The Sources and Directions of Technological Capability Accumulation in Korean Semiconductor Industry

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ABSTRACT

In this paper we analyze the technological accumulation processes in the Korean semiconductor industry from the institutional approach. Institutional approach, which is closely connected with Neo-Schumpeterian tradition, has emerged as an alternative theoretical framework to neoclassical approach to understand the process of producing technological knowledge. Traditional wisdom of neoclassical approach revealed the limitation to explain the complex nature of knowledge creation and diffusion. US patent data are analyzed in terms of the increasing trend of numbers and its content to measure the rate and direction of technological capability accumulation. This analysis shows that semiconductor technologies are one of the fastest growing fields among Korean technological activities. Moreover, the analysis of patent content suggests that fabrication technologies are the most important area within the technological development of semiconductors, whilst circuit design and testing technologies are beginning to increase in significance. In addition, it is examined how private sectors and public institutions have contributed to generate technological capabilities, and the relationship between them has been changed during the development processes. It is found that Korean firms enhanced their technological capabilities from the learning and assimilation of imported technology to enhanced in-house R&D capabilities in the later stage. The support of public institution and government policy also played significant role to this successful transformation in conjunction with the vigorous R&D investment of public sector.

I. INTRODUCTION

The success of the Korean semiconductor industry in the world dynamic random access memory (DRAM) market, an accepted high technology area, is recognized as remarkable. Business and policy studies have presented a number of reasons for this achievement, especially given Korea's late entry into the market. These include the massive investment capabilities of *chaebol* (large diversified business conglomerates in Korea) firms and their product strategy focused on DRAMs [1], successful developmental corporatism between *chaebol* firms and government [2], dynamic techno-management capabilities [3], and dynamic resource leverage [4]. Among these factors, we are most concerned with the technological capability accumulation processes of the Korean semiconductor industry.

As Nelson and Pack [5] pointed out, there are two main approaches to examining the success of development in newly industrialized countries (NICs). One approach examines it through accumulation of investment based on neo-classical growth theory, whilst the other focuses on learning based on evolutionary theory. The advantage of the evolutionary approach is that by focusing on technology learning activities, it is able to examine the endogenous capabilities for sustainable development, an area the neo-classical approach cannot encompass within its resource allocation framework. Whilst the neo-classical approach concentrates on existing resources in a static way based on maximization assumption, the evolutionary approach assesses the way in which capabilities satisfy the changing environment in a historical context.

Even though there was no substantial knowledge base in this area, a look at the history of the Korean semiconductor industry shows that the innovative players in the field achieved an impressive technological *catch up* in a very complex technology area. More than that, they now competed with the leading international companies, at least in the DRAM area. Gaining an understanding of the technological capability accumulation process of the Korean semiconductor industry in an evolutionary sense therefore has significant implications for other developing countries, as well as extending the boundary of innovation studies.

This paper adopts institutional approach to enable us to investigate factors such as the interrelationships in the capability accumulation process. Institutional approach, which is closely connected with Neo-Schumpeterian tradition, has emerged as an alternative theoretical framework to neo-classical approach to understand the process of producing technological knowledge. Traditional wisdom of neo-classical approach revealed the limitation to explain the complex nature of knowledge creation and diffusion. From an evolutionary viewpoint, however, technology is regarded as a complex process within the context of a national system of innovation (NSI).

The NSI concept has gained much attention in the literature in recent years. It tries to understand the relationship between technological and economic growth as well as national differences in the rate and type of innovation. Despite various approaches to NSI [6]-[8], it is broadly defined as "the network of institutions in the public and private sector whose activities and interactions initiate, import, modify and diffuse new technologies" [9]. It therefore includes those elements of national R&D capacity invested in business, education and training, science and policy making institutions [10].

In this paper, we investigate i) the direction of technological capability building, ii) the ways in which the Korean innovating players acquired technological knowledge, and iii) how endogenous technological capabilities evolved within the context of supporting institution and business strategies.

1. Conceptual Framework

The technological capability accumulation process has been studied at the margins of the traditional economic literature. Although recent efforts at innovation studies on developing countries give a better understanding of the innovation process, the transition process from the technology use phase to the technology changing and generating phase has hardly been investigated. This is partly because developing countries have depended to a large extent on advanced countries for their sources of innovation. However, this situation has changed with the emergence of "latecomer" firms such as Samsung in the DRAM area and Acer in the PC area, who directly compete for leadership in the world market.

One of the first studies in this area by Hobday [11] provides a conceptual theory for the path of technological accumulation in electronics in East Asian developing countries. This is centerd around a company level analysis. The theory suggests a 'reverse product life cycle' as one of the main features of the technological development path in electronics in developing countries. According to this theory, there is a general tendency for latecomer firms in developing countries to begin with simple tasks and accumulate capabilities systematically in a steady manner, with skills and knowledge gradually building on each other. In this model, process and product technology are closely linked. Early entrants begin by absorbing basic manufacturing skills. Process innovation then occurs once operational capabilities have been learned. Once firms have accumulated process innovation skills, they seek to improve the quality of their products and make changes to the design. Finally, R&D occurs in the later stage of a catch-up learning path.

This theory reverses the traditional model of innovation as seen in Vernon's "product life cycle model" [12], which shows R&D as an early and central part of innovation process. In this respect, it shares its main theme with Lee *et al's* technology

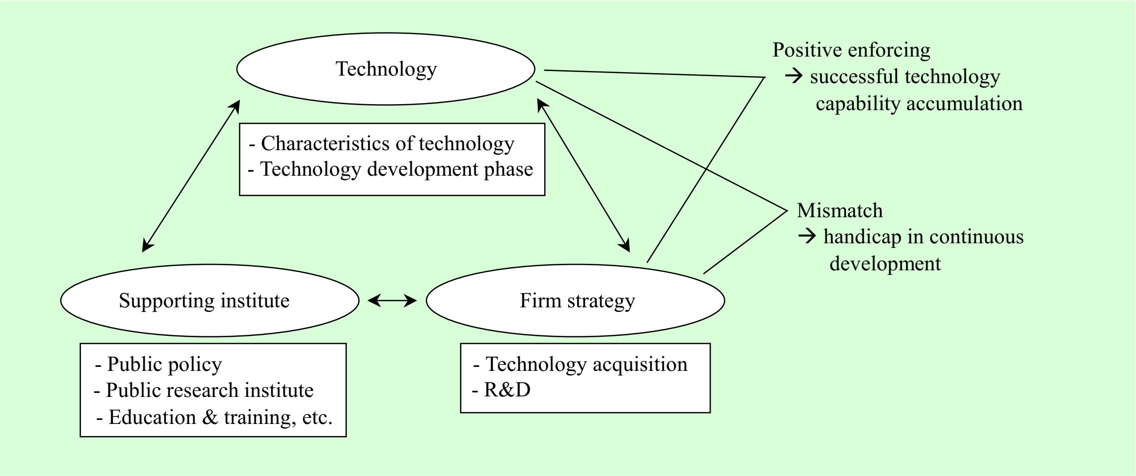

Fig. 38. Co-evolution process between technology, supporting institutes and business strategy.

development process model [13] for developing countries, as it assumes certain developmental stages according to the product life cycle.

In a very general sense, these evolutionary development stage models reflect the experience of technology development in developing countries. However, rigid ideas about stages and sequences may be misleading unless they encompass consideration of the interaction process between technological capabilities, supporting institution and business strategies, especially at the sectoral and individual firm level. The rate at which a company in a particular country proceeds in accumulating capabilities is largely influenced by the business strategies and supporting institutional (or infrastructural) arrangements which correspond to the level and characteristics of technological development. In a scale intensive industry, for example, it may be important to develop investment related capability and accordingly, direct and indirect financing support from the government to reduce the investment risk. In the case of a science based sector like biotechnology it may be important that entrepreneurial venture firms flourish, so the main policy would reside in supporting spin-offs from universities and public institutes. On the other hand, the technological development phase has to be contemplated in the design of national policy. In the early stages of technology emergence, for example, one of the major roles of government will be co-ordination in setting standards. In the later stages, on the other hand, it will be helping firms to exit and shift into a high value added area.

The comparative advantage achieved by certain nations is created rather than innate, and both private and public actions may be needed for such advantage to be built [14]. In addition, it has to be recognized that private and public actions exist in a historical context. As 'new institutional economics' has suggested, institutions change optimally in response to changes in economic circumstances. Put another way, technological capabilities have advanced successfully with the appropriate public institutional arrangements and business strategies. A mismatch between a set of supporting institutions and strategies with the character and phases of technology development is therefore a handicap to adapting to a rapidly changing environment. This process is summarized in Fig. 1.

2. Methodology

In order to examine the characteristics of technological accumulation in the semiconductor industry, we have combined both technological building process and patent analysis at the private sector and public institutions level.[1] First of all we have made an attempt to measure the international and sectoral technological advantage using US patents. We have selected semiconductor related patent abstracts from 1985 to1995 covering a sample of 533 patents chosen on a patent title and abstract keyword basis. We then categorized the sample on the basis of type of technology, and whether the patent could be used in circuit design, fabrication, assembly or technology testing. In the next step we have combined the patent analysis and development of technologies at the firm level to identify core technologies and sources of innovation in the catching-up process and how public institutions interplay with private sector. In the final part of the analysis is concern with the relationship between changing sources of innovation and the role public institutions as technological capabilities enhance.

Despite the common employment of patents to measure national technological capabilities, there are clear limitations to their usage. Firstly, the main purpose of using patent statistics is to get an approximate measurement of the nation's technological capability, but the propensity of patents differ from industry to industry according to ease of imitation and the strategies of the firm involved [15]. In addition, it is difficult to gauge accurately the usefulness of the invention by looking at a patent abstract or the frequency of patent citation. Nevertheless, patent abstracts do indicate the direction of technological accumulation, and their usefulness will be more effectively assessed when we examine their utilization in the process of product innovation.

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[1] The rationale for using US patent statistics is that: 1) the US market is the preferred place to apply for protection; 2) Korea's major export partner in the semiconductor industry is the US; and 3) over the last decade patent infringement issues have been heavily connected to the US market. To compare the international strength we used the share of foreign residence patenting activities in the US as well as the Science Policy Research Unit (SPRU) 34 classification methods.

II. OVERALL PATTERNS OF TECHNOLOGICAL ACCUMULATION

There are various ways of measuring technological activities at a national and sectoral level. Only a few studies, however, have used patent statistics in relation to newly industrializing countries [16]-[19]. We begin with an aggregate view of Korean technological activities, together with international comparisons. As can be seen from Table 1, the share of utility patents from foreign countries in the US indicates [20] that Taiwan and Korea are the only countries to show a significantly increasing trend compared to selected OECD countries. Moreover, in 1995 Taiwan ranked sixth after industrialized countries like Japan, Germany, United Kingdom, France and Canada, with 1,620 utility patents. This was equivalent to a 3.5 % share of all foreign patents. Korea ranked seventh, with 1,161 patents and 2.5 % of foreign utility patents granted in the US. The overall pattern of foreign residence patenting activities in the US shows that it is highly concentrated by a few nations, and industrializing countries like Taiwan and Korea are becoming more active.

Measuring a nation's competitiveness from an international perspective, revealed technological advantage (RTA) is the most commonly adopted. It was developed by Soete [21] and is defined as a particular country's share of the US patent activity within a sector divided by that country's share of total US patents. It therefore measures the country's performance in a particular sector relative to its aggregate performance. If RTA is above average, it reflects the relative strength of the country in that sector, and if below the average it reflects the relative weakness of the country. On this basis we have calculated RTA from 1985 to 1994 using the SPRU classification.

As can be seen from Table 2, Korea's major technological strengths are located in the electronics sector, including semiconductors,

Table 4. International comparisons by foreign residence patenting activities in the US.

(Unit : %)

Country	'90	'91	'92	'93	'94	'95
Japan	45.4	46.4	48.5	49.4	49.1	47.6
Germany	17.7	16.9	16.2	15.3	14.8	14.4
France	6.7	6.7	6.7	6.4	6.1	6.2
UK	6.5	6.2	5.4	5.1	4.9	5.4
Canada	4.3	4.5	4.3	4.3	4.4	4.6
Taiwan	1.7	2.0	2.2	2.6	3.2	3.5
South Korea	**0.5**	**0.9**	**1.2**	**1.7**	**2.1**	**2.5**
Italy	2.9	2.7	2.8	2.9	2.7	2.4
Switzerland	3.0	2.9	2.6	2.5	2.6	2.3
Sweden	1.8	1.6	1.4	1.4	1.5	1.8
Netherlands	2.2	2.2	1.9	1.8	1.9	1.7
sub-total	92.8	92.9	93.3	93.4	93.1	92.6
rest of the world	7.2	7.1	6.7	6.6	6.9	7.4

Source: US Patent and Trademark Office, *Technology Assessment and Forecast Report*, 1996

Table 2. Revealed technological advantage (Korea).

Class	Technical fields	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94
1	Inorganic chemicals	0.0	3.2	0.0	0.0	1.0	0.0	0.0	0.3	0.0	0.4
2	Organic chemicals	1.4	0.0	1.0	0.7	1.0	1.1	0.6	0.7	0.6	0.5
3	Agricultural chemicals	4.9	0.0	0.0	0.0	0.0	0.0	1.5	0.5	0.8	0.4
4	Chemical processes	0.9	0.4	0.4	0.0	0.7	0.5	0.6	0.4	0.7	0.6
5	Hydrocarbons, mineral oils, fuels and igniting devices	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	Bleaching, dyeing and disinfecting	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	3.6
7	Drugs and bioengineering	1.3	0.6	0.0	0.2	0.3	0.5	0.2	0.3	0.4	0.3
8	Plastic and rubber products	0.0	0.0	0.0	0.0	1.9	0.9	0.5	0.5	0.4	0.7
9	Materials (including glass and ceramics)	0.9	1.5	0.5	0.7	0.6	0.4	0.5	0.4	0.5	0.3
10	Food and tobacco (processes and products)	0.0	2.6	1.6	0.0	0.6	0.0	0.6	1.3	0.9	0.2
11	Metallurgical and metal treatment processes	0.0	0.0	0.0	2.7	0.0	0.4	1.0	0.6	0.6	0.4
12	Apparatus for chemicals, food, glass, etc.	0.0	0.7	0.4	1.9	0.8	0.7	0.4	0.5	0.8	0.8
13	General non-electrical industrial equipment	0.8	2.2	1.5	0.2	0.6	1.1	0.3	0.9	0.6	0.4
14	General electrical industrial apparatus	0.6	3.4	3.0	3.5	2.2	2.9	1.9	2.1	2.1	1.9
15	Non-electrical specialized industrial equipment	1.2	0.4	0.6	0.7	0.6	0.2	0.3	0.2	0.3	0.3
16	Metallurgical and metal working equipment	0.0	0.5	0.0	0.3	0.3	0.4	0.4	0.3	0.4	0.4
17	Assembling and material handling apparatus	1.0	0.0	1.0	2.4	1.7	1.4	1.2	1.1	1.1	1.1
18	Induced nuclear reactions: systems and elements	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0
19	Power plants	0.0	0.0	6.4	1.6	0.0	0.0	1.1	0.0	0.7	0.4
20	Road vehicles and engines	1.1	0.0	1.3	1.1	1.1	1.3	0.4	0.8	0.2	0.6
21	Other transport equipment (excluding aircraft)	5.4	1.0	1.5	1.8	0.9	0.4	1.1	0.2	0.3	0.4
22	Aircraft	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	Mining and wells machinery and processes	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.1
24	Telecommunications	2.0	0.0	1.3	1.6	1.0	1.1	1.4	1.0	0.9	0.9
25	Semiconductors	0.0	0.0	0.8	0.0	0.8	4.1	4.2	3.5	4.3	4.5
26	Electrical devices and systems	0.0	1.4	2.0	1.7	1.4	1.8	2.7	2.2	1.1	1.4
27	Calculators, computers, and other office equipment	0.0	0.0	0.0	0.4	1.0	2.2	2.2	2.0	1.4	1.7
28	Image and sound equipment	0.7	0.5	2.4	2.4	3.8	2.6	4.0	4.9	5.0	5.2
29	Photography and photocopy	0.0	0.0	0.0	0.0	0.0	0.8	0.3	0.7	0.6	0.7
30	Instruments and controls	0.6	1.1	0.4	0.7	0.6	0.8	0.8	0.6	0.8	0.6
31	Miscellaneous metal products	3.4	3.1	1.1	0.6	1.8	1.0	0.8	0.8	0.7	0.4
32	Textile, clothing, leather and wood products	7.3	1.8	5.3	2.7	3.9	0.4	0.4	0.3	0.7	0.3
33	Dentistry and surgery	0.0	0.0	0.4	0.3	0.2	0.1	0.2	0.4	0.2	0.1
34	Others (Ammunitions and weapons, etc.)	1.0	3.1	1.5	1.7	0.9	0.3	0.4	0.4	0.4	0.3

Source: Based on data supplied to SPRU by the US Patent and Trademark Office and in sound and image equipment. But although this evidence lends support to Korea being an important producer of semiconductors, and the second largest producer of consumer electronics, other sectors are beginning to assume growing importance. These include bleaching technology (6), general electrical industrial apparatus (14), assembling and material handling apparatus (17), electrical devices and systems (26), and calculators, computers and other office equipment (27). RTA also suggests that Korea has a weakness in chemical and mechanical sectors. In the next section we make a more detailed analysis of Korean patents following the methodology referred to previously.

III. THE DIRECTION OF CAPABILITY BUILDING IN THE KOREAN SEMICONDUCTOR INDUSTRY

The success of the semiconductor industry in Korea has been well recognized. In 1993 it accounted for 31.6 % of total electronics exports and 9.7 % of the country's total exports [22]. Moreover, domestic businesses have gained in international strength as a result of their success in the DRAM market. In 1994, for example, Samsung Electronics ranked seventh in the semiconductor suppliers' market, Goldstar was in 20th position and Hyundai Electronics 21st. Korea has not only become the second largest DRAM exporter but its three major semiconductor companies now account for 21.3 % of total production in the world DRAM market. This section concentrates how the rapid catch-up process of technological capability accumulation occurred inside the *chaebol* firms.

1. Main Features of the Capability Building Process

Our analysis of semiconductor patent abstracts shows that major patenting activities in the USA are dominated by the *chaebol* and the Electronics and Telecommunications Research Institute (ETRI) (see Table 3). In addition, although Samsung Electronics continues to be the overall leader, both Hyundai and Lucky-Goldstar (LG) have shown an increase in their patenting activities in recent years.[2] A clear indication from this is that technology development is driven by the corporation, but the role of public institutions cannot be ignored.

There are three ways of interpreting the data. The first significant aspect of patenting activities is the way in which the *chaebol* began to reveal their technological activities, which derived from the accumulation

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[2] We have consolidated subsidiaries whose names are different from their parent companies on the basis of "Top 3000 largest firms in Korea (1994)." This includes Gold Star Electron Co. Ltd, Samsung Display Devices Co. Ltd, Samsung Electro Mechanics Co. Ltd, Samsung Electron Device Co. Ltd., and Samsung Semiconductor & Telecommunications Co. Ltd.

Table 3. Share of technological activities in semiconductor related patents.

(Unit: %)

Company and Institute	1991	1992	1993	1994	1995
Samsung Electronics	74	88	61	54	40
Hyundai Electronics Industries	16	6	13	16	24
Lucky-Goldstar (LG)	5	2	18	21	23
ETRI	2	2	3	6	10
Others	3	2	5	3	3
Total	100	100	100	100	100

Source: Based on data supplied to SPRU by the US Patent and Trademark Office

of technology. Secondly, in the late 1980s the international environment changed substantially, intellectual property protection issues surfaced as an important issue, and patent infringement began to increase in industrialized countries. An example of this was Samsung and Texas Instruments (TI) case. In 1988 Samsung was sued by TI for violation of patents and had to pay over US$90 million. As a result the *chaebol* initiated a strategy of more emphasis on patent management, including an increase in their patent applications to US Patent and Trademark Office, an increase in their purchasing of intellectual property from overseas, and an increase in cross licensing strategy to avoid patent infringement. Finally, the role of public institutions continued to be significant for national technological development. As noted later, in the development process of 4M, 16M, 64M and DRAM, ETRI acted not only as a coordinator but as a participant in several national R&D programme in the development of semiconductor technology.

2. The Direction of Technology Capability Using Patent Abstract Analysis

Based on the following patent analysis we can trace the paths of technology capability enhancement in the Korean semiconductor industry. The product development time also reflects the technology accumulation process. Korean semiconductor firms narrowed their development time gap with foreign competitors, and finally took a leading position in the world DRAM market from the development of 16M DRAM onwards, as shown in Table 4.

Throughout the technology development process, Korean firms accumulated technological capabilities step by step. At the stage of early product development, Korean companies concentrated on the learning and assimilation of imported technology and then on taking the imported design through to manufacturability. Subsequent to this learning process, they built their own in-house based development capability. Samsung, for example, completed

Table 4. Development and mass production time of DRAM products.

DRAM products	World first develop	World first MP*	Korea develop	Korea MP	Time gap (years) develop	Time gap (years) MP
64K DRAM	1977	1980	1983	1984	6	4
256K DRAM	1980	1982	1984	1985	4	3
1M DRAM	1983	1985	1986	1987	3	2
4M DRAM	1986	1989	1988	1990	2	1
16M DRAM	1987	1992	1990	1992	3	0
64M DRAM	1992	1995	1992	1995	0	0
256M DRAM	1994		1994			

∗ MP: mass production

Source: various issues of Electronics News (in Korean)

the whole product development process of a 1M DRAM project without significant technology imports. The company also displayed an expanding process design capability as they selected different process technologies from their Japanese competitors in 4M DRAM. Enhanced capabilities were also being mirrored in design capability. The adoption of a new design specification was seen in the 16M DRAM process, whilst Samsung made its own design specification for 64M DRAM. In addition, both Hyundai and LG also pursued purposive strategies in gaining process technology from foreign competitors in their 16M DRAM development project [23].

The basic features of capability building are also reflected in the patent content analysis. As for the taxonomy of the technology of semiconductors, this can broadly be categorized into material, equipment and wafer fabrication, circuit design, assembly and product testing. In the case of Korean semiconductor companies, they built up their business in the early 1960s based on assembly, whilst in the 1980s they embarked on a more memory oriented strategy, with heavy investment in wafer fabrication. As a result, the core technology capabilities were centerd around fabrication. Other technologies such as material, circuit design and equipment were regarded as the weakest area in the Korean semiconductor industry. In 1992, Korea's circuit design technologies had reached only 40 %, material 10 %, and equipment 3 % of the level achieved in advanced countries (measured and compared by peer review [24]). However, Fig. 2 delineates the recent changes in technological capabilities. Our sample suggests that fabrication technology related patents are regarded as the most important, partly because *chaebol* main business is focused on

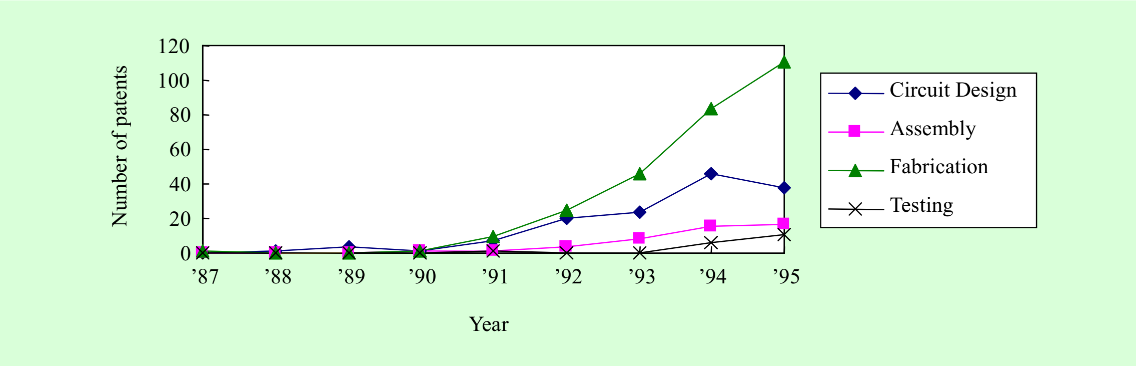

Fig. 39. Patenting trend of semiconductor technology.

DRAM products in manufacturing technology. Moreover other related semiconductor technologies, such as circuit design technology, show increasing trends in technological accumulation in recent years.

From a historical perspective, it is noteworthy to see how Korean *chaebol* firms have demonstrated product diversification within DRAM products as their technological capability has accumulated. Samsung progressed from production of standardized products towards various improved versions of DRAMs, such as the multi-bit 4M/16M DRAM, low power consumption 4M DRAM, Cache RAM, Synchronous DRAM, Window RAM and Flash memory. Hyundai has also shown diversification into multi-bit DRAM, VRAM, whilst LG has entered into the development of Rambus DRAM, Flash memory and so on. In addition to this diversification within the DRAM product range, the three firms recently began diversification into non-memory products like microprocessors, microcontrollers and ASICs. This indicates that diversification strategies were based upon manufacturing capabilities. Most of the diversification efforts were arranged with technology alliance partners who wanted to access superior manufacturing capabilities.

IV. CO-EVOLUTION OF TECHNOLOGICAL CAPABILITY, SUPPORTING INSTITUTION AND BUSINESS STRATEGIES

1. The Changing Patterns of Sources of Innovation at the Firm Level

During the development process, Korean *chaebol* semiconductor firms relied on various and changing sources of technology acquisition. These technology acquisition mechanisms and channels have evolved through time and become more complex as latecomer firms sought to acquire more

Table 5. Trend in the number of licensing agreements by Korean semiconductor industry.

Year	~1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Number	13	4	9	9	15	16	24	17	39	31	16	15

Source : KITA in various years

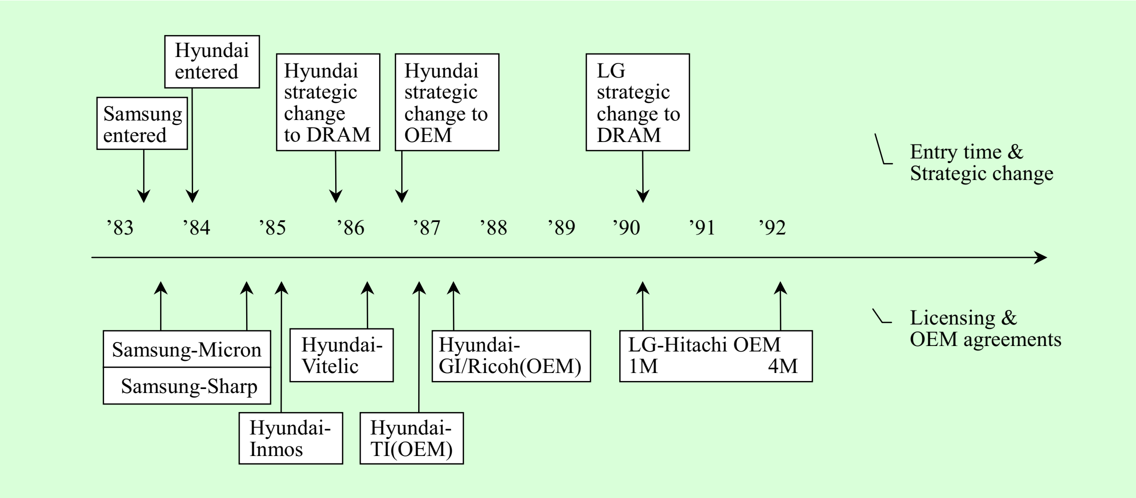

Fig. 40. Entry of Korean *chaebol* and major licensing and OEM partners in the early stage of semiconductor business.

demanding technologies to enable them to compete closer to the technology frontier [25].

Most of the *chaebol* semiconductor firms relied on licensing and OEM in the early stage of technology developmen. Table 5 shows the growing trend in the number of licensing agreements from the mid-1980s onwards, when *chaebol* firms entered into DRAM production [26].

From Fig. 3 it can be seen that the technology acquisition mechanisms in the early stages for each of the *chaebol* firms were licensing agreements and original equipment manufacturer (OEM) arrangements.[3]

Samsung licensed 64K and 256K technology from Micron Technology (USA) for chip design and mask technology, whilst process technology was licensed from Sharp (Japan). Technical training and assistance were included in the licensing agreements,

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[3] As Hobday points out, Korean firms have used various channels for acquiring foreign technology such as joint ventures, licensing, OEM, informal means and joint technology development.

Table 6. Technology agreements and acquisitions by three Korean semiconductor firms after 1990s.

Type of agreement	Partners	Technological area
One-way licensing	Samsung-DSP Group	OakDSPCore, DSP technology for speech/audio processing, telecommunications, etc.
	Samsung-Oki	16M synchronous DRAM
	Samsung-MTI	16M SRAM
	Hyundai- Mosaid	4M multi-bit, 16M DRAM
	Hyundai-Compass	ASIC tool
	LG-Mosaid	16M DRAM
	LG-Rambus	Rambus DRAM
	LG-Compass	ASIC tool
	LG-Sun Disk	Flash memory
	LG-TI	Test technology
	LG-Illinois Uni	Codec
Cross-Licensing	Samsung-Fujitsu	Semiconductor technology
	Samsung-Philips	Semiconductor technology
	Samsung-IBM	Semiconductor technology
	LG-MTI	Semiconductor technology
Joint technology development	Samsung-NEC	256M cell technology
	Samsung-Toshiba	16M Flash memory, ICs for LCD
	Samsung-Mitsubishi	Cache DRAM
	Samsung-A.N.L.	Fuzzy chip
	Samsung-GI	ICs for HDTV
	Samsung-ASPEC	GaAs
	Samsung-SGS-Thomson	Micro cores for telecommunication
Joint investment	Samsung-Towa	Equipment
	Samsung-TI	Production in Portugal
	Samsung-Array	Development of digital signal processor (DSP)
Acquisition	Samsung-HMS	GaAs
	Hyundai-Bright Microelec.	Flash memory
	Hyundai-AT&T-GIS	ASIC technology

Source: various sources including Predicast(1995), Joo(1995)

which proved to be of great value in the step by step learning process with foreign engineers from the licensing partners.

In contrast to Samsung, Hyundai and LG entered the DRAM market more recently, in 1985 and 1989 respectively. In entering the DRAM market, OEM arrangements were regarded to be important sources of technology acquisition. Hyundai made OEM arrangements with TI, GI and Ricoh, while LG made arrangements with Hitachi. In both cases, they had the advantage of technological advice from their OEM partners. As Hobday [11] points out, coupling of technology and market mechanisms enabled latecomers to use market signals as a focusing device for technological learning and investment. Whilst *chae-*

Table 7. Semiconductor R&D centers of Samsung.

Item	Kiheung	Bucheon	U.S. (SSI)
Pilot line & main activities	memory line MEGA line ultra line	micro line chips for consumer electronics industrial electronics	advanced micro product
Main products	memory products	ICs for TV/VTR/Audio/Telecom/Micom, etc. Custom IC Logic device DSP	8 bit MCU PC chipset 32 bit RISC ASIC

Source: Samsung Electronics Co.

bol firms depended on foreign sources in the first stage, there were significant changes in the form and content of technology sources. Recently, for example, as their own capabilities expanded, Samsung made several cross-licensing agreements and arrangements for R&D cooperation across a broad range of semiconductor products, primarily based on DRAM manufacturing capability, as shown in Table 6 [27]. Beyond the one-way licensing, cross-licensing and joint technological development take the major position in the inter-firm agreements. This indicates that as a result of core technological capabilities formulated inside the company, technological sources diversified and became more co-operative and horizontal rather than hierarchical.

In addition, along with co-operative technology agreements, in-house R&D capabilities have become a major sources of innovation. The three dominant *chaebol* semiconductor firms have all equipped formal R&D centers. Moreover, the role and function of the R&D organization has diversified into a number of units to satisfy the increasing demand for in-house R&D capabilities. Samsung, for example, has three major R&D centers relating to semiconductor technology: the Kiheung center which specializes in memory product, the Bucheon center for non-memory products, and the Samsung Semiconductor Inc. (SSI) center in the United States specializing in advanced micro products. These are shown in Table 7.

In summary, it is clear that the Korean *chaebol* semiconductor firms have enhanced their technological capabilities through product development processes. The major sour-ces of innovation have changed in accordance with technological capability enhancement, in particular moving towards in-house R&D capability. In addition, the hierarchical relationship with foreign sources of innovation has developed into co-operative relationship, with *chaebol* working as equal rather than junior partners in technology.

2. The Role of Public Institutions in Capability Accumulation

Some argue that public institutions are an important leverage resource in the technological growth of developing countries [4]. Most public research institutes in developing countries were set up in the early stages of economic development and mainly funded by government in centralized laboratories with the aim of supporting economic development by promoting science and technology.

As the economies in these countries have developed, however, public research institutes have attempted to meet the new challenges, particularly in Korea, where the *chaebol* have became the main generators of technological competence. While it is outside the scope of the paper to conduct a full assessment of the role of public institutions in Korean semiconductor development, it is important to point out at least some of the major activities and strategies of the lead institution ETRI in support of Korean technology development. In the semiconductor industry development process, ETRI has supported private firms in each phase of development. In the very first stage of industrial development, Korea Institute of Electronics Technology (KIET), which was merged with Korea Electrical Technology and Telecommunications Research Institute (KETRI) into the present ETRI, built up a substantial facility for, and considerable competence in, semiconductor technology. KIET conducted researches on semiconductor technology, including design and process technology, for the purpose of supporting direct industrial production. This was in line with its aim as a technology generator for the industrial development in electronics.

Along with the restructuring of KIET for reasons of its integration with KETRI, its semiconductor production facility was sold to LG (Lucky-Goldstar), one of the Korean *chaebol*, which sought to develop its own in-house production capability. This was viewed as a successful example of 'spinning in,' by which a group from a public research institute merged with existing private enterprise [28]. The background to this decision related to the restructuring of ETRI's role and function in a national economy. ETRI had positioned itself as a new technology generator rather than a supporter of industrial production and testing [29], in particular as the industry enhanced its own in-house technological capability.

The current strategy of ETRI in the semiconductor industry's development is twofold: as a supporter of new technology development and as a co-ordinator of industrial technology development. The former includes the responsibility to conduct pioneering research in newly emerging technology areas such as GaAs semiconductor and customized ICs for telecommunications equipment. Its other task is to co-ordinate national R&D projects which cover VLSI technology, including 4M, 16M, 64M DRAM, and involving the participation of businesses, academics and public institutes. The main participants are the three major Korean *chaebol* semiconductor firms, Samsung, Hyundai and LG. In the national context, ETRI has provided a vehicle for semiconductor companies to collaborate in key areas, access government funds for R&D and R&D management expertise. For example, in the 4M DRAM project, design and process technology, directly related to product development, was selected as a main collaborative research domain. By contrast, in the 16/64M DRAM project, goals were expanded to include enabling technology areas such as equipment and materials.

3. The Co-evolution Process of Capability Building

As we have demonstrated, the Korean semiconductor industry at least in DRAMs has successfully caught up with and even forged ahead of advanced countries in a short period. Our patent analysis and other qualitative data show strong evidence of technological capability enhancement during its industrial development process. More specifically, the Korean semiconductor industry achieved qualitative catch-up as its technological capabilities expanded from fabrication technology to design technology.

An important underpinning of this successful catch-up process rests in the virtuous interplay between public institutes, business strategy and technological capability. The strategy of ETRI, in particular, has changed from being a direct generator of industrial technology to a co-ordinator of industrial technology development and high level research in selected areas. In addition, as their own technological capabilities were enhanced, firms transformed their technology acquisition strategy into one based on in-house capability and with more equal and co-operative forms of technology agreement.

This virtuous co-evolution cycle was reinforced to generate comparative advantage in the Korean semiconductor industry. There is strong evidence that the accumulation of technological capability involves a complex interaction within the national innovation system. From this perspective, planning for technological development in other nations must be considered in the context of institutional arrangements which create and coordinate national resources for technological capability accumulation.

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research by J.-Y. Choung [30] for part of his doctoral thesis, and the strategy of the semiconductor industry at the firm level draws on research by H.-R. Hwang [31] for part of her doctoral thesis.

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