Enhancing Productivity through Innovation:
Korea’s Response to Competitiveness Challenges

(Preliminary Draft)

Joonghae Suh*
Korea Development Institute

1. Introduction
2. The Korean Economic Environment
   2.1. Structural Changes in Korean Industry
   2.2. Overview of Industry’s Competitiveness
   2.3. China Factor
3. Catching-up Model in brief
4. Changes in Korea’s Innovation System
   4.1 R&D Activities
   4.2 The Emergence of Innovation Networks
5. Discussion

References

* Korea Development Institute, P.O. Box 113, Cheongnyang, Seoul 130-012, Korea. (T)82-2-958-4171, (email) suh@kdi.re.kr. This paper is prepared for the KDI 33rd Anniversary Conference on Industrial Dynamism and Competitiveness in the East Asian Economies.
1. Introduction

The production systems in the East Asia that have prevailed over the past years are dissolving rapidly. The factors underlying these changes seem to be different from those in the past. Multinational enterprises are apparently a driver of the change as in the past; but there are differences in today’s changes. The world economic environment is changing rapidly. Hot debates on the architecture of the new international economic order are undergoing as well observed in WTO and DDA round tables. Globalization becomes a catchword or cliché nowadays, but there appear some countervailing movements against it; and there remain many issues to be resolved for a new international economic order to be settled. The rapid advances of information technology are enabling to overcome the limitations of physical distances and thereby to organize the production activities more effectively through the global supply chains. In line with the forces of globalization and IT revolution, the integration of low-cost economies to the world economy raises new challenges to national economies, in particular to Korea, forcing them to move towards knowledge-based innovative economies.

The changes describe above raise several questions. Theoretically, can the conventional theories of industrial development and international trade be maintained as the framework of explaining these changes? To what extent, and what aspect of the phenomenon? If not, quoting Gerschenkron, “how can we know if we knew what we would know”? From a policy point of view, is the rise of these low-cost economies a threat? Under what conditions is it an opportunity? Is “industrial hollowing-out” a revelation or result of structural adjustment responding to the changes in economic environment? Or, is there something more fundamental? Is “the China Fear” in Japan
and Korea justified, or exaggerated reaction from the losing businesses? What are the policy framework and options to make these changes an opportunity for further growth?

It is not sure how long Korea can maintain international competitiveness in her flagship exporting products such as textile, automobile and IT products. What we have found from the first-year research, though preliminary to make a clear conclusion and definitive interpretations, is that the basis of international competitiveness of the Korean exporting products is not so strong and Korea needs to find out new engines of growth. The challenges faced by today’s Korean economy would be termed as, in need of better words, the transition from the catch-up model to a knowledge-based economy. What are the requirements for a successful transition?

In terms of productivity of the economy as a whole, Korea is far behind other OECD economies. Against the existing productivity gap, we have seen a worrying sign in Korea’s investment trend. It is worth reminding that Korea has shown very high machinery and equipment (M&E) investment ratio in the past years, but recent years we have seen rapid decreases. Compared two period between 1993-1997 and 1998-2002, OECD economies on the average has increased M&E investment from 9.4% to 10.8%, in terms of percentage average as of GDP. In contrast, Korea has shown decreases from 13.8% to 11.2%, yet still above the OECD average. It is noticeable to see that US and Japan has increased their M&E investment. Looking into Korea’s M&E investment by size of firms, the decreases by large companies are conspicuous, in particular after the years of the financial crisis. Concerning business R&D investment, OECD countries have shown increasing trend, and Korea as well.

What does the trend imply? Is it the sign that Korea is transforming her economy from input-driven economy to one that is knowledge based? There are lots of issues to be investigated more rigorously and in-detail. We will do further research this year. For
a moment, I will show some of the first-year research results of KDI project and focus on two issues – to make innovation system more effective and the current status of SME.
Figure 1: Income and productivity levels of OECD countries, 2002
Percentage point differences with respect to the United States

Note: 1. Based on hours worked per capita. 2. GDP per hour worked.

Figure 2-1: GDP per capita and GDP per hour worked (US = 100)

Figure 2-2: GDP per hour worked and hours per capita (US = 100)

Note: Total OECD excludes Poland and Turkey.
Table 1: Investment Trend of OECD Countries
(Unit: period average, % as of GDP)

<table>
<thead>
<tr>
<th></th>
<th>Machinery and equipment</th>
<th>Business R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korea</td>
<td>13.8</td>
<td>11.2</td>
</tr>
<tr>
<td>Sweden</td>
<td>8.9</td>
<td>11.4</td>
</tr>
<tr>
<td>Netherlands</td>
<td>9.3</td>
<td>10.8</td>
</tr>
<tr>
<td>Germany</td>
<td>8.2</td>
<td>9.5</td>
</tr>
<tr>
<td>Japan</td>
<td>12.6</td>
<td>13.5</td>
</tr>
<tr>
<td>USA</td>
<td>9.3</td>
<td>12.3</td>
</tr>
<tr>
<td>OECD average</td>
<td>9.4</td>
<td>10.8</td>
</tr>
</tbody>
</table>

Source: OECD.

Figure 3: Machinery and Equipment Investment of Manufacturing by size-class
(Percentage share as of shipment)

Source: National Statistical Office
2. Korea’s Economic Environment

2.1 Structural Changes in Korean Industry

The industrial structure of the Korean economy has changed gradually since the 1980s; as the industrialization process matured, the share of manufacturing became saturated while service sectors as a whole tended to take a larger portion of gross economic activities. The manufacturing sector started to account for smaller shares in the late 1980s. However, its share recovered to the previous level after starting to increase in the second half of the 1990s: the manufacturing sector has shown a high growth rate since the mid-1990s. And productivity in the manufacturing sector has improved greatly; particularly, high productivity increases are found in manufacturing firms that survived the financial crisis through successful restructuring.

Over the long term the manufacturing sector maintained a stable level, whereas the service sector has been stagnant. Above all, productivity in the service industry is lower than in manufacturing. In this regard, even though the service industry takes a larger share in terms of employment, its share is constant in terms of added value. This fact implies that enhancing productivity in the service sector is the crux of raising the overall economic growth rate.

Within the manufacturing industry, differences by scale of business have widened both within and between sectors. The expanding gaps by size of enterprise are the most evident in inter-sectoral differences in growth rates and total factor productivity (TFP) growth. The electronics and automobile sectors contribute significantly to the growth rate of the manufacturing industry and to TFP growth. Especially, these growth rates are ascribable to rapid productivity increases mainly by large conglomerates since the

---

1 Sections 2.1 and 2.2 are excerpts of KDI (2003).
1990s. Furthermore, analysis of manufacturing productivity by sub-sector and by five categories of firm-scale found the higher growth rates in electronics and automobiles, with the larger share of conglomerates. And these conglomerate firms make a higher contribution to the growth rate of productivity and increasing productivity. These results show that large conglomerates are expected to maintain the leading role in the growth of the manufacturing industry for the time being. In contrast, except for the smallest firm-cohort, those with less than 10 employees, smaller firms show poor records in productivity growth. Productivity improvement of smaller firms is an important task for sustainable growth and improvement of the competitiveness in manufacturing in general.

The phenomenon of widening gaps between sectors and between firms, which we call bifurcation or polarization, is also identified in the analysis of financial structure. According to the results analyzing financial stability and profitability from 1990 to 2002, while both total assets and tangible asset investments have been on a downwards trend since the financial crisis, the gap between large conglomerates and SMEs have widened. In addition to this deepening polarization, signs of a decrease in the rate of growth in tangible assets give rise to apprehension in light of an expansion of growth potential. However, we found a positive sign that Korea’s economy is transforming into an innovation-driven economy, as the number of technology-intensive SMEs increased dramatically since the financial crisis.

The KDI study estimated productivity indices for the various industries in the manufacturing sector using plant-level manufacturing survey data for 1984-2001 compiled by the National Statistical Office. The data were re-compiled according to the 29-sector classification system of the KDI Multi-Sector Model, and, for five major industries, the data were rearranged into sub-industries according to each industry’s supply chain. The plants were classified into five categories according to the number of
workers, and the analysis was performed for three sub-periods; 1985-89, 1989-97 and 1998-2001. The study estimated both single-factor productivity, such as labor productivity and capital productivity, and total factor productivity (TFP), which was estimated by both the growth accounting method and multi-lateral method.

**Labor and Capital Productivity**

The results showed huge gaps in labor productivity among industries and among size groups. Labor productivity was high in the basic metals and electronics industries while it was low in the textiles and garments, metal products, and precision instruments industries. We also found that larger plants recorded higher labor productivity throughout the period: labor productivity was higher in larger plants and the gap with smaller plants was widening.

Analysis of the growth rate of labor productivity showed a similar pattern. Specifically, labor productivity grew most rapidly in the electronics industry as well as the machinery and transportation equipment industries, while it lagged in the textiles and garments, paper products and publishing and metal products industries. The overall growth rate of labor productivity has risen persistently after the economic crisis. Analysis of the growth rate of labor productivity by plant size reveals an important result. Over the entire period, larger plants recorded higher growth rates. In addition, we found that in the first sub-period (1985-89) labor productivity growth in smaller plants outpaced that in larger plants, but this trend reversed in the second sub-period (1989-97), and the gap between large and small firms widened in the third sub-period (1998-2001) when productivity growth was led mostly by large firms.

Capital productivity has been relatively over time, and differences in capital productivity between industries and by firm size are narrowing, except for several industries. Capital productivity by plant size shows an “inverted U” shape, i.e.,
medium-sized plants show the highest capital productivity.

**Total Factor Productivity (TFP):**

For the entire manufacturing sector, the annual average growth rate of TFP computed by the growth accounting method, was estimated to be 4.33 percent for 1985-2001. Estimated TFP growth was slightly above 4 percent until the late 1990s, and rose sharply to 11.68 percent since the economic crisis. The food and beverage, textiles and garments, and precision instrument industries showed slow TFP growth for the entire period, while the electronics industry showed an extremely high TFP growth rate, high enough to lead the TFP growth of entire manufacturing sector. In addition to the electronics industry, the machinery and transportation equipment industries also recorded high TFP growth rates, particularly in the late 1990s. The growth pattern of TFP by plant size is similar to the trend in labor productivity. That is, TFP growth rates were higher among smaller than larger firms in the first sub-period, but the trend reversed in the second sub-period, and the gap widened in the third sub-period. Productivity estimates produced by the multilateral index method showed almost the same patterns.

In sum, the growth and technological progress of Korea’s manufacturing sector has been led by the electronics and automobile industries, and, in particular, by the fast productivity growth of large firms in the 1990s. This can be explained by the fact that the large firms have relatively big shares of industries where productivity growth has been fastest.

It is expected that the growth pattern of the manufacturing sector led mostly by large firms will persist for the time being. At the same time, however, it is necessary to pay special attention to the increasing share of firms in the smallest size category and to the slow productivity growth of medium-size firms (with 100 to 300 workers), since
it would be impossible to sustain a high growth rate and improved competitiveness in the manufacturing sector without sufficient productivity growth of small- and medium-size firms.

2.2 Overview of Korea’s Industrial Competitiveness

Electronics

The Korean electronics industry has a dual, or an unbalanced, structure. It is comprised of large conglomerates that play a leading role both in domestic and global markets and the remaining groups of companies that are weak in their technological competence. Considering the electronics industry in general, competition with China is fierce in such sectors as computers and home appliances where price plays a key role in competitive advantage. Competition with China is relatively low in such sectors as memory chips, particularly semiconductors, and display units where non-price factors, such as technological leadership, are more important. Of particular interests is the dramatic increase in the global market share of Chinese firms in communication equipment, rising as one of Korea’s major competitors, presumably due to the role of MNEs in China.

The obstacles to further development of the electronics industry are found in the dual structure, such as the gaps between conglomerates and SMEs both between and within sectors. While leading conglomerates that have global business strategies can maintain their competitiveness through procurement of parts all over the world; the development of industries in general cannot be sustained without improving competitiveness of firms at a lower level. This conclusion implies that the government should make more efforts to rectify the dual structure, which indicates the importance of nurturing smaller, technologically agile firms.
Automobiles

The dual structure is found also in the automobile industry, which is bifurcated into the two groups of companies: final auto assemblers led by conglomerates, and component suppliers made up of SMEs at the lower level. While firms in the final assembly sector are assessed to have a competitive advantage that enables them to penetrate into overseas markets, the persistent weakness of parts suppliers is expected to be an element of vulnerability in the competitiveness of the automobile industry in general.

Whilst modularization has become important in securing competitiveness in the parts industry, it is currently being implemented as a way of reducing costs for automobile components in order to compensate for wage differentials between final auto assemblers and parts suppliers. As R&D becomes the most critical strategic element in sharpening competitive edge, first-tier companies as well as many second- and third-tier ones are expanding their R&D investment. Still, one of the biggest obstacles for the parts suppliers is the shortage of high-skilled labor in the production line due to their wage differentials compared to final assemblers.

Parent companies strengthened their global sourcing as a result of business restructuring after the financial crisis and the progress of market opening and informationization. In this circumstance, conglomerates dealing with component suppliers have faced a turning point, changing from the previous vertical relationship. Competence of parts suppliers is weak in such areas as independent technological development, purchasing and sales, and capabilities of collecting information on global market trends, mostly relying on the parent companies. Whereas Chinese enterprises have higher price competitiveness, they lag behind Korea in terms of the level of technology, which delays the rise of Chinese firms as threatening competitors to Korean firms. However, building up firms’ core competence requires accumulation of long-
term experience. Taking into account that Korean parts makers do not have a considerably higher capability in developing technologies compared to Chinese firms, Chinese firms can be expected to catch up to Korean firms in the near future. An upgrade in the quality of work force is needed to strengthen innovation capabilities and to expand the production capability of parts suppliers to the level where scale-economies are realized.

**Machinery**

The machinery industry faces a challenge to transform its current production system to one that is based on generic technologies, which enables the production of differentiated products. In general, Korea’s machinery producers show dexterity in manufacturing and assembly, where company competitiveness originates. On the other hand, competitiveness is found to be low in the specialized machinery sector, which requires integration and application of new technology. This characteristic is largely due to the industrial structure of the machinery industry that is composed of, mostly, SMEs.

An ideal efficient and competitive production structure would be one where SMEs specialized in core parts and materials strongly support the industrial base and conglomerates perform large-scale projects as well as lead the machinery industry. Ninety-eight percent of the Korean machinery industry is composed of SMEs, based on the number of enterprises. As the majority of firms are small with the sales composed mostly of single products, they lack sufficient competence to function as the bedrock of the machinery industry due to their poor motivation for technology development. In contrast, big companies have not in general reached as the stage in which they can lead the development of the overall machinery industry, even though they achieved business rationalization through restructuring after the financial crisis.
Figure 4. Trade Pattern among China, Japan and Korea
Therefore, a pressing task is to consolidate the system-base of the industry, a system where specialized firms are closely linked through supply chains and innovation networks. It is also urgent to improve technological capability in machinery design and generic technologies, where Korea has big gaps compared to advanced countries. To accomplish this task, it is necessary to promote inward investment by foreign companies, which are leading the global industry, as well as to reinforce industry-academia linkages.

**Chemicals**

The chemical industry includes such diverse industries as petrochemicals, fine chemicals, and rubber and plastic. While it is linked with a series of production chains, obvious differences are found in each sub-sector in terms of production structure, required technologies, and other aspects. While the industry’s value of production, amount of exports, and share of value-added just decreased slightly after the financial crisis, the chemical industry has recently experienced a recovery trend and some products meet global standards in light of production scale.

There are contrasts between capital-intensive industries as petrochemicals and rubber and plastic and technology-intensive fine chemicals. Whereas the petrochemical sector, led by large conglomerates, has an export-to-production ratio of over 40%, with a high comparative advantage index, the fine chemical sector mostly remains oriented toward domestic demand with a lower competitiveness index in the global market. In terms of productivity, the petrochemical industry generally attains a high level of productivity due to the high capital intensity, while that of the fine chemical industry is low. However, a high level of competitiveness does not necessarily relate to a higher level of productivity in petrochemicals compared to fine
chemicals. Without adjustment of the excess facilities and R&D efforts for new products, its current competitiveness cannot be maintained.

In the chemical industry in general, prerequisites for sustained growth include development of new businesses and innovation of production process. Especially, the industry in general should re-orient its growth strategy to explore new markets through the development of differentiated products thus changing the current strategy of focusing on standardized products. More large companies are to be induced to enter into the fine chemical sector thus playing a leading role in the development of the industry as a whole. In tandem, the government should make more efforts to rationalize the industrial structure by inducing autonomous restructuring of over-capacity in petrochemicals and enhancing cooperation between large firms and smaller firms.

**Textiles and Garments**

The share of the textile and garment industry in Korea’s economy has been gradually shrinking since the 1980s. However, it still occupies a key position, with 15% of total employment in the manufacturing sector as of 2001. The industry’s share of exports increased, in spite of a slowdown in, exports, with US$13.9 billion in the black in 2000. As domestic textile and garment industries have tended to lose their competitive edge in general, the long-term trend of industrial decline is expected to continue.

Considering the textile and garment industry in general, recovering to the levels of its heyday is difficult to expect. Yet, the textile and garment sectors still have potential for further development, with strategic specialization in synthetic yarn and synthetic fabrics, where Korea has a high degree of competitiveness, and strengthening design and brand marketing, which enables upgrading quality. For instance, developing
super-functional textile materials and their commercialization is important for preventing a radical decline in the domestic textile industry, as well as upgrading industrial structures. Reactivating the fiber and textile sectors requires creation of demand in the garment industry. It is also essential to create a demand for apparel with fashionability and marketability. Furthermore, innovation of a distribution system in the garment industry is critical for overcoming limitations of market size and creating further demand. Additionally, an initial generation of market environment is also required for domestic textiles businesses to convert into various kinds of small lots through formulating a distribution network of low- and medium-priced fashion clothes.

2.3 China Factor

Overall, the rapid expansion of the Chinese economy creates a new growth opportunity for the East Asian countries and the world. The scale of China’s economy has grown 4.5 times from 1985 to 2002; and China’s entry into the WTO creates additional momentum for her trading partners for a bigger market with eased trade barriers. The question is, then, who will benefit relatively more from China’s development. The answer is not straightforward, since the effect of increased trade depends on several factors.

The following figures show China’s trade specialization pattern and the comparative advantages of China and her trading partners in Asia\(^2\). Index for comparative advantages of international trade is calculated; and the manufacturing industry is dis-aggregated into 22 sub-sectors, and these sub-sectors are classified into four groups according to OECD standard of R&D intensities. Changes in China’s trade

\(^2\) CTB in the figures represents for contributions to trade balance that are calculated by OECD method in percentage of manufacturing total. Positive CTB means structural surplus or comparative advantage; whereas negative CTB structural deficit or comparative disadvantage. For industry classification according to R&D intensity and the method to calculate comparative advantage, see OECD, Science, Technology and Industry Scoreboard, 2001.
specialization pattern are more apparent in bilateral trade with some Asian countries.

- With ASEAN:
  In high-tech industries, China has comparative advantages in precision instruments, pharmaceuticals. In all mid-high tech industries, China has comparative advantages. China has structural surplus in most of mid-low tech industries except petroleum refining and rubber and plastic. In low-tech industries, China has comparative advantages in paper and textile.

- With Korea:
  Trade between China and Korea had begun in full scale in 1991 when two countries restored diplomatic relationships. It is very interesting to notice that in high-tech industries China has comparative advantages except communications equipment including semiconductor, though the margin is narrow. In mid-high tech industries, China has comparative advantage in electrical machinery including home electronics; and, Korea shows comparative advantages in the remaining mid-high tech industries. In mid-low tech industries, Korea has strong comparative advantages in rubber & plastic and petroleum-refining; and, except these two, China has comparative advantages. In low-tech industries, China has comparative advantages expect food.

- With Japan:
  China’s trade with Japan shows very stable specialization patterns in high tech and mid-high tech industries, where Japan has mostly strong comparative advantages. In contrast, in mid-low tech industries China is gaining her comparative advantages; and, in low-tech industries, China has
comparative advantages except food.

China’s international trade shows an overall specialization pattern that is strong structural surplus in low-tech industries whereas structural deficits in the remaining manufacturing industries. But it is noteworthy that China’s pattern of trade specialization is changing rapidly. For example, computer and office equipment in the high-tech sector and electrical machinery in the medium-high tech sector are rapidly changing from structural deficit to structural surplus.

China’s changing pattern of trade specialization exemplifies how comparative advantages can be created. The rise of China’s computer and communications equipment industries is a case in point. Coupled with the strategies of multinational corporations to capitalize on the growth potential of a country with a population of 1.2 billion, the Chinese government has introduced deliberate industrial policies to commercialize strong technological base. Indigenous firms are growing and accumulating technological capabilities that are comparable to those of foreign competitors. Technologically dynamic firms such as Huawei, (Box), are not prevalent in most developing countries; but, in fact, numerous Huawei’s are growing in China. These factors interacting with others not mentioned here give positive feedback in the form of high economic growth and enhanced international comparative advantage.

China’s trade relationships with other Asian economies show where its economy is moving. Currently, China’s economy has strong comparative advantages in low-tech industries; but, at the same time, it is gaining comparative advantage in more technology-intensive sectors. Already, China has strong comparative advantages over ASEAN in some high-tech and most mid-high tech industries. China even shows comparative advantages over Korea in some high-tech industries, albeit with a small margin. But with Japan, there exists wide gap in high-tech and mid-high tech industries.
Therefore, it is to be expected that competition between China and ASEAN and Korea will intensify in the near future; but China will not be an immediate threat to Japan in world markets for high- and mid-high tech products.

**Box: Huawei Technologies Co. Ltd**

Established in 1988 by an army wireless communication engineer, Huawei Technologies is a high-tech enterprise that specializes in research and development, production and marketing of communications equipment. Taking 40% share in the Chinese market, Huawei’s competitive strength is to produce high-tech products with lower costs, which enables it to compete with foreign suppliers both in domestic and overseas markets. It has succeeded in winning the competition in supplying communication equipment projects in Vietnam, Thailand, Indonesia, South Korea and Brazil. Sixty percent of its 16,000 workers hold MA degrees, and more than 2,000 are Ph.D.s. Huawei spends more than 10% of its sales in research and development – US$342 million in 2001. With a headquarters in Shenzhen, Huawei has 11 R&D centers, among which are five overseas research institutes in Silicon Valley, Texas, Stockholm, Bangalore, and Moscow. It has numerous collaborative R&D projects with domestic and US universities. With its state-of-art design technologies, Huawei designs ASIC in-house and out-sources production to a US foundry company on an OEM basis.

3. Catching-up Model in brief

The configuration and constellation of the KIS has largely been shaped by overall economic development strategies, namely the catch-up model. This model has brought both limitations and advantages to the KIS. This section will briefly review the process of building technological capability within the broader framework of economic development. The development strategies which have influenced the shape of the KIS can be summarised as follows: 1) government-led mobilisation of strategic resources for achieving development goals; 2) export promotion cum rapid market expansion; 3) selective industrial promotion, notably in the heavy-chemical industries; 4) governmental support for the growth of big business; 5) utilising foreign technologies; and 6) constructing S&T infrastructure, institutions and R&D programmes for industrial demands. The last two points are the main focus of concern in this section.

Although Korea, as a late-industrialising country, has depended heavily on foreign technologies, it has also made efforts to accumulate technological capabilities. At the initial launch of its economy-wide economic development plan, Korea was poorly endowed with factors necessary for industrialisation except for a plentiful labour force. Furthermore, the technological competence of Korean firms was far below world standards. Consequently, it was inevitable or natural to look toward foreign sources for technologies. After the industrialisation process launched in 1962, there was remarkable growth in imports of foreign. The process of technological capability building in Korea is characterised as a dynamic process of the interplay between imported technologies and indigenous R&D efforts.

---

3 This section is based on Suh (2000).
Reviewing the process of industrialisation since the 1960s, there appears a general pattern of technological development across industries with some industry-specific variations. Table 2 presents the pattern in Korea’s machinery industry. The table shows that technology transfer and in-house R&D are two principal modes of building technological capability in the machinery sector and other industries in general.

During the early stages of industrialisation, technologies are imported in packaged forms. Turn-key based plant imports were most common during those years, and assembling technologies were imported for the purpose of knock-down production and/or OEM. Then, afterwards, self-sufficiency in technology was enthusiastically pursued, although it was not achieved in a short period. Localisation of some technologies was one of the main goals both for government and private firms. In this period, imported technologies changed to un-packaged ones and the importation of operation technology increased in order to enhance productivity. After achieving, to some extent, the goal of promoting self-reliant technologies, the next step was to get Korean products into world markets. In order to do this, it was necessary to expand domestic markets. In this period, imported technologies were relatively more sophisticated and advanced, involving material-related technologies and control and design technologies. Throughout all periods, the ratio of OEM to own brand name (OBN) has steadily decreased.
Table 2: The technological capability building process in Korea’s machinery sector

<table>
<thead>
<tr>
<th>The process of development</th>
<th>Technology imports</th>
<th>Production and R&amp;D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1960s – 1970s</strong></td>
<td>Policy goal: establishment of production base</td>
<td>Packaged technology: turn-key based plants</td>
</tr>
<tr>
<td>Characteristics: heavy dependence on imported technologies</td>
<td>Assembling technology</td>
<td>OEM-dominated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Almost no in-house R&amp;D</td>
</tr>
<tr>
<td><strong>Early 1980s</strong></td>
<td>Policy goal: promotion of self-reliance</td>
<td>Unpackaged technology: parts/components-related technology</td>
</tr>
<tr>
<td>Characteristics: Import-substitution, Localisation of parts/components Production</td>
<td>Operation technology</td>
<td>Product development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In-house R&amp;D begins</td>
</tr>
<tr>
<td><strong>Late 1980s – 1990s</strong></td>
<td>Policy goal: export-promotion by Means of expansion of Domestic market</td>
<td>Materials-related technology</td>
</tr>
<tr>
<td>Characteristics: beginning of plant Exports, learning advanced and core technologies</td>
<td>Control technology</td>
<td>Product innovation</td>
</tr>
<tr>
<td></td>
<td>Design technology</td>
<td>Process improvement</td>
</tr>
<tr>
<td></td>
<td>High-quality product tech.</td>
<td></td>
</tr>
</tbody>
</table>

The pattern of technology transfer differs slightly across industries, particularly in the early years. Unit production industries, such as shipbuilding and machinery, relied mainly on formal transfer in the form of licensing and consultancy for the initial erection of production facilities and product design. Mass production industries, such as electronics and automobiles, also depended on formal transfer but to lesser extent. Instead, more emphasis was placed on engineering efforts for implementation. Continuous process industries, such as chemicals, cement, paper, and steel, were established on a turn-key basis.

Since the early stages and throughout the 1970s and 1980s, technology imports prevailed, and are still an important source of technological innovation. Recently, however, the outsourcing of foreign technologies has become more sophisticated, and
the modes of technology transfer have become diversified and complex. Exchanges or alliances, for the mutual benefit of both parties, are beginning to take the place of unilateral technology imports. Furthermore, interest in foreign technologies is shifting towards more high-tech areas and/or design technologies, and the scope of foreign partners has widened considerably.

The growth of R&D activities in the private sector shows a similar pattern. During the earlier period of industrialisation, systematic in-house R&D efforts were hard to find out. It was not until the 1980s that Korean firms endeavoured to build in-house technological capability by institutionalising R&D activities. In the early 1980s, the R&D activities of private firms focused on the adaptation and assimilation of imported technologies. Product development was the main feature of R&D in those years. Since then, with a base of accumulated experiences and knowledge, a number of firms in some specific industries have been able to make some product innovations. Throughout these years, efforts to improve the production process have continued.

The pattern outlined above is clearly illustrated in Figure 5, which plots the trend of the relationship between technology imports noted as payment for foreign technology licensing fees and indigenous R&D efforts noted in terms of R&D expenditures over industrial production from 1976 to 2002. The trend changed substantially over the years. Indigenous R&D efforts remained at an insignificant level until the early 1980s, but since then R&D intensities have increased considerably. Consequently, the overall relationships between imported technologies and indigenous R&D efforts have changed from substitution to being complementary. Figure 5 shows that the trend of relationships changed around 1982. The turning is not accidental; this year marks the launch of NRDP, when private enterprises began to establish in-house R&D laboratories.
The changing relationship between royalty payments and R&D originated mainly from two sources: increased R&D efforts in the private sector, and governmental policy changes. Throughout the 1980s TI increased steadily and maintained its pace. At the same time, however, systematic in-house R&D efforts in the private sector have begun to prevail. Underlying this change, three driving forces, inter alia, have been influential. First, as the Korean economy moved to technology-intensive industries, foreign sourcing of technology could not meet the required technological standards. As foreign firms become more reluctant to release their technologies, it becomes harder to acquire advanced technologies by depending solely on the conventional means of technology imports. Second, the cost advantage of cheap skilled labor was exhausted after the early 1980s. Therefore, Korean firms felt the need to develop their own technological capabilities.
Underlying the changing relationships, both the private sector and the government have made concerted efforts to develop technological capabilities. First, there has been a fundamental shift in business strategy. In earlier years, international competitiveness relied mostly on such cost factors as low wages and scale economies based on mass production. And as imported technologies were of a kind that required simple assimilation and adaptation, there was no need to organise R&D activities. In later years, in contrast, as the cost advantage of cheap skilled labour was exhausted and the economic structure was transformed into more technology-intensive sectors, there was a pressing need for institutionalised R&D activities. The private sector met this need by establishing in-house R&D laboratories. Accordingly, the pattern of international technology transfer has changed substantially, towards more sophisticated and complex forms.

In accordance with the stages of economic development, the Korean government has successively changed the orientation of S&T policy. In the earlier years, more emphasis was put on building the infrastructure for technological development, whereas in later years the emphasis shifted towards more specific targeted technological development. In the early years of launching full-scale economic development plans, the Korean government recognised very clearly that science and technology would play important roles in the coming years. In the 1960s, two noteworthy policy measures were initiated in this regard: the establishment of KIST (1966) and of MOST (1967). These two institutions, together with KAIS, which was established in 1971, have exerted powerful influences over the S&T community in Korea. MOST has been the main designer of Korea’s overall S&T policy; KIST has played the role of technological functionary in responding to industrial demands for rapid economic growth; and, KAIS (later KAIST) first implemented the concept of the research-oriented university into the
Korean higher education system. Subsequently, several important policies have been successively enacted; among others, the establishment of specialized GRIs since the 1970s, and, since the early 1980s, full-scale national R&D programmes.

The process of building technological capability is best considered from the aspect of the choice of technology. The fact that most imported technologies are in a mature stage of development shows that products are already standardized in the world market. Moreover, in order to compete with foreign firms in world markets, i.e. produce standardized products without having technological superiority, cost advantage has to be achieved by economies of scale. Consequently, technologies that render economies of scale in production have been preferred. Large plants in petro-chemicals, semiconductors, shipbuilding, steel, and the automotive industry exemplify the choice of technologies of this kind. Most of these industries demonstrate economies of scale in production as well as large plant size. In looking at industrial linkages, Korean industries in general show vulnerable backward and forward linkages when starting a new venture. For instance, when the semi-conductor industry was launched, there were neither adequate backward linkages to the equipment and raw materials sector nor forward linkages to the computer sector. The strategy of development for both government and private firms has been to assume that such lacked elements as components and raw materials will come from foreign sources. Combining imported technologies with cheap labor in the earlier period and fully exploiting human factors in the later period has enabled Korean firms to compete in foreign markets. In general, Korean firms have shown adroit movement in the operation of imported plants and the absorption of imported technologies. The choice for big technology is also closely related to the government's aggressive export-promotion policy and to large firm oriented industrial policy.
R&D Activities and Industrial Competitiveness

Korea’s industrial R&D spending is highly concentrated within a small number of industries. ICT sectors (communications equipment, semiconductors, computers, and electrical and electronic products) account for 57.6% of the total manufacturing R&D expenditure, followed by the automotive sector (19.6%), chemicals (9.8%), machinery (3.9%), and iron and steel (3.8%). All of these industries, except for chemicals and machinery, make a positive contribution to the trade balance. Furthermore, Korea is one of the major exporters of high-tech products, although the value content of Korea’s exports, including high-tech products, is still low. For instance, Korea’s up-market share in EU-15 countries is below the OECD average, while its down-market share is one of the highest, exceeded only by that of Turkey, the Czech Republic, and Poland.\(^4\) Korean industries, despite their high R&D intensity, have not yet been successful in harnessing R&D potential to added value in their products.

\(^4\) For more information, see OECD STI Scoreboard 1999.
Figure 6: R&D intensity and TSI in Korean Manufacturing Sectors

1992

2002
4. Changes in Korea’s Innovation System

4.1 Business R&D Activities

In the past years, large firms played a leading role in industrial R&D activities. Since the early 1980s, private enterprises began to establish in-house R&D centers, and large firms established most of them at that time. For example, the Directory of Korean Technology Centers published by Korea Industrial Research Institutes in 1985 listed 141 industrial R&D centers, out of which only 15 centers belonged to SMEs. Another characteristic of industrial R&D activities in past years is their mostly adaptive nature. This was mainly because R&D activities were to assist the production of mature products. Technologies invented elsewhere were transferred by licensing contracts or other means of technology transfer, and adapting those transferred technologies to the requirements of the production process was the major goal of industrial R&D activities.

The trend has changed, particularly since the financial crisis in 1997. As shown in Figure 7 although SMEs are still responsible than less than one third of total R&D expenditures, their spending is increasing more rapidly than that of large enterprises (LEs), which results in an increase in SMEs’ share. During the period 1995 and 2000, SMEs’ share of total industrial R&D expenditures has doubled. Do the increased R&D spending by SMEs and their increased R&D share imply that SMEs’ role in industrial innovation activities is also increasing.

---

5 This section is based on Suh (2003).
The financial crisis in 1997 and the restructuring efforts afterwards had an unexpected effect on Korean business. Profitability came to be recognized as more important than market expansion. Firms’ spending for technological development is no exception. Companies, particularly large firms, have endeavored to downsize and streamline their R&D laboratories in line with business restructuring. Downsizing forced many R&D personnel to leave large firms; and many of these displaced professionals have established small-scale, specialized R&D laboratories or technology-based small firms. As shown in Figure 8, the number of corporate R&D centers increased very rapidly since the financial crisis, and most of the newly established corporate R&D centers are small in size.6

---

6 In addition to the restructuring of large firms, other factors contribute to the increase in small-sized corporate R&D centers. The government’s drive to create “venture” companies and changed capital market conditions for start-up companies are among them.
The increasing number of small-scale, specialized R&D centers or technology-based small firms will change the industry’s landscape. First, a direct effect is the increases in R&D expenditure and intensity by SMEs. Second, the existence of technologically agile small firms will lead to changes in business relationships, particularly between large and small firms. Supporting statistics are following.

Total R&D expenditures by SMEs doubled between 1997 and 2000, whereas expenditures by large enterprises increased by only 5.1%. The increases in total R&D expenditures by SMEs is partly due to the sharp increase in the number of SMEs that spend on R&D activities, as manifest by the sharp rise in the number of SME R&D centers. But the R&D intensity of SMEs, defined as the ratio of R&D expenditures over sales, also increased, from 2.8% in 1997 to 3.1% in 2000. In contrast, the R&D intensity of large enterprises decreased from 2.1% in 1997 to 1.8% in 2000. In sum, not only is the number of SMEs that spend on R&D increasing, but also SMEs are intensifying their R&D activities since the financial crisis. The same observation and conclusion apply to the case of researchers. From 1997 to 2000, SMEs strengthened their R&D activities by sharply increasing the number of researchers they employed, whereas the number of
researchers at large enterprises remained almost during this period.

The effects of the financial crisis on the R&D activities of SMEs vary across industrial sectors. R&D expenditures have increased in almost all of sectors, except ships and boats, railroad equipment, and communication services. In terms of R&D intensity, chemicals, including medicine and pharmaceuticals, electrical products, transportation equipment, including automobiles and parts, ships and boats, railroad equipment and aerospace, and services in electricity, gas and water and communication show decreases. Note that R&D intensities of SMEs in Korea’s ‘flagship industries,’ such as chemicals and transportation equipment, have all decreased by a big magnitude. In contrast, IT related sectors such as computer & office equipment, semiconductor & electronic parts, and communication & media equipment have all showed big increases in R&D expenditures or intensities. The different pattern in R&D expenditures across industrial sectors is also to be found in the pattern of changes in the number of researchers in different industrial sectors. Particularly striking are the semiconductors and electronic parts, communication and media equipment, and the business services sectors, where the number of researchers including Ph.D.s and R&D expenditures increased more than three times. These are sectors in which specialized, small R&D centers are burgeoning; and therefore, networking and collaboration could be expected to be more prevalent than other sectors.

4.2 The Emergence of Innovation Networks

Based on cross-shareholding, subsidiary companies in a Chaebol are mostly vertically integrated. Vertical integration can be seen in that subsidiary companies in a Chaebol take part in various stages of a supply chain. Diversified business structures of Chaebols might allow to developing horizontal division of labor among subsidiary
companies of a Chaebol; but, horizontal relationships between Chaebols or subsidiary companies of different Chaebols are less prevalent. The expansion strategy of Chaebols, which aims to widen business areas as possible, results in more diversified business structures for Chaebols; but, it obstructs the development of horizontal relationships between companies, in particular those between Chaebols and SMEs.

The business relationships that were prevalent in the past years have been changing after the financial crisis. Chaebols could no more pursue as aggressively as in the past the expansion strategy based on debt financing and cross-shareholding. Instead, they had to substantially lower their debt-ratios and to rationalize their diversified business structures. The new strategy was to concentrate on core businesses and to sell out or spin off unprofitable businesses. As is shown in the TABLE 3, 442 business branches that had employed 67,863 people had been spun off to independent companies. Samsung has rendered 161 spin-off companies, followed by Hyundai with 98 companies, LG with 94 companies and SK with 45 companies. Spinn-off companies from these four Chaebols account for 398 companies, more than 90 % out of total. The number of spin-off companies peaked at the year of 1998, when the repercussions of the financial crisis on the corporate restructuring were also at its highest.
Table 3: Spin-offs from Chaebols

<table>
<thead>
<tr>
<th>No. of mother co.</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>Total</th>
<th>No. of employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung</td>
<td>16</td>
<td>0</td>
<td>115</td>
<td>29</td>
<td>5</td>
<td>12</td>
<td>161</td>
</tr>
<tr>
<td>Hyundai</td>
<td>12</td>
<td>36</td>
<td>27</td>
<td>18</td>
<td>8</td>
<td>9</td>
<td>98</td>
</tr>
<tr>
<td>LG</td>
<td>15</td>
<td>5</td>
<td>18</td>
<td>51</td>
<td>14</td>
<td>6</td>
<td>94</td>
</tr>
<tr>
<td>SK</td>
<td>11</td>
<td>3</td>
<td>11</td>
<td>11</td>
<td>13</td>
<td>7</td>
<td>45</td>
</tr>
<tr>
<td>Hanjin</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>POSCO</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Hanwha</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Doosan</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>103</td>
</tr>
<tr>
<td>Ssangyong</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Dongbu</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Dongyang</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Hyosung</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>CJ</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Kolon</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Hyundai Dept.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Daewoo E.</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>76</td>
<td>47</td>
<td>178</td>
<td>124</td>
<td>53</td>
<td>40</td>
<td>442</td>
</tr>
</tbody>
</table>

Note: Spin-off is confined to the cases of MBO (management buy-out) and EBO (employee buy-out). Source: Federation of Korean Industry, 2001.

The increasing tendency of large enterprises to make strategic alliances with venture companies is another new trend that has occurred since the financial crisis. Strategic alliances had been more prevalent between large enterprises; but it was hard to find those between large enterprises and SMEs before the financial crisis. Two factors, among others, are worth to note. First, backed by the expansion strategy, large enterprises, particularly Chaebols, usually set up their own business branches or subsidiaries when new opportunities arose or found. In other words, large enterprises preferred to internalize new business opportunities rather than to externalize them. The second factor was that since the number of technologically advanced SMEs had been few, the number of partners for alliances with LEs was also few. Under these circumstances, strategic alliances between firms, particularly between LEs and SMEs, will not be well developed.
The situations described above have also been changed since the financial crisis. Because of the more stringent financial constraint, LEs should concentrate on core businesses. Spinning-off, as is explained above, is other side of the concentration. And there come a large number of technologically agile smaller companies. These changes have rendered a new trend of increasing strategic alliances between LEs and SMEs.

TABLE 4 shows some examples of strategic alliances between LEs and new technology based firms, or venture companies in the Korean parlance. Samsung Electronics’ strategic alliances with about 100 venture companies focus on non-memory chips where it has the strong necessity to enter into and needs business partners. LG Electronics runs what they call LG Venture Club composed of venture companies founded by retirees from LG Electronics or other LG companies. (See below for details on LG Venture Club.) LG Chemical has made strategic alliance with four venture companies and plans to increase the number of partners. SK and CJ are collaborating with venture companies for R&D projects for entering into new businesses where they do not have competence.
Table 4: Strategic Alliances between LE and Venture Company

<table>
<thead>
<tr>
<th>Company</th>
<th>Strategic Alliance Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung Electronics</td>
<td>Strategic alliance with about 100 venture companies. Focusing on non-memory chips</td>
</tr>
<tr>
<td>LG Electronics</td>
<td>LG Venture Club</td>
</tr>
<tr>
<td>LG Chemical</td>
<td>Made alliances with 2 domestic and 2 overseas venture companies</td>
</tr>
<tr>
<td>SK</td>
<td>Project for developing pharmaceutical products with 11 venture companies</td>
</tr>
<tr>
<td>CJ</td>
<td>Project for developing pharmaceutical products with 2 venture companies. Plan to make alliances with 20 venture companies</td>
</tr>
</tbody>
</table>

Source: Dong-A Ilbo, March 27, 2002.

Although there is no complete information on the new business relationships between LEs and SMEs such as in TABLE 4, we can further assume that strategic alliances and other kinds of business relationships between LEs and SMEs are rapidly increasing. There are, at least, two grounds for the assumption. First, the necessity of strategic alliances is stronger than before the financial crisis. When LEs need to enter into new businesses, partnership with NTBF (new technology-based firms) will be less costly and risky than total internalization. Second, smaller NTBF will have an incentive to make alliances with LEs that have advantages of scale economies. Partnership with LEs will allow NTBF to safeguard their growth by utilizing LEs’, for example, capital and marketing advantages.
5. Discussion

The Korean economy is facing a new environment. There are new technologies in such fields as ICT, biotechnology and new materials. As economic activities will be more knowledge-intensive, so the transition to the knowledge-based economy requires significant changes in work and production organizations, industrial relations and in the structures of governance. The world economy is becoming more integrated in both trade and investment; this fosters (and is caused by) freer movement of capital and production activities across national borders. The trend toward globalization emphasizes the importance of the global integration of national economic activities. That the Korean economy has matured and developed at a level comparable to advanced economies implies that the available stock of technologies drawn on through conventional technology transfer is exhausted. How well are Korean firms responding to these changes? Can the Korean economy achieve sustainable economic growth in the future?

Making Innovation System more effective

Under the new economic setting, both domestically and internationally, the conventional ways of technological development will not be as effective as they have been in the past. Standing at the crossroads, faced with new challenges, private firms need a new strategy. The task for Korean private enterprises is to make the transition from borrower to innovator. This presents several issues for discussion.

First, the industrial structure shows the weakness of upstream sectors, particularly in the capital goods industry. This weakness is closely related to the predominance of large firms, notably Chaebols, and the government's industrial policy. In accordance with the aggressive export-promotion policy that complements the tiny domestic market,
the imported technologies are both mature in life cycle, and able to render economies of scale in production. Consequently, a few large firms have made large-scale investment, with the aid of favourable government support. The production structure has centred on end products, and ignoring support firms and industries has resulted in heavy dependence on the foreign sourcing of materials, parts, and components. This chronic phenomenon renders the Korean economy vulnerable to external changes in the foreign market. Accordingly, strengthening upstream industrial linkages is one of the most urgent tasks for the Korean economy.

Second, related to the first issue, a small number of Chaebols and research institutions are dominating innovation activities. The dominance of Chaebols, per se, is not an evil. The problem lies in the diffusion of innovation. The internal diffusion of technological innovation is not so active in Korea. The lack of domestic diffusion among firms is well demonstrated by the fact that repetitive importation of foreign technologies is common. Furthermore, the diffusion from research institutions to private firms is not as effective as expected. More organic co-operation between domestic firms, particularly between large firms and SMEs, and more active collaboration between research institutions and private firms are imminent. In this regard, we have observed a positive sign of change, for example, the emergence of innovation networks between conglomerates and SME. It is needed to sustain this trend.

Third, technological co-operation between domestic firms and foreign firms should be promoted. In the past, the Korean economy has benefited from the inflow of advanced foreign technologies. Now, new modes of co-operation such as cross-licensing and strategic alliances need to be utilised more. Facing rapid changes in technological opportunities and the expansion of globalisation, private enterprises need to strengthen the development of human resources and international R&D networks.
SMEs in transition

Today’s SME in Korea face a challenge to strengthen their technological capabilities and thereby to move up to higher ladder of value chains. Unlike the new technology-based firms (NTBF) or those small numbers of firms that can make partnership relations with chaebols or other firms, however, the prospect for the rest of SME is not necessarily positive.

Figure 9 below\textsuperscript{7} gives a snapshot on the current status of manufacturing SME in Korea. The figure classifies manufacturing SME into three: those that are actively exporting, those that are spending money for R&D, and those are certified as “venture”. Exporting can be interpreted a measure to indicate firm’s overall competitiveness; R&D spending as a measure of firm’s technological capability; and venture certification as an entrepreneurial capability to enter into a new business. Intuitive conclusions can be drawn from the figure. Most of Korean SME are home market-oriented that only about 12% manufacturing SME are actively engaged in exporting, which might imply that they are vulnerable to market opening. Notice that the share of those active SMEs in exporting decreased by 10 percentage-point from 1998 to 2002. In terms of technological capability, about 18% SME have ever spent money for R&D purpose – an increase by 10 percentage point from 1998. This implies that majorities of SMEs are weak in their technological capabilities; but there is a positive sign of increase. In contrast, the fact that 9 % of manufacturing SME get the certification of “venture”- a significant increase from 3% in 1998 - might be a promising indicator for the prospect

\textsuperscript{7} The data are from Korea Federation of Small and Medium Business, and as of 1998. “Active exporting” firms are those that exporting more than 30% of total sales.
of Korea’s SME in the future.

Figure 9: Classification of SME by Activities

Despite the debate on the nature of “venture” in Korea, it is evident that venture activities in Korea is very active. An indicator is the investment in venture capital as a percentage of GDP. OECD (2003) shows that Korea is one of countries above OECD average.
 References

Korea Development Institute, *A Comprehensive Study on Industrial Competitiveness of Korea*, Seoul: Korea Development Institute, 2003. (In Korean)


OECD, *Main Science and Technology Indicators*, various issues.


http://www.sourceoecd.org