly important because even large enterprises cannot sustain competitiveness without technologically strong domestic SMEs.

Lessons

Korean experiences offer some lessons for policy makers responsible for the development of education, trade, and technology in developing countries. There is no doubt that education determines a nation's ability to absorb new knowledge and technology. Education provides individuals with initial tacit knowledge, which is an essential building block of technological learning. The government should assume full responsibility for promoting the development of human resources. Investing in education in advance, as Korea did in the 1960s and 1970s, is essential to laying a foundation for industrial development. As an economy develops, technological competence becomes critical. To build up technological competence, high-caliber scientists and engineers are needed who are capable of dealing with developments at scientific and technological frontiers. In other words, advanced education in science and technology should come first when preparing to enter a knowledge economy. In the case of Korea, education and industrialization helped to sustain and accelerate their mutual development. Education made technological learning, and therefore industrialization, possible, while industrialization enhanced the rate of return on investment in education, further promoting demand for education.

Korea's industrialization evolved from imitation to innovation. In the initial stage, Korean industries attained technological capability through informal channels for technology transfer, such as OEM production arrangements, reverse engineering of imported machines, technical training as part of the importation of turnkey plants, and so on. Contrary to the experiences in other developing countries, in Korea FDI played a modest role in technological learning. To lay the initial technological foundation, many Korean industries resorted to nonmarket processes, relying on the ability of workers to absorb acquired technology. This approach enabled them to acquire technology at lower cost and maintain independence in their business operations. But Korea had to pay a high cost for this. It had to forgo many of the technological opportunities that foreign direct investors might have offered.

By adopting an outward-looking development strategy, the government drove Korean industries into the competitive international market, putting them under great pressure to acquire learning. Korean industries responded to these pressures by investing heavily in technology development. By developing technological competence, they have been able to survive international competition and establish world prominence in high-technology areas such as telecommunications, semiconductor memory chips, liquid crystal displays, automobiles, shipbuilding, and so on. Protectionist policy may be effective in creating initial market opportunities for domestic industries, but if such a policy is prolonged, industries will develop immunity to market pressures for innovation. It may be for this reason that export-oriented firms achieved technological learning more rapidly than import-substituting firms.

Since the early 1960s, the government has played a key role in Korea's development. The government first initiated S&T development as part of the national economic development plan and subsequently led its development, not just as a rule setter but also as a target setter and financier. But as industrial development proceeds, it has become increasingly difficult for the government to intervene in economic as well as R&D activities because of the increased scale and complexity of industrial activities. Therefore, the pattern of government intervention in science and technology had to change from direct involvement to indirect involvement as a facilitator and promoter. The Korean government's policy supports have been very effective in promoting R&D and innovation in the private sector, but they also have created a culture that tends to make private enterprises overly dependent on government policy in making business decisions.

In sum, Korea owes much to its human resources and outward-looking development strategy for technological development and industrialization. The Korean experience offers two major lessons. First, human resources are the key to S&T development and thus to economic growth, and, second, nothing can motivate private businesses to invest in technology development better than market competition. For Korea to sustain the past development into the future, it has to strengthen capacity in basic scientific research and improve the framework conditions for innovation, the core of which is a competitive market.

Notes

1. Korea is a very small, resource-poor country: its land area is only 220,000 square kilometers or 99,000 square kilometers excluding the northern part, which is currently under a different political and economic system. Korea's land, of which 75 percent is nonarable mountains, produces not a single drop of oil and contains virtually no valuable natural resources. Still it has to support a population of 70 million people.
2. This number is an estimate based on the figure for 1969, which was 5,337 (MOST 1984).
3. However, Confucianism may have adverse effects on the development of science and technology in Korea: it stresses patriotism and demands loyalty to the traditional values and, therefore, tends to devalue new, unconventional ideas. Korean society, like other Confucian societies, is less open to different ideas and systems, which works as a barrier to innovation.
4. Foreign investors also did not view Korea as an attractive place for investment. Even though Korea took a very open and liberal policy on foreign direct investment in the 1960s, few investments were made primarily because of the questions about Korea's political stability and economic outlook.
5. For more discussions on the roles of technology suppliers and recipients in different modes of technology transfer, see Kim (1997, 100–03).
6. Another negative effect is that large-scale loans that had been brought in instead of FDI might have contributed to the financial crisis of 1997 (Chung and Suh 2006).
7. Some—for example, Amsden (1989)—say that the Korean government played the role of the market in allocating development resources during the early period of development when the Korean market system was not mature enough to function efficiently.
8. OECD (1996, 91–92). The ratio of technology imports to business R&D was 15 percent in 2007 (KOITA 2008).
9. In addition to the restructuring by large firms, the government's drive to create venture companies changed the capital market conditions for start-up companies.

10. The survey covers 2,737 companies of 23 industries for the period from 2002 to 2004. It follows the OECD manual and has been authorized as official national statistics by the National Statistics Administration of Korea.
11. There are cases where R&D investments are constrained by the shortage of suitable manpower. OECD (2003) emphasizes the importance of the supply of skilled scientists and engineers as one of the framework conditions for achieving R&D spending targets.
12. The major legal bases for the incentives are the Technology Development Promotion Law (1967) and the Industrial Development Promotion Law.
13. Despite the overall effectiveness of the programs, the STEPI study concludes that the numerous programs are not well understood by the potential users and need to be made easier and simpler to understand and access (Shin and others 2006a).
14. NSTC (2009) provides an analysis of how government R&D programs contributed to the development of major export items.
15. This follows the OECD categorization of high-tech, high-medium-tech, medium-low-tech, and low-tech.
16. In the case of office machinery, the ratio of R&D expenditures to sales increased from 5 to 6 percent in Korea during 1990–2007, contributing to the increase in Korea's share of world trade from 2 percent in 1980 to 6 percent in 2007. More contrasting is the case of telecommunications equipment, where R&D intensity increased from 3 to 6 percent over the same period, which contributed to the change in its share of world trade from 0 in 1980 to 7 percent in 2007.

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