The Korean Innovation System: From Industrial Catch-Up to Technological Leadership?

Martin Hemmert

1 Introduction

South Korea (subsequently: Korea) has achieved unprecedented economic growth and development throughout the last four decades. As a result, the country has been transformed from an underdeveloped economy dominated by agriculture into a full-fledged industrial economy.

Most of the country's stunning economic growth and development, particularly in the early stage of transformation, has been achieved through a rapid industrialization process. This industrialization was enabled by the mobilization of domestic resources (labor and, increasingly, capital) combined with the introduction of foreign technology. In other words, Korea relied to a very high extent on imported technology, including technology embodied in production facilities, during the early stage of its industrialization. International competitiveness was secured by producing commodities as well as increasingly sophisticated goods at a reasonable quality and low cost.

However, the internal and external conditions under which the Korean economy operates have changed drastically throughout the last two decades. Since the country has entered the group of high income countries, low labor cost cannot work any more as a competitive weapon. Moreover, as a highly industrialized economy with an increasingly large high tech sector, Korea apparently cannot rely any more predominantly on imported technology. Rather, the internal generation and development of cutting-edge technology has become increasingly important for Korean firms to stay competitive in the world markets for such complex and sophisticated goods as semiconductors, digital displays, mobile phones, or automobiles.

This chapter assesses Korea's current technological competitiveness as well as the country's long term perspectives regarding technology and in-

novation in a systemic way by analyzing its national innovation system. Thereby, a comprehensive view of the conditions for the generation and diffusion of technology in Korea is provided, and strengths and weaknesses are discussed and evaluated in this overall context. This chapter is organized as follows: First, I will briefly discuss the concept of national innovation systems and explain how it is applied here. Thereafter, the Korean innovation system will be analyzed through a brief historical review and analysis of aggregated indicators, followed by a discussion of its different parts and an overall evaluation. Finally, some implications from the Korean as well as from the non-Korean perspective are briefly outlined.

2 The Concept of National Innovation Systems

National innovation systems have emerged as an analytical concept since the late 1980s (Freeman 1987; Dosi et al. 1988; Lundvall 1992; Nelson 1993). According to Lundvall (1992:12), such systems include 'all parts and aspects of the economic structure and the institutional set-up (of a country) affecting learning as well as searching and exploring'. In concrete, he identifies the internal organization of firms, inter-firm relationships, the role of the public sector, the institutional set-up of the financial sector, R&D intensity and R&D organization as its basic elements. Similarly, Nelson and Rosenberg (1993:19) raise the country-specific allocation of R&D activity and the sources of its funding, the characteristics of firms and the important industries, the roles of universities, and government policies aimed to spur and mold industrial innovation as common features of national innovation systems.

These definitions indicate that the concept of national innovation systems rests on two basic notions: that the country level is an important one when measuring technological competitiveness and performance, and that this performance is determined not by a single factor, but by a wide range of institutions and by the interaction between them. In other words: a systemic approach is prescribed to understand and analyze the technological performance and competitiveness of countries.

The national innovation systems approach does not imply, however, that the country level is necessarily the most important or even the only level applicable for such a systemic analysis. In fact, other analytical dimensions, such as regional (Braczyk et al. 1998) or sectoral innovation systems (Breschi and Malerba 1997) have been proposed as well. The question could even be raised of whether the ever-growing technological exchange and interdependence between countries has not rendered obsolete the na-

tional innovation systems concept itself. However, the growing popularity of this framework among researchers and policymakers on the national and supranational levels (Lundvall et al. 2002) indicates that notwithstanding the increasing technological globalization, the national level is still widely considered as a highly relevant one when analyzing innovation systems and technological performance. The popularity of the national systems framework appears to rest on perceptions that the organizations and institutions which are central for the development and diffusion of technologies maintain strongly country-specific features and that activities and interactions within, rather than between, countries still play a dominant role for many technological innovations (Patel 1995).

In the process of elaborating the national innovation systems concept, quite detailed frameworks which include a large number of actors and interactions between them have been developed (e.g., OECD 1999). A fine-grained analysis of the Korean innovation system which embraces all these factors in detail would go beyond the scope of this chapter. Instead, the subsequent discussion of the Korean innovation system will be based on a somewhat simpler framework following the analytical approaches of previous studies. Prior research on national innovation systems has almost invariably considered (1) the R&D activities of the business sector, (2) the government and the public research sector, (3) the higher education system and universities and (4) the interaction between these three sectors which materializes in flows of capital, human resources and knowledge. Furthermore, all three sectors produce innovation-related output, such as scientific papers, patents, and new products and processes (Figure 1). Following a brief historical sketch and an overview of aggregated indicators of innovation-related input and output, the subsequent analysis will be based on this analytical framework.

3 The Korean Innovation System

3.1 Overview: Historical Development and Current State

Studies of Korea's technological development (Hillebrand 1996; Kim 1997) indicate that the country's catch-up throughout the last 50 years can be divided into three stages: (1) the period of introduction and imitation of foreign technology until the 1970s, (2) the period of formation of industrial R&D capabilities in the 1980s and (3) the period of building up basic research capabilities since the 1990s. These three periods are also clearly reflected in the development of the country's R&D intensity during the last decades (Figure 2).

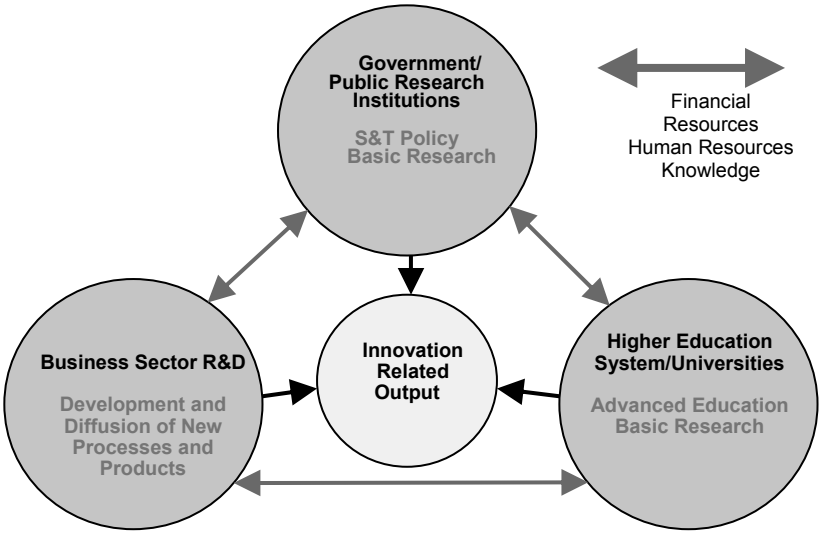

Fig. 1. Analytical framework

During the first period which began after the liberation from Japanese colonial rule in 1945, Korea developed itself mainly through the introduction of technology from abroad. In many cases, foreign technology was adapted directly through the construction of industrial facilities by non-Korean firms in turnkey projects. This method of industrial development was particularly popular during the rule of President Park Chung-Hee in the 1960s and 1970s. Through straightforward and massive industrialization, Korea achieved the transformation from an agricultural to an industrial economy in a relatively short time period. In technological terms, however, the development process was mainly limited to the adaptation and imitation of technology from outside. Until the early 1980s, the country's R&D intensity was below 1% of its National Income, reflecting the fact that relatively little formal R&D activities were conducted in Korea.

Thereafter, Korean firms began to invest massively into R&D during the 1980s, resulting in a steep increase of the economy's R&D intensity to almost 2% in the early 1990s. This development was led by the country's big industrial groups (chaebols). The chaebol managers increasingly perceived the necessity to build up internal R&D capabilities in order to develop new products and improve existing products. Moreover, whereas Korea continued to rely to a high extent on technological know-how from outside (Lee 1998), the formation of absorptive capacity (Cohen and Levinthal 1990) to utilize advanced foreign technology more effectively was another motive for investing strongly into R&D. It seems, however,

that the focus of the country's R&D investment during this stage was clearly on applied knowledge in industrial technology. Still relatively little emphasis was placed on more upstream R&D activities, particularly basic research.

In the third stage of technological development which began in the 1990s, Korea's national R&D intensity continued to rise and reached a level of almost 3%, which is one of the highest in the world, in 2004. This further rise not only in absolute, but also in relative investment into R&D can be deducted to two factors. First, the country's industrial firms, in order to improve their international competitiveness further and to take and maintain the global technological lead in various fields, continued to increase their R&D investment.

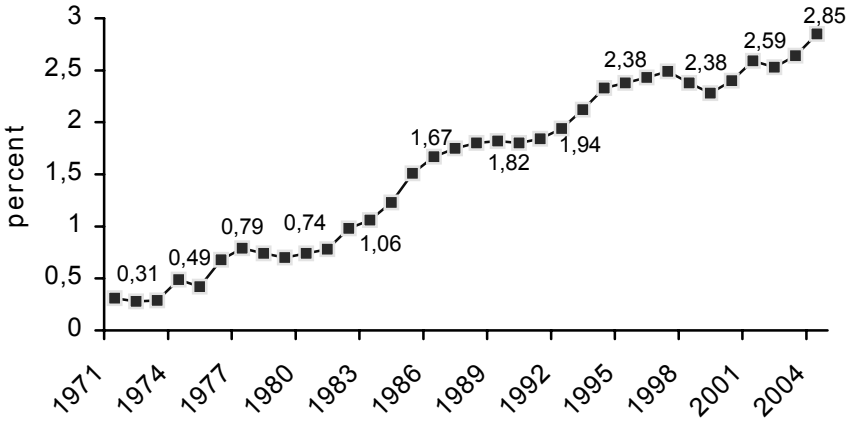

Fig. 2. Development of Korea's R&D intensity
Note. R&D intensity: R&D expenditures/Gross National Income
Source: KITA (2006)

Second, Korea's government also placed higher emphasis on R&D and upgraded the country's research infrastructure significantly.

In Table 1, aggregated data on Korea's recent technological position are summarized in comparison with the world's largest and technologically most advanced economies. In terms of input, the density of R&D personnel is still somewhat lower than in other leading countries for which data are available. As regards R&D intensity, which can be regarded as the most comprehensive input-related indicator, however, Korea has surpassed the leading European countries and is now trailing Japan only among the world's major economies. In other words, Korea is now one of the coun-

tries in the world which devote relatively most of their resources to technological learning and technological progress.

As regards output, whereas Korean firms have captured a significant share of the global market in some R&D intensive industries, the country's technological level still appears to be somewhat below the world's most advanced countries in certain aspects, such as scientific publications, patents and the position in international technology trade. Thus, at a first glance, it seems that the efficiency of Korean R&D is lower than in the other countries, given the relatively high amount of its input and the relatively low level of its output.

This interpretation of the data needs to be qualified in two ways, however. First, some of the indicators are biased towards other countries and therefore tend to understate Korea's relative position.

Table 1. Sience and technology indicators for Korea and leading OECD countries (2003)

Indicator	Korea	US	Japan	Germany	France	UK
Input-oriented indicators:						
R&D expenditures / GDP (%)	2.63	2.68	3.15	2.52	2.18	1.88
R&D personnel / 1000 heads of population	3.89	n.a.	6.91	5.73	5.60	n.a.
Output-oriented indicators:						
Scientific papers / 1000 heads of population	0.39	0.94	0.59	0.84	0.81	1.21
Triadic patent families* / million heads of population (2002)	13.2	63.6	103.5	88.1	39.8	34.4
Technology exports / technology imports	0.25	2.48	2.68	0.98	1.60	2.32
OECD export market share (%) in						
electronic industry	12.46	19.76	19.01	9.29	4.33	5.64
office machinery / computer industry	8.60	19.50	11.50	9.29	3.32	7.59
pharmaceutical industry	0.35	10.21	2.06	12.18	9.45	9.88

Note. * Patents granted by the US Patent & Trademark Office and filed at the European Patent Office and the Japan Patent Office
Source: OECD (2005a); MoST (2005a)

Second and more importantly, the data in Table 1 give only a static picture and do not take the time lag between input and output, which tends to be very significant in the field of R&D, into account.

In other words, the output data should be regarded as the results of a country's R&D efforts several years ago rather than as the outcome its current R&D activities. As has been shown in Figure 2, Korea's R&D intensity was still considerably lower as recent as in the 1990s. Moreover, an analysis of time series reveals that Korea has rapidly improved regarding all output indicators shown in Table 1 throughout the last years. Notwithstanding these considerations, however, the data suggest that Korea still

has not reached yet the level of the most advanced countries in some areas of its technological output.

Taken together, the historical review of Korea's technological development and an aggregate assessment of its current position indicate that (1) Korea has successfully caught up technologically to the world's leading countries within only a few decades, (2) the country's relative level of R&D investment is now one of the highest in the world and (3) its technological output is also rapidly increasing, but still appears to be somewhat unbalanced and partially below that of the leading countries. Due to their very nature, however, the aggregated data do not allow more detailed insights. Therefore, the current situation of the Korean innovation system and its strengths and weaknesses are analyzed further through a discussion of its main parts.

3.2 The Business Sector R&D

As shown in Figure 3, more than three quarters of Korea's R&D is conducted in the business sector, illustrating the high importance of this sector for the Korean innovation system. Whereas in most advanced countries the majority of R&D activities are conducted by the private sector, the percentage of R&D falling to industry is the highest in Korea among all major OECD countries.

In terms of distribution of business R&D among industries, the situation clearly reflects the strong overall concentration of Korean firms on certain products and technological fields (Figure 4). In particular, the electronic parts industry plays a dominating role, followed by the automobile industry and audio/video/communication equipment industry. In contrast, other R&D intensive industries, such as pharmaceuticals or instruments, are very weak in Korea.

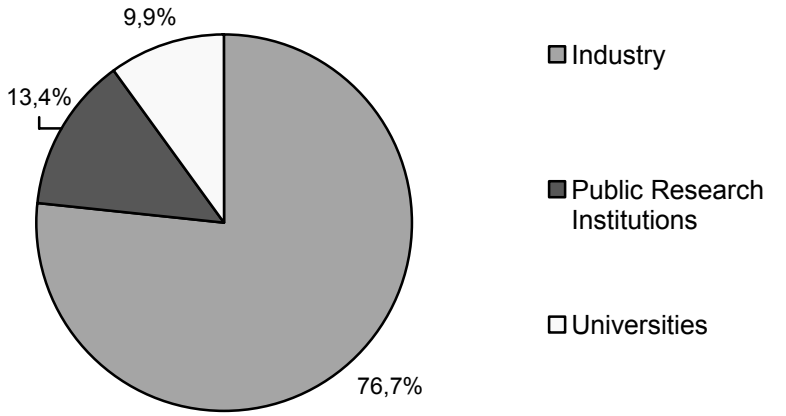

Fig. 3. Korea's R&D expenditures by performing sector (2004)
Source: MoST (2005a)

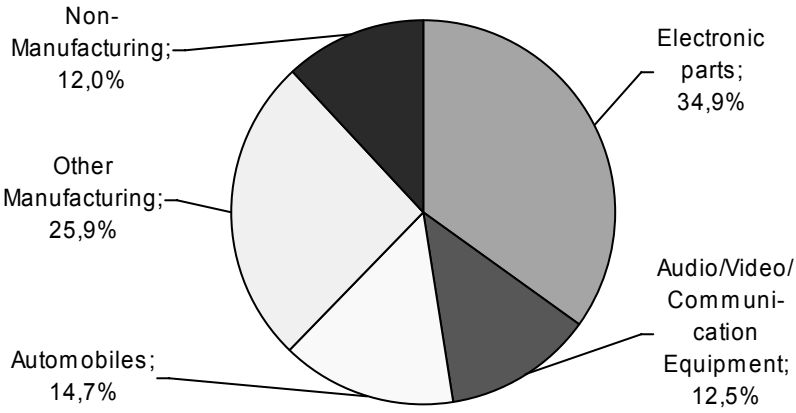

Fig. 4. Composition of Korea's business R&D by industries (2004)
Source: MoST (2005a)

Data on the concentration of Korean industrial R&D (Figure 5) reveal that large firms play a much bigger role here than small and medium-sized firms. Korea does not constitute an exceptional case in this respect. The concentration of R&D on large firms is even stronger in some other ad-

vanced and bigger countries, such as the US, Japan and Germany (OECD 2004). As the lower part of Figure 5 shows, however, the majority of Korea's industrial R&D is not only concentrated on large firms in general, but also on a small number of large firms. In fact, the R&D expenditures of Samsung Electronics alone amounted to 4.79 billion Won in 2004 (Samsung Electronics 2005), which was equivalent to 28.1% of Korea's total industrial R&D expenditures in this year. These numbers starkly illustrate that the dominating role which the big chaebol firms played in the formation of Korea's industrial R&D base still prevails.

Furthermore, the R&D investments of Korea's large industrial firms were also rewarded with remarkable competitive achievements in recent years. Again, the performance of Samsung Electronics is particularly eye-catching, as this firm maintained a dominant position in the global memory chip industry for the last 15 years (Shin and Jang 2005). However, other large Korean firms also established themselves as technologically leading competitors during the last decade.

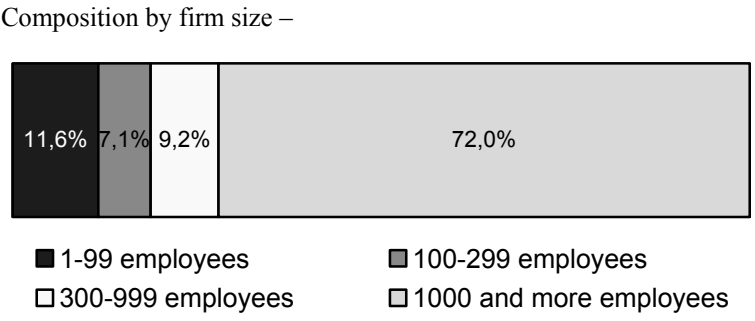

Fig. 5. Concentration of Korea's business R&D expenditures (2004)
Source: MoST (2005a)

At the same time, however, the same leading Korean firms continue to rely to a considerable extent on foreign technology which is often embodied in the parts and materials they purchased. For instance, Korea's dependency ratio on imported materials and components has been estimated recently at 70% for DVD players, 50% for mobile phones and 91% for LCDs (OECD 2005b). These data illustrate the relative weakness of the Korean supplier industry.

Taken together, some large Korean firms have attained technologically leading positions in various high tech industries during recent years. Their technological leadership has a narrow base in two ways, however. First, it applies only to a relatively limited range of industries. Second, it also does not cover the whole vertical value chain, but often its downstream parts only, whereas many parts and materials have to be imported from foreign suppliers.

The relative weakness of Korea's supplier industry has been often perceived as a weakness of the country's SME sector in general. In recent years, however, an increasing number of smaller R&D intensive venture firms have entered the stage in Korea. For illustration, a few examples of such firms are given here:

- Reigncom, an independent, globally competing producer of MP3 players founded in 1999
- AhnLab, founded in 1995, a producer of Antivirus Software which also expanded its operations to other Asian countries
- Daum Communications, founded in 1995, a provider of a broad range of internet services, such as email, web-based entertainment, online shopping and financial services
- Innowireless, a manufacturer of test and measurement equipments for wire and wireless networks founded in 2000
- Anybil, a provider of wireless internet homepage building tools also founded in 2000
- Cell Biotech, founded in 1995, a biotechnology firm

These and other firms share several features: they have been founded since the mid-1990s, are relatively small with a few hundred employees at most, independent (not members of any business group), very R&D intensive and growing fast. Their existence and success proves that notwithstanding the still dominant role of large chaebol firms in Korean industrial R&D as a whole, a new generation of innovative independent firms has established itself. When considering the fact that such firms have been almost non-existent in Korea until about 10 years ago, it seems likely that their role in the Korean innovation system will gain further importance in the future. Their growth has been supported by governmental support pro-

grams for venture firms which have been created since about 1997 and will be discussed further in the next section. Another supporting factor appears to have been the restructuring of the Korean economy after the financial crisis of 1997 that resulted in large-scale layoffs by many chaebols which also included considerable numbers of highly skilled R&D personnel. Whereas the most skilled and talented researchers and engineers traditionally had a strong preference to work for large firms, they have been increasingly available for venture firms due to the post-1997 shakeout and the subsequent change of attitudes among parts of the R&D workforce. However, it seems that the propensity of university graduates to enter large firms has increased again during the last years following the recovery of the Korean economy after the crisis. Therefore, it still remains to be seen whether the behavioral change in the R&D workforce regarding their job preferences is a lasting one.

Finally, a soft factor also needs to be mentioned when discussing industrial R&D in Korea: the strongly hierarchical management of Korean firms (Morden and Bowles 1998) which essentially seems to prevail also after the financial crisis. Even in the cases of venture firms, their founders, which are typically also their CEOs, appear to play a very dominating role. Research on innovation management suggests that whereas such hierarchical management may be suitable for maximizing efficiency and organizational flexibility, it also has a detrimental effect on creativity and therefore hinders breakthrough innovations (Amabile 1998). It cannot be denied, however, that notwithstanding their hierarchical management, some Korean firms were successful in recent years to achieve and maintain technological leadership in a number of fields. Thus, it remains an open question which overall effect the Korean management style has an innovativeness (i.e. whether Korean firms have been innovative despite or because of their management style). Further research on Korean innovation management is needed to clarify this issue.

3.3 The Government and Public Research Sector

The principal governmental organization in Korea responsible for the formulation and implementation of science and technology policy is the Ministry of Science and Technology (MoST) which was founded in 1967. During the subsequent decades, this policy field, and thereby the MoST itself, gradually gained attention. One recent event which symbolizes this tendency was the upgrading of the Minister of Science and Technology to the rank of a Deputy Prime Minister in October 2004.

The overall composition of the Korean government's R&D spending (Figure 6) shows, however, that the related activities are highly fragmented. Less than one fifth of the total governmental R&D spending falls to the MoST, and no less than five other Ministries also hold a considerable share. These data indicate that notwithstanding the rising importance and status of the MoST, its position in Korea's science and technology policy is still by no means dominant. Rather, a variety of Ministries unfold their own activities in this field. Moreover, since not all of these activities are necessarily well coordinated, the effectively fragmented structure of science and technology policy potentially results in a considerable overlap between different programs implemented by various Ministries. This situation appears problematic from an efficiency perspective.

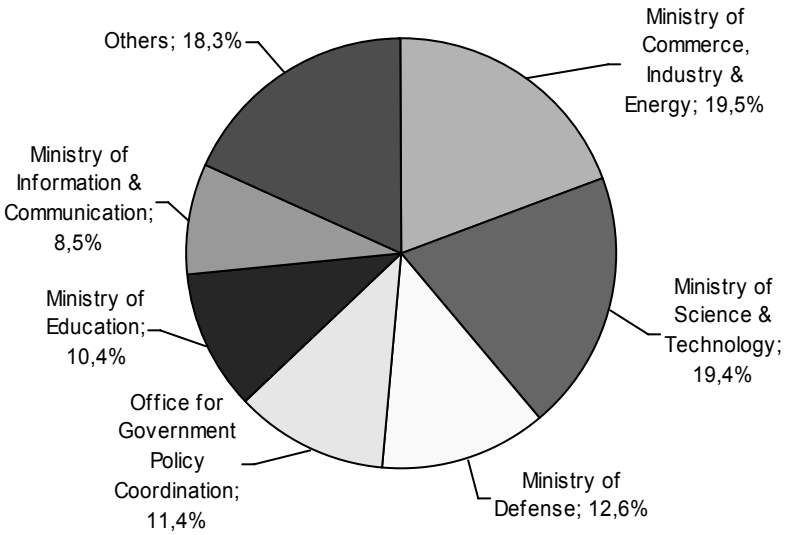

Fig. 6. Composition of Korea's governmental R&D budget by ministries (2005)
Source: MoST (2005b)

One main task of science and technology policy is the funding and governance of public research institutions. The Korean R&D statistics distinguish between three types of non-business research institutions: governmentally affiliated, governmentally supported, and others. As the data in Table 2 show, however, the governmentally supported institutes, though not formally affiliated with the Korean government, are overwhelmingly funded by it. Thus, it is safe to assume that they are also effectively under governmental control. It is this group of institutes which are biggest by average unit size that account for the majority of non-business funded R&D in Korea.

Table 2. Structural data on Korea's non-business research institutions (2004)

Type of institutes	Number of institutes	Total budget (billion KRW)	Proportion of governmental funding (%)	Total number of researchers	Average number of researchers per institute	Main field orientation
Governmentally affiliated	76	484.4	99.8	4,058	53.4	Agriculture
Governmentally supported	27	2,191.4	95.4	8,530	315.9	Engineering
Others	56	288.8	56.3	3,134	56.0	Medicine and Engineering

Source: MoST (2005a)

Most of them are focused on engineering-related R&D, thereby giving this field a dominant position in Korea's non-business R&D. Approximately 55% of the total research manpower in this sector falls to engineering (MoST 2005a). This field orientation appears to be a good match with the country's business R&D, which is, as discussed in the previous section, strongly focused on the electronics and automobile industries and therefore can be expected to have a particularly strong need for scientific engineering knowledge.

The management of the governmental (including governmentally supported) research institutes has been criticized for its rigidity. In particular, inflexible employment practices have been identified as a major problem. After the crisis of 1997, however, employment rules, as well as managerial practices in general, have become much more flexible, resulting in a potential rise of the efficiency and effectiveness of the public research sector in Korea (Yim et al. 2005).

Another potentially important role of science and technology policy is giving direct support for the business sector's R&D activities. In 2003, 5.3% of the Korean business sector's total R&D spending has been financed by the government (OECD 2005a). This proportion is somewhat lower than in some leading countries such as the US where defense-related governmentally funded R&D programs play a major role, but similar to that of many European countries like Germany and much higher than in Japan where less than 1% of the business R&D is financed by the government. In other words, the financial support of the Korean government for business R&D appears neither particularly high nor particularly low when compared with other developed countries.

As regards contents, the support of venture firms was a major focus of the Korean government's R&D support policies directed at the business sector in the years after 1997 (OECD 2005b). On the one hand, problems in the governance of these support programs which partially have been due

to a lack of experience of the governmental agencies' staff have resulted in windfall gains, as many firms which received governmental support proved not to be very successful or innovative (Lim 2005). On the other hand, however, the governmental support programs apparently helped to create the sector of innovative new venture firms in Korea which has been discussed in the previous section, although the importance of the governmental help can be evaluated on a case-by-case basis only. Moreover, the screening process for R&D subsidies given to the venture business sector has been improved during the last years (OECD 2005b).

A further important aspect of science and technology policy is the protection of intellectual property by the government. Whereas this protection was weak during the early stages of Korea's technological catch-up in order to foster technology diffusion, it has been tightened several times since the 1980s and is now regarded as quite strong by international standards (Lim 2005), thus giving relatively strong incentives for innovation to inventors.

In total, notwithstanding certain problems, science and technology policy and the public R&D sector appear to have been grown up in Korea to a level which can be considered as adequate for a developed and technologically advanced country. This assessment is also supported by the fact that the country's total governmental R&D spending amounted to 0.63% of GDP in 2003, a level which is not much lower than in any of the world's leading countries and higher than in some of them like Japan or the UK (OECD 2005a).

3.4 The University and Higher Education Sector

The university and higher education sector performs two main functions within the innovation system of a country: (1) skill formation through higher education and (2) contribution to knowledge creation and knowledge transfer through research activities conducted at universities. As regards the first function, Korea's position appears to be very strong, at least in quantitative terms. According to OECD data, the proportions of the population between the age of 25 and 34 years with an upper secondary school education and a tertiary (university) education in 2002 were the highest and the third highest in Korea among all OECD countries, respectively (OECD 2005b). More recently, the formal level of education among young Koreans is even more impressive: in 2004, no less than 99.7% of all middle school graduates advanced to high schools and 81.3% of all high school graduates advanced to universities (KEDI 2004).

The outstanding formal level of higher education in Korea, particularly among the younger generations, can be explained with two interrelated factors: a long-term national tradition of appreciation of high education levels which can be linked to strong Confucian cultural roots and the extremely high importance which the education level, as well as the prestige of the educating institution, plays for future career opportunities of individuals.

Notwithstanding these notable achievements, however, there is widespread discontent with the quality of the education system in Korea. Firms complain that the skills acquired by university graduates do not match their needs for top level specialists, requiring them to invest further into their young employees through large scale internal training programs (OECD 2005b). Moreover, a large number of Korean parents perceive the quality of education in other countries as clearly better than in Korea and therefore send their children to Western countries for secondary or tertiary education. Whereas this 'brain drain' generally does not appear to be desirable from a Korean perspective, it still partially contributes to skill formation of the Korean workforce due to the backflow of numerous graduates from foreign universities and high schools to their home country after having acquired advanced and culturally diverse knowledge.

In recent years, the Korean government initiated various programs to improve the quality of secondary and tertiary education. Moreover, the focus of college entrance exams, which constitute a crucial point regarding the career opportunities of Koreans, is gradually shifting from testing memory and learning skills to examining problem solving skills (OECD 2005b), thereby inducing further changes in secondary education through altering incentive structures. Whereas these developments should help to raise the perceived quality of higher education in Korea, it remains to be seen how fast and to what extent improvements can be made.

As regards research activities, the data in Figure 3 show that only about 10% of Korea's R&D is conducted by universities. This proportion is one of the lowest among the OECD countries (OECD 2005a), indicating that the role of higher education institutions for research is relatively small in Korea. In fact, until quite recently, universities have predominantly been regarded by Koreans as education institutions, and their research activities met relatively little attention.

This attitude has clearly changed since the 1990s, however. Governmental and private funding of university research has steeply expanded, resulting in an almost threefold increase of their R&D expenditures within less than 10 years (Figure 7).

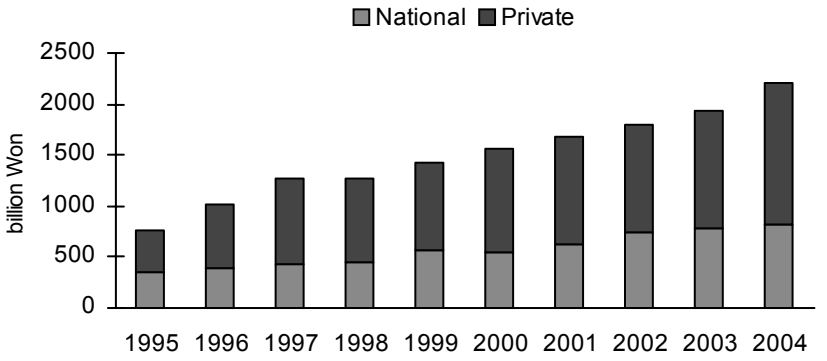

Fig. 7. R&D expenditures of Korean universities
Source: MoST (2005a)

Thus, Korea has invested heavily into the expansion of its academic research capabilities throughout the last decade. The still relatively low portion of R&D performed by universities, as shown in Figure 3, reflects their low initial level as well as the fact that Korea's business R&D also rapidly increased during the last years.

The recent efforts to improve the university research base are not limited to quantitative expansion through increased spending. In addition, governmental programs such as 'Brain Korea 21' are also aimed at improving the quality of research through the creation of centers of excellence and the upgrading of R&D facilities (Moon and Kim 2001). As a result, many universities in Korea now give much higher priority to research activities of their faculty than in the past. If these efforts are continued, a considerable increase regarding the role of university research in the Korean innovation system can be expected in the foreseeable future.

3.5 The Linkages between the Sectors

Finally, the interaction among the three sectors of the Korean innovation system which have been previously discussed is considered to evaluate how frequently and smoothly resources and knowledge are transferred between these three parts, or, in other words, how effectively the nation's knowledge stock is utilized and increased through inter-sectoral collaboration and mobility.

Throughout the last decades, the innovation-related interaction between industry, government and universities appears to have been very limited in Korea. This applies to the mobility of human resources as well as to flows

of capital and knowledge. As was discussed earlier, the industrial R&D base developed first, whereas the other parts of the Korean innovation system were upgraded mainly since the 1990s. During the initial stage of the catch-up process, industrial firms relied to a very high extent on foreign technology sources. Subsequently, this reliance was gradually reduced through the formation of internal R&D resources. In other words, foreign external knowledge was partially replaced by internal knowledge. In contrast, domestic external knowledge sources, such as governmental R&D labs or universities, did not play a major role in this substitution process because firms did not regard these knowledge sources as highly relevant for their own domain at that time.

Thus, it seems that the low interaction between the parts of the Korean innovation system is mainly the result of the country's fast and timely uneven catch-up process during the last decades. Regardless of the reasons, however, weak linkages between industry, government and universities are perceived as a major constraining factor regarding the effectiveness of national innovation systems since they limit the utilization of existing knowledge as well as the formation of new knowledge through the combination of complementary knowledge from different sectors (OECD 1999).

Notably, the situation has largely improved since 1997. As was mentioned already, highly skilled human resources in science and technology, which previously have been concentrated on large business groups, have been increasingly moving to small- and medium sized firms as well as to government labs and universities as a result of the economic restructuring during the crisis and of increased labor flexibility. Moreover, a venture business sector has also been created, mainly through the help of governmental support programs.

Research collaboration between industry and universities is also increasing due to recent administrative measures, such as the establishment of technology transfer offices within universities (OECD 2005b), but most likely also due to the improved R&D capabilities of the universities themselves. As a result, the number of patents which are co-invented by members of different organizations has been steeply increasing since the 1990s (Lim 2006). Nevertheless, the general perception in Korea is that there is still ample room for expanding and deepening such collaborations.

A final aspect which also enhances the performance of a country's innovation system is international collaboration. Whereas Korean firms have initially built their catch-up process on the import of foreign technology and still rely to some extent on it, other forms of international R&D links have been very few in Korea until the 1990s. After 1997, the number of foreign R&D centers located in Korea doubled to 122 (OECD 2005b), and the proportion of Korean R&D financed from abroad increased from

0.06% in 2000 to 0.49% in 2004 (MoST 2005a). This proportion, however, is still very low when compared with other countries, indicating that there is still a large unused potential for improvement through the formation of international R&D linkages. Moreover, most of these foreign R&D centers have no or weak linkages with local R&D organizations (Bok et al., 2006). This further suggests that the global integration of the Korean innovation system could still be improved to a high extent.

3.6 Overall Evaluation

The review of the development and current state of Korea's innovation system conducted in this chapter has shown that the country has not only become a full-fledged industrial economy which is successfully competing on the world markets, but also now possesses a fully developed national innovation system which supports its future competitiveness. The analysis of the different parts of the Korean innovation system has revealed a large number of specific findings which are summarized in Table 3.

In the course of the preceding analysis, a number of notable strengths of Korea's innovation system were identified:

- In some R&D-intensive industries, such as microelectronics and telecommunications, large Korean firms have achieved global technological leadership.
- The country possesses a considerable knowledge base in engineering which is supported by the large number public R&D labs in this sector.
- Enhanced by a very strong national propensity for education and learning, the general education level has become one of the highest in the world.

At the same time, the review also revealed some weaknesses of the Korean innovation system:

- The overall industrial structure is relatively unbalanced. In particular, the technological level of SMEs is weak by international standards.
- There is a lack of highly skilled technical specialists.
- The research capabilities of universities are relatively low.
- The country's knowledge stock is not utilized to its full extent due to underdeveloped linkages between firms, government labs and universities.

Table 3. Overall assessment of the Korean innovation system

Institutional sector	Basic structure	Strengths	Weaknesses	Recent developments
Business sector R&D	Strong concentration on business groups and on a few industries	Strong international competitiveness in specific sectors	Very uneven industry structure; weak SME sector	Continued expansion of large firms; formation of venture business sector
Government and public research institutions	Relatively large-scale governmental R&D subsidies for firms; public R&D labs mostly focused on engineering	Good sectoral fit between public sector and industrial R&D	Highly fragmented S&T policy	Higher priority given to and stronger coordination of S&T policy; new focus on venture nurturing
Higher education system and universities	Very high general education level; universities primarily education oriented	Very strong general commitment to education; high general skill level and knowledge pool	Mismatch between education contents and industrial needs; weak research base of universities	Stronger research orientation of universities; higher priority given to application-oriented skills
Linkages between sectors	Few intersectoral flows of human resources, capital and knowledge	_____	Underutilization of knowledge stock due to weak inter- sectoral linkages	Higher mobility of skilled human resources; gradually increasing university-industry collaboration

All these weaknesses are to a high extent the outcome of Korea's late and fast development which resulted in a number of imbalances within its innovation system as well as its economy as a whole. Notably, however, most of them have been addressed already in recent years, and considerable progress has been made in several areas. For instance, a growing and promising body of innovative venture firms has evolved, and the research

capabilities of universities are in the process of a large scale upgrade. The most important remaining tasks appear to be the strengthening of intersectoral as well as international linkages of the Korean innovation system.

Notwithstanding these remaining challenges, however, it is evident that Korea has a quite strong and competitive national innovation system already. Through a continuous expansion of R&D resources and the implementation of various reforms, particularly after 1997, the country has become ready to change its international role from a technological catch-up nation to a contributor of cutting-edge knowledge and technological leader in some areas. In fact, notwithstanding their continued partial reliance on foreign technology, Korean firms have already become global technology leaders in various R&D intensive fields. In this light, the qualification of Korea's innovation system as having 'remained largely based on a catch-up model' in the OECD's most recent country report on Korea (OECD 2005b:103) appears highly disputable.

4 Conclusion

From a Korean perspective, as has been pointed out already, the most important remaining challenge to strengthen the national innovation system appears to be a stronger development of the linkages between its different parts as well as of its international linkages. As regards the second aspect, the country's ongoing partial reliance on foreign technology which is widely perceived as a liability could possibly be turned to some extent into an asset. In other words, the linkages with foreign firms and organizations which are still existing from the catch-up period should be considered to be utilized for strengthening the country's international technology links rather than to cut them in order to attain 'national autonomy' which generally seems to be a questionable goal in an age of growing global technological interdependence.

Given the large technological advancements Korea has made during the last decades, the new international linkages to be developed from now on are different from the past ones, however. Rather than receiving foreign technology only, Korea needs to supply knowledge also to develop strong reciprocal technological links with other countries. Furthermore, this approach requires Korean firms and organizations to change from a strongly national mindset which was prevalent in the past to a more global mindset which also seriously considers the partners' viewpoint and long-term interest.

From an international perspective, the findings regarding Korea's innovation system imply that Korean firms need to be taken seriously not only as competitors in general, but also as innovating competitors and technology leaders in high tech industries. The age when they were following only the technological paths created by others is over.

In a more general sense, Korea as a whole should be regarded now as a technological advanced country which has something to offer to the world. In other words, strengthening international technological links appears to be a potentially rewarding and fruitful approach not only from a Korean perspective, but also from a foreign perspective.

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