An International Comparison of Technological Systems : The Case of CNC Machine Tools in Korea, Sweden, and U.S.A.

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Summary

Focusing on a product, this paper reconstructs the concept of technological systems first introduced by Carlsson and Stankiewicz (1991).

Based on the model and our earlier works, we compare the salient features of technological systems for computer numerically controlled (CNC) machine tools in Korea, Sweden, and the United States. We also try to measure the performance of the systems in an international comparison. Major findings are as follows: (1) The length of 'learning period' for local (national) technological system is substantial, even though it is a catching-up case. (2) The key success factor of the technological system appears to be the connectivity among various actors or infrastructures, rather than just the existence or formation of those. (3) In three countries' experience, the government played an important role in the formation of each own technological system. (4) The performance of Korea's technological system for CNC machine tools during the past two decades (1981-97) seems to be better than that of Sweden and the U.S. Lastly, many policy implications are presented.

Key words : technological systems, evolution, CNC machine tools, international comparison

1. Introduction

The innovation and diffusion of a new technology is the result of a collective effort in addition to an individual one, and is undertaken in the context of a system or network (OECD, 1992;

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Saxenian, 1994). Therefore, it may be even more relevant to speak about the technology base of such a system, rather than the firm-specific technology base. Along this line of thought, various systems approaches to the study of technological change have been suggested in the economics literature: national innovation systems (Freeman, 1988; Lundvall, 1988, 1992; Nelson, 1988, 1993; and subsequently many others), Michael Porter's 'diamond' (Porter, 1990), technological systems (Carlsson and Stankiewicz, 1991), sectoral innovation systems (Breschi and Malerba, 1995; Malerba, 2002), and regional innovation systems (Saxenian, 1994).

The purpose of the present paper is to compare the developments of the CNC machine tool industries in Korea, Sweden, and the United States using the technological systems approach, which was first introduced by Carlsson and Stankiewicz (1991). The approach may be useful in that it not only focuses on a technology/product or technologies/products rather than industrial clusters, nations, or regions but also emphasizes the fact that systems evolve over time, i.e., the number and composition of actors, institutions, relationships among them, etc., vary over time.[1]

The paper is organized as follows. In section 2, we reconstruct the concept of technological system, focusing on a *product* (CNC machine tools) as the unit of analysis. Section 3 compares the salient features of technological systems for CNC machine tools in Korea, Sweden, and the United States in terms of system evolution, components, and their linkages. Section 4 measures the performance of the systems in an international comparison. Finally, in section 5 the findings are summarized and policy implications drawn.

2. The Concept of Technological Systems

2.1 The Technological System Components

Technological systems have been defined as 'network(s) of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilize technology'. They consist of dynamic knowledge and competence networks (Carlsson and Stankiewicz, 1991). As seen in Figure 1, the main building blocks of a technological system are (1) industrial organization (IO), (2) technological infrastructure (TI) as a hard core of the system, and (3) institutional infrastructure (II).

1) See Edquist (1997) and Carlsson *et al.* (2002) for the distinctions between technological systems and other concepts.

2.1.1 Industrial Organization

Industrial organization is the network in which actors interact in order to produce or buy a product. Since we take a product focus,[2] the actors and institutions are all within a given

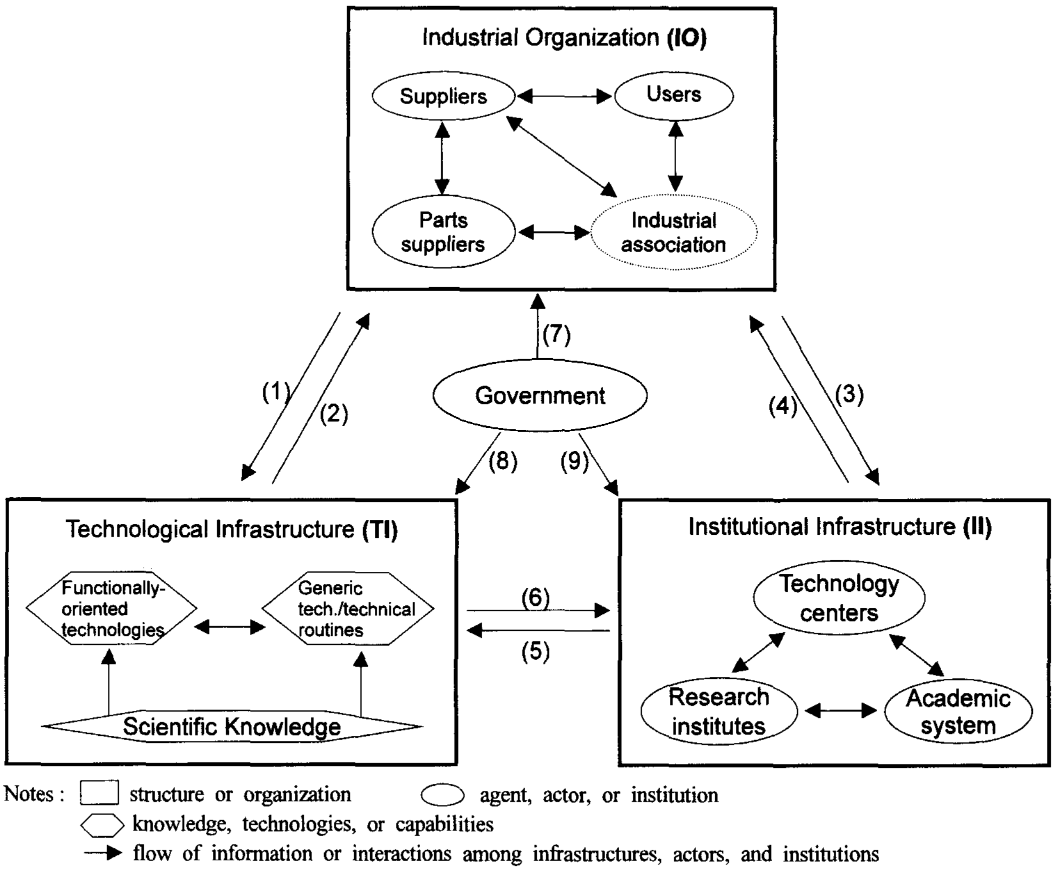

Fig. 1 : The Technological System Focused on *a Product*

2) The main focus in the analytical framework of technological systems is certainly on a technology or technologies. However, in applying the framework, several methodological alternatives are available. Concerning the level to which the analysis is applied, we have found that the system approach may fruitfully be applied to at least three levels : to *a technology* in the sense of a knowledge field, to *a product* or *an artifact*, or finally to *a set of related products and artifacts* aimed at satisfying a particular function, such as health care or transport. The first unit of analysis was pursued in Granberg (1997), Rickne (2002), Laestadius (2002), and Fridh (2002). The second and third approach was used by Carlsson (1995) and Eliasson (1997), respectively. In this paper we take a *product*, CNC machine tools, as the initial seed from which the system is defined. This is why we named it the technological system for CNC machine tools.

While the unit of analysis in standard industrial economics is the 'sector' ideally composed industry. of firms with products addressing the same homogeneous and well-defined market, that of industrial network in the technological system is broader and more complex. It includes market and non-market interaction in the following three dimensions of network: input-output relationships, geographic space, and cooperation. Input-output relationships include user-supplier interaction linking innovating firms to users of innovation (Lundvall, 1985 and 1988), vertically integrated sectors (Pasinetti, 1981), or links to supporting industries (Porter, 1990). Geographic space refers to the industrial districts located in a region. Industrial districts may be linked either to the national or to the global context. Lastly, cooperation is more important than competition, although both are needed. The need for cooperation stems from the particular features of scientific and technical knowledge and the strong ongoing trend towards the fusion of disciplines and previously separate technical fields (OECD, 1992).[3]

Industrial networks are often informal rather than formal. The firms in the industrial organization share technical knowledge through informal, mostly personal, networks established through professional conferences, meetings, publications, etc.

2.1.2 Technological Infrastructure as a Hard Core

Given a product, the industrial organization supports and is supported by technological infrastructure (relation 1 and 2 in Figure 1). Technological infrastructure is a set of science, engineering, and technical knowledge. The knowledge set is potentially available for two or more private firms or user institutions. It goes beyond the sum of the firm-based knowledge since it involves knowledge embodied in various types of institutional arrangements that include both firms and other agents in the system.

As suggested by Granberg (1995), technological infrastructure consists of generic technologies, functionally-oriented technologies, and technical routines. Generic technologies are the product and process technologies available to all firms. Functionally-oriented technology is a set of technologies (e.g., measurement) that can be used to perform particular functions. The concept is similar to infratechnologies (Tassey, 1991) or functionally-related technologies (Porter, 1990).

3) The other side of coin is that inter-firm cooperation lead to oligopolistic supply structures, resulting in restrictions on the access to technology by firms which are not parties to such cooperation (Porter, 1990). However, we assume that cooperation can result in positive effect, for instance, network effect, rather than such negative effects.

2.1.3 Institutional Infrastructure

By the institutional infrastructure of a technological system we mean a set of institutional arrangements (both regimes and organizations) which support and regulate the process of innovation and diffusion of a technology or product. There may be two types of infrastructure: technology/product-specific and general. The technology/product-specific institutional infrastructure includes educational institutions (including universities and teaching facilities), public or private research institutions, and technology centers. The educational system, particularly the universities of technology, plays a dual role in that the output of the system is both training of people and research results. The linkage between academia and industry (relation 3 and 4) channels university expertise into industrial practice. Institutional infrastructure influences and is influenced by technological infrastructure (relation 5 and 6).[4] For example, functionally-oriented technologies such as measurement and test methods are developed by government laboratories, universities, industry consortia, etc. In turn, actors within the institutional infrastructure utilize technological infrastructure.

The general institutional infrastructure - not presented in the model - includes the financial system and patent legislation that lowers the uncertainty and risk inherent in the innovative processes. The political system or value system influences the generation and diffusion of technology indirectly.

Government is not a direct component of institutional infrastructure. Government is a main actor (policy-maker) who can influence industrial organization (relation 7), technological infrastructure (relation 8), and institutional infrastructure (relation 9) individually as well as improve the connectivity among them, thereby enhancing the dynamic efficiency of the technological system. In many cases, networks are formed as a result of spontaneous actions on the part of independent actors. But under certain circumstances, e.g. in period of rapid technical change, the government may have an important role to play in the formation of technological systems. Therefore, government can be another bloc of a technological system.

2.2 Technological System Dynamics

A technological system is not static[5] and evolves with alterations in the contents of its components as well as in the relationships among actors and institutions. A technological system is involved

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4) Other traditional infrastructures such as human capital infrastructure an physical capital infrastructure also embody technological infrastructure. However, the latter is more specific and less tangible than the former. See Justman and Teubal (1996) for the difference.

5) The concept of technological systems is similar to Erik Dahmen's 'development blocs' (Dahmen, 1989) in that it is dynamic. See Carlsson (1995) and Carlsson, et al. (2002) for more detail.

with the generation, innovation, and diffusion (or utilization) of technology. It may be useful to divide it into three phases: embryo, infant, and adolescent. We define the embryo stage as the stage before the first commercial application of new technology (generation of technology). This is followed by an infant stage that consists of the first commercial applications (development and innovation) while the adolescent stage is where the new technology finds a multitude of applications (diffusion).

Along this time axis, the change in the system is characterized by the kinds of actors or institutions involved and the function/range/intensity of activities performed by them. At first, there must be not only the generation of a new technology (or a new kind of product) but also a fertile environment, as well as something or someone to get the process started;[6] initiatives must be taken to foster experiments with the new technology; these must give rise to entrepreneurial activity by either new or existing entities; capital must be supplied; at the same time, the different types of economic and technological competence also need to be built and diffused within industrial organization, including suppliers and users; as many different types of actors and institutions are involved, bridging functions must be developed by the bridging institutions.[7] In the more mature stage, the most important features of the systems are connectivity (the degree to which various components in the system are tied together), the mechanisms which create variety within the system, the competence of each actor, and the characteristics of knowledge mechanisms which determine the potential spillovers.

At some point, the emerging system is complete enough (in terms of technological infrastructure, industrial organization, and institutional infrastructure) to generate sufficient increasing returns to develop in a self-reinforcing way. For instance, competent venture capital can only develop after some time since it is composed of actors (with access to funding) with strong capabilities in the particular industry/technologies concerned. These actors need to go through a learning period prior to forming the particular part of the capital market which is labeled competent capital.

6) An entrepreneur, government, or critical mass (a certain density of relationships among various agents) can play such a role. The basic idea of critical mass is that there is a certain minimum number and intensity of interactions required for sustained economic activity to place.

7) Bridging institutions refer to arrangements and/or organizations that establish and maintain interaction among various actors in the system such as firms, academic or research institutions, and government agencies. The role of bridging institutions is not only to disseminate technological knowledge but also to provide a compensating mechanism for weakness and lack of domestic capabilities within other parts of a technological system. In addition, the institutions help to accumulate and integrate technological knowledge as result of innovative activities, which otherwise tend to be highly firm-specific, and make them useful and available to other firms as well.

2.3 The Technological System for CNC Machine Tools

Based on the above discussion, we formalize the technological system for CNC machine tools as in Figure 2. The industry consists of three types of actors: specialized builders, user firms, and parts suppliers. The user firms are tool / equipment manufacturers such as automobile, general machine, precision machinery, electronics as well as other engineering. The part suppliers are the firms that produce CNC equipment, servomotors, ball bearings, etc., required in assembling a CNC machine tool. The technological innovation is generated by these three types of actors individually as well as the interaction among them. Among various linkages among actors, the user-to-builder links have played important role (Rosenberg, 1976; Lee, 1996). Furthermore, the user firms have motivated their direct involvement in the development of machine tools,

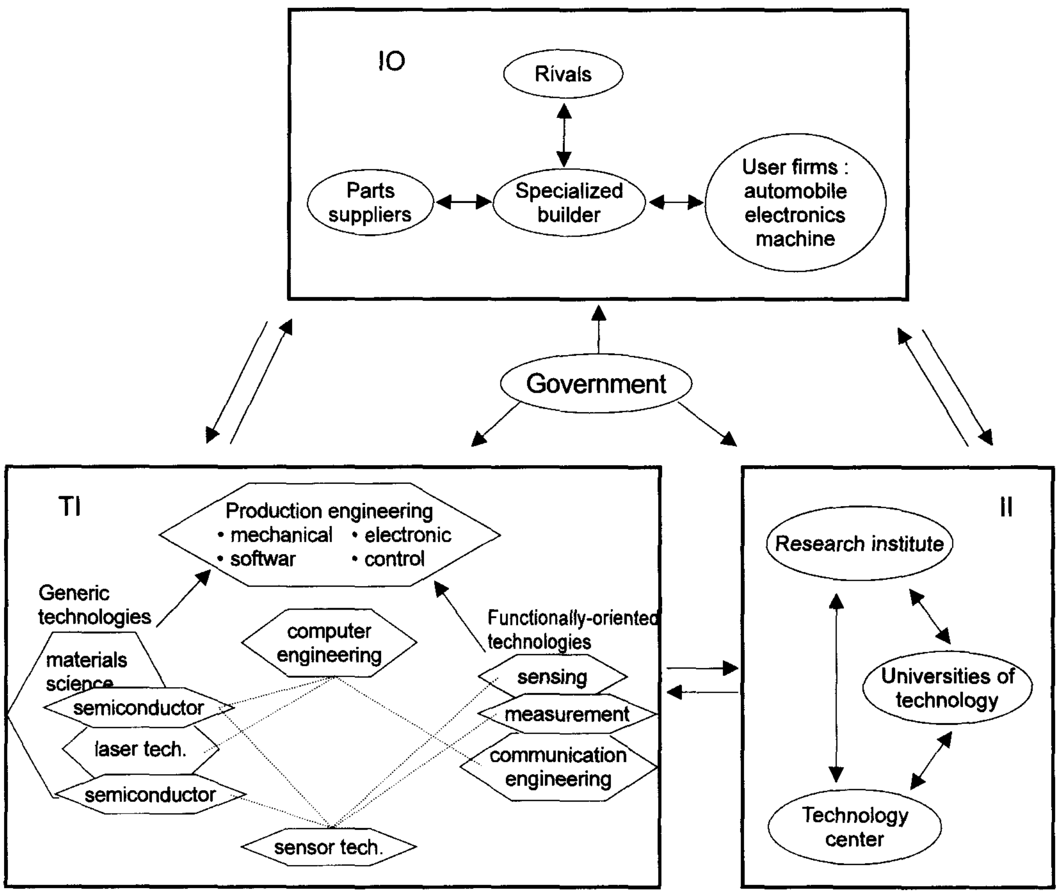

Fig. 2 : The Technological System for CNC Machine Tools

often entailing an entrepreneurial entry.[8] This is due to the high degree of customization, which means user firms' own specific and strong needs for function, quality, and parts availability for machine tools. Thus we can predict that the closer the user - builder relationship is, and the more competent the user firm is, the more innovation is generated. The 'proximity' between user and builder can be obtained only if users and builders are in the same geographical region, if they have similar manufacturing philosophies, and if there are no technological, cultural, and legal boundaries separating them (Carlsson and Taymaz, 1993; Carlsson and Jacobsson, 1994).

A CNC machine tool has three main units; the control unit, the actuating system, and the machine tool proper. The first reads numerical information about the metal part to be machined and stored in a tape, and translates it into commands that activate the servomechanisms of the actuating system. These are connected by mechanical means to the moving parts of the machine tool, usually the tool spindle and the worktable.[9] Therefore, CNC technology depends on production engineering such as mechanical engineering, electronic and electric engineering, computer software engineering, and control engineering.

A successful CNC machine tool depends on a number of generic technologies, which are components of technological infrastructure. These include semiconductor technology, laser technology, fiber optics, heat treatment technology, etc. These fields are all 'generic' in the sense of not being a priori confined to any particular application or functional area. These generic technologies depend on the level of material science, which in turn is based on physics and chemistry.

In order for CNC machine tools to perform the basic tasks and to be integrated into the broader FA system, a number of functionally-oriented technologies are needed. These include sensor technology, measurement/test method, and communication engineering. These three fields of technology are all 'functional' in that they are a large and highly diversified assemblage which is held together by a shared concern with the general function of 'sensing', 'communicating', and 'measuring', respectively. Since CNC technologies have been increasingly emphasizing flexibility in terms of product variation and system-oriented control, sophisticated measurement and control algorithms are needed greatly. Specifically, one element of CNC machine tools where these functionally-oriented technologies play an essential role is the controller.

8) This case includes Volvo, British Aerospace, Toyota Motor, Toshiba, Hitachi, etc. (Carlsson and Jacobsson, 1994; Lee, 1996)

9) There are two types of CNC technology; the closed-loop design which has the feed back system and open-loop design which does not have that system.

3. International Comparison of Technological Systems for CNC Machine Tools[10)]

3.1 Overview of Technological Systems Evolution

The evolution of a technological system may be global in character, but we deal with a local case. The evolution of the technological system for CNC machine tools in Korea, Sweden, and the United States refers to that of a local (national) part of the global technological system. Since the first NC machine tool (milling machine) was invented in the United States, the cases of Korea and Sweden deal with how a new technology is introduced in a follower country and how a system built up around it. According to our earlier definition, Table 1 presents each system's development stages.

Table 1 : The Development of Technological Systems for CNC Machine Tools in the U.S., Sweden, and Korea

	Embryo stage	Infant stage	Adolescent stage
U.S.	~ 1952	1953 ~ mid-1970s	mid-1970s ~
Sweden	~ 1957	1958 ~ early-1980s	early-1980s ~
Korea	~ 1977	1978 ~ late-1980s	late-1980s ~

3.1.1 The United States

The development of NC tapped the resources of a sophisticated research university with the help of R&D funds and procurement contracts by the U.S. Air Force. The first NC machine tool in the world was invented by the MIT Servomechanism Laboratory in 1952.[11)] Since then, the infant stage started both globally and locally. At the end of 1950s several machine tool firms entered the development of NC control systems, including a handful of manufacturers with diversified product lines and builders of specialized equipment.[12)]

A wider diffusion of NC technology occurred after the mid-1970s when performance improvements and cost savings achieved thanks to the use of microprocessor-based controls. In table

10) Otherwise noted, this section is based on our earlier works, Carlsson (1989), Carlsson (1995), and Sung and Carlsson (2003).

11) See Carlsson (1984) for an account of historical circumstances of the emergence of CNC technology in the U.S.

12) At the 1960 Chicago Machine Tool Show, 40 firms displayed NC equipment (American Machinist, 1960). A 1964 buyer's guide includes 196 NC machine tools and 75 control system lines from 49 manufactures (American Machinist, 1964).

2, the share of (C)NC machine tools in total machine tool production in the U.S. surpassed 20% in 1975. Until latter half of the 1970s, the U.S. was unquestionably the leading producer of CNC machine tool output in the world market. The (C)NC shares of the value of machine tool output were significantly lower elsewhere. But as Japan and Germany surged ahead in the 1980s,[13] the U.S. was unable to respond. With severe structural change (between 1977 and 1982, at least 64 mergers and acquisitions), it has been estimated that between 1981 and 1986, the number of firms in the U.S. machine tool industry was reduced from 700-750 to about 400.

3.1.2 Sweden

As noted earlier, Sweden was a follower country in (C)NC technology. This means that we need to be aware of 'initial conditions' prevailing in the country in the sense of technological specialization and institutional set-up. The 'initial conditions' prevailing in Sweden can broadly be characterized by:

- a traditional strength in mechanical engineering;
- a fairly strong position in parts of electro-mechanical field;
- very close user-supplier relations in precisely the areas of strength in electro-mechanical field

Table 2 : Share of (C)NC Machine Tools in Total Machine Tool Production in the U.S., Korea, Sweden, and Japan, Selected Years, 1964-1990

(Unit : %)

Year	USA	Korea	Sweden	Japan
1964	8.7	-	-	-
1970	13.5	-	-	6.1
1975	21.0	-	-	12.7
1977	20.2	0.0	-	18.7
1980	28.5	4.8	28.6	39.1
1985	30.2	21.7	-	55.4
1988	35.5	26.7	-	59.4
1990	40.7	35.2	-	65.4

Sources : Carlsson (1984) and Mazzoleni (1999).

13) The Japanese were the first to capitalize on the new CNC technology. In the mid-1970s they began to phase out conventional machine tools and moved instead into CNC machine tools. Already in 1977, the number of CNC machine tools produced in Japan surpassed that in the U.S.

Two Swedish firms have a significant presence in the technological system for machine tools: SMT Machine Company in CNC lathes and SAJO in machining centers. The SMT Machine Company has a history in design and production of CNC machine tools. Already in 1957, it had produced a CNC milling machine. Since then, the infant stage started. By 1965 a rudimentary capability had been achieved in the production of numerical control units. The firm entered very early into the production of its own CNC units with the help of a computer manufacturer that saw the machine tool market as a good potential one. In a reconstruction after a crisis in 1970, the firm decided to specialize in producing CNC lathes based on microcomputer technology - being one of the first to do so. This risk taking paid off, and throughout the 1970s the firm was profitable, largely on account of the early technological lead that it had created. In the early 1980s, it produced 250 CNC lathes annually.[14)]

The second Swedish firm, SAJO, entered the machining center industry in 1977, leaving its traditional focus on CNC milling machines. As in the case of SMT Machine Company, since the mid-1980s, SAJO has done product development work related to specific customer demands.

3.1.3 Korea

In Korea, Hwacheon Machinery Works Co. first developed a CNC lathe commercially in 1977. Korea was behind the U.S. by 25 years and Sweden by 20 years. As a case of technological catching-up, this resulted from obtaining absorptive capacity through acquisition of foreign technology. The use of CNC machine tools by domestic firms increased sharply in the second half of the 1980s. As seen in Table 3, while the domestic demand for CNC lathes was only 64 units in 1981, it rose about 1,500 units in 1987. Therefore, 1977 and late-1980s constitute the historical turning points of the development of the Korean technological system for CNC machine tools, respectively. Thus, the evolution of the Korean system may be divided into three phases: embryo stage (before 1977), infant stage (1978~late-1980s), and adolescent stage (after late-1980s).

The 'initial conditions' at the embryo stage can be characterized by:

- Existence of 'conventional' machine tool industry
- Development of user industries due to heavy and chemical industry (HCI) drive policy
- Emergence of the *Chaebol system*

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14) However, the firm did not use this technological lead to develop volume production.

With the above initial conditions, Korea started to form its own technological system for CNC machine tools. First of all, domestic firms started to use imported CNC machine tools from 1974. As seen in Table 3, Korean manufacturers imported 283 units of CNC lathes during 1974-76. This helped Hwacheon design the first CNC lathe through 'learning by reverse engineering' (Korea Industrial Bank, 1991). The first CNC lathe was also the result of cooperation between Hwacheon and Korea Institute of Science and Technology (KIST), which is a kind of industry-academia link. KIST developed a program for CNC equipment and relay circuits, and this was attached to the machine tool made by Hwacheon. KIST was staffed with Korean scientists who had been educated and working overseas, mainly in the U.S. Thus, the direct import of trained personnel from foreign countries was a source of this technological capability.

Table 3 : Production, Trade, and Share of CNC Lathes in Korea, Selected Years, 1974-2001

(Unit : values in million U.S. dollars)

Year	Production		Exports		Imports		Domestic Consump.[1]		Exports/ Production	Imports/ Consump.	Share of CNC[2]
	Units	Value	Units	Value	Units	Value	Units	Value	(% of units)	(% of units)	(% of value)
1974	0	0	0	0	258	3.7	258	3.7	-	100.0	0.0
1975	0	0	0	0	2	0.1	2	0.1	-	100.0	0.0
1976	0	0	0	0	23	0.4	23	0.4	-	100.0	0.0
1977	1	-	0	0	16	1.1	17	1.1	-	94.1	0.0
1981	84	4.0	46	1.8	26	10.7	64	12.9	54.8	40.6	10.5
1985	566	17.9	155	6.1	87	8.0	498	19.9	27.4	17.5	28.9
1987	1605	88.6	335	17.7	192	18.4	1462	89.3	20.9	13.1	50.7
1993	2573	192.2	559	25.4	149	28.0	2163	194.8	21.7	6.9	75.4
2001	5410	310.9	3498	187.6	682	34.0	2594	157.2	64.7	26.3	92.8

Notes : 1) Production minus exports plus imports.
2) Share of CNC lathes in total production in lathes.

Sources : KOMMA, *Machine Tool Statistics Handbook*, various years.

After the first production of CNC lathe, many domestic firms entered into the CNC machine tool industry. First of all, the industry was influenced by the Chaebol system. Some chaebol affiliates such as Kia Heavy Industries Co. (now Wia Corporation), Daewoo Heavy Industries Co. (now Daewoo Heavy Industries & Machinery LTD.), Hanhwa Machinery Co., and Hyundai Motor Company initiated machine tool production and began to produce CNC machine tools from the early 1980s. At the end of the infant stage, the CNC machine tool industry consisted of 9 firms (7 chaebol affiliates and 2 non-chaebol affiliates). At this stage, linkages with foreign entities have been a major source of technological capabilities, especially learning capacity. The learning capacity was obtained mainly through technology transfer from advanced countries. Another link to foreign technological systems was financial takeover of foreign companies. In the case of Tongil Heavy Industries Co., the company acquired two German firms that had been foreign technology agreement partners.[15]

During this stage, the Korean government induced some chaebol-based large firms to enter into the CNC machine tool industry through financial support. On the other hand, protection was another strong way of assisting the CNC machine tool industry. All products below a certain size limit had to be supplied by domestic builders. As this limit was set at very large size, the vast majority of CNC lathes could not be imported. As a result, the import share of CNC lathes dropped to 13.1 percent in 1987, when local production became significant (Table 3).

The adolescent stage started from the late 1980s, when the use of CNC machine tools by domestic firms increased sharply. As a result, some builders like Daewoo had developed a whole series of CNC lathes and machining centers (Jacobsson, 1993). In the late 1990s, the industry could produce all kinds of CNC machine tools such as CNC lathes, machining centers, CNC milling machines, etc. Technological competences also increased. The number of CNC machine tool-related patents applied to Korean Intellectual Property Office by domestic applicants increased from 10 (36% of the total) in 1986 to 56 (86%) in 1995 (Korea Institute of Patent Information, Korea Industrial Property Right Information Service).

In this stage, the Korean government focused its recent efforts on the development of technological infrastructure. The government has induced actors such as specialized builders, part suppliers, research institutes, and universities to develop CNC control technology and advanced manufacturing system technology (including generic technologies and functionally-oriented technologies related to CNC machine tools) through the Mid-term Technology Development Project and the 'G7' Project, respectively, which they were large-scale projects with funding from government and industry.

During the adolescent stage, some venture firms emerged with the development of venture capital market and succeeded in their business. These includes Turbo-Tek, Wonil Precision Machine Co., Hankwang Co., etc., which are listed on KOSDAQ as a successful firm. This means that domestically trained engineers came to play an important role, and venture capital replaced the *chaebol system* and the government as the leading source of funding.[16] Since the late 1990s,

15) Then Heyligenstadt, one of them, was often judged to be the foremost problem solver in large and custom-made lathes and machining centers in Germany.

16) While the number of venture capital companies was only 27 in 1990, it rose 147 companies in 2000. As a

therefore, Korea's technological system for CNC machine tools seems to have moved from its adolescent stage to a self-sustaining stage.

3.2 Technological System Components

In this section, we compare the salient features of the technological system components for CNC machine tools in Korea, Sweden, and the U.S., based on our model. The degree of strength in system components is summarized in Table 4.

3.2.1 Industrial Organization

In the Swedish case, there is a sufficiently large set of highly competent buyers including ABB, Electrolux, SAAB, and Volvo. Their competence and user-builder collaboration are conducive to building a strong industrial network. There have been traditionally strong links between the now defunct Swedish builders (SMT Machine Tool Company and SAJO) and several leading users, especially ABB, SAAB, and Volvo. The crucial aspect in such a close relationship was not the financial or ownership link but rather close collaboration with a technically advanced buyer. In the case of CNC grinding machines, the new technology was developed internally within an advanced user, SKF.

In contrast, the U.S. system has weak industrial networks not only because of free market ideology, antitrust policy, and enforcement but also because of the relatively weak and inconsistent role played by U.S. trade association in technology development and commercialization (Aram *et al.*, 1992). Advanced American users of machine tools have been more geared to mass production than to flexible automation and have therefore not stimulated U.S. builders in that direction. Partly for this reason, many U.S machine tool builders failed in conjunction with the shift from hardwired NC machine tools to CNC (Carlsson and Jacobsson, 1997).

Korean industrial networking is similar to the Swedish case in many respects. User competence and builder-to-builder cooperation are the most prominent features. Some chaebol affiliates, for example, Kia Heavy Industries Co., Daewoo Heavy Industries Co., Hanhwa Machinery Co., and Hyundai Motor Company played such a role. In the cases of Daewoo and Kia, when they entered into the CNC machine tool industry, each had an automobile company within their

result, Korea ranked the fourth in terms of the ratio of venture capital investment to GDP in the world, following Israel, the U.S., and Canada (Korea Institute for Industrial Economics and Trade, 2002). The share of government-guarantee loans in the total lending of commercial banks also decreased from 33.8 percent in 1987 to 25.4% in 2000(Korea Institute of Finance, 2001).

business group as a competent user. Builder-builder linkage was reinforced by the Korea Machine Tool Manufacturers' Association (KOMMA), which was established in 1979. The linkage was also reinforced through Korea Industrial Electronics, which was established as a joint venture for R&D in 1988. The company was financed by 5 domestic builders including Daewoo, Kia, and Doosan on a shareholder basis.

Table 4 : Comparison of Technological Systems for CNC Machine Tools in the U.S., Sweden, and Korea

Components	U.S.	Sweden	Korea
Industrial organization			
User competence	+	+ + +	+ +
User-builder linkage	+	+ +	+
Builder-builder linkage	+	+	+ + +
Institutional infrastructure			
Academic infrastructure	+ +	+	+
Research institution	+ + +	+ +	+ +
Technological infrastructure			
Generic technology	+ +	+	+ +
Functionally-oriented tech.	+ + +	+ +	+
Connectivity between blocks			
Bridging institutions	+	+ + +	+ +
Critical mass	+	+ +	+ + +
Government policy	+	+ +	+ + +

Note : Number of pluses indicates the relative strength in each dimension

But the user-builder linkages are relatively week. This is due to the dependence on imports (especially from Japan) as well as the preference for reverse engineering in the past. Although the chaebol-oriented industrial structure has been conducive to the formation of the system, it seems to be an obstacle in the future.[17] Furthermore, while the chaebol-oriented industrial structure may fit for other technological systems such as semiconductors (Chang, 1999), it is unlikely to work well for CNC machine tools where economies of scope and a high degree of flexibility are required.

17) This is reflected in the current restructuring of the *Chaebol system* in Korea. Since the IMF bailout, Kia Heavy Industries is merged into Hyundai business group and renamed Wia Corporation. Daewoo Heavy Industries also renamed Daewoo Heavy Industries & Machinery LTD. according to the group dismantlement plan. Hyundai Precision Co. (now Hyundai MOBIS) handed over the division of machine tools to Hyundai Moto Company.

3.2.2 Institutional Infrastructure

In Sweden, the academic infrastructure has played a supportive rather than a leading role in the technological system for CNC machine tools. Although academic infrastructure constitutes an important component by supplying competence and forming a part of the bridging institutions, its main function has been in training people rather than research, and its research has been oriented toward application/implementation rather than theory. Especially, in the case of CNC machine tools (as well as in some other cases studied, see Carlsson (1992)), the universities have not performed well. Other government bodies, in particular the Swedish Board for Technical development, had had to compensate for a slow and inadequate adjustment by the universities.[18)]

The role played by U.S. universities has been prominent in the formation of a new technological system, for instance, electronics and genetic engineering (Carlsson and Jacobsson, 1997). In the case of CNC machine tools, however, the academic infrastructure system appears not to have played a particularly strong role. The role of the academic infrastructure in machine tools has been influenced by the military sector. The main function has been to train engineers. On the research side it seems as though the excitement (and funding) of aerospace research, combined with the relatively mundane and applied nature of mechanical engineering research, steered people away from academic research in subjects related to machine tools. Thus, even leading U.S. machine tool firms admit to relying to some extent on German research in mechanical engineering.

The Korean experience illustrates the same phenomenon. However, institutional change was central to the evolution of the technological system for CNC machine tools, chiefly taking place in Changwon Machinery Industrial District. Various kinds of facilities including Korea Institute of Machinery and Material (in 1981) and Changwon National University (in 1985) were established within the industrial district.[19)] Most of both technical and general universities have the departments related to computer, electronics or mechanical science. Although the academic infrastructure has played a supportive rather than a leading role in the technological system for CNC machine tools, training engineers was no small task in a country in the process of catching up.

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18) The universities need to be pro-active and flexible: pro-active in order to be able to supply industry with specialized skills and new knowledge in emerging technological field; flexible in order to adjust the orientation of education from old technologies (e.g. ship building technologies) to new (microelectronics).

19) 9 builders and user firms in general machinery, electronics, and transportation equipment were also based in the district.

3.2.3 Technological Infrastructure

The U.S. has the strongest science base and generic technologies among the three nations. Especially, the country gained a lead early on and has maintained its competitiveness in semi-conductors, computer software, and systems engineering. This is reflected in the continuing U.S. lead in computer-aided design (CAD). However, the U.S. is still weak in mechanical engineering, which is a core technology of CNC machine tools. As mentioned above, even leading firms have relied on German research in that field.

In contrast, Sweden is relatively strong in mechanical engineering. The post - war Swedish development has taken place through increasing the level sophistication and organizational technology in the large firms, based on the old mechanical engineering technology of the industrial revolution.[20] Because of the strong orientation to mechanical engineering technology, this has been beneficial for CNC machine tools but not necessarily for other technological systems.

Korea is weak in technological infrastructure as well as in science base. Thus, the firm-based manufacturing technologies had been obtained through technology transfer. These technologies include the manufacturing technique of machining centers, CNC control technology, and flexible manufacturing system (FMS)-related technologies. As a result, various CNC machine tools were identified and their performance was improved.[21] Nonetheless, CNC controllers could not be produced due to the deficiency of generic technology and the FMS-related technologies were limited at simple level. In the case of semiconductors, Korea is still specialized in general-use DRAM rather than customized products, more relevant to CNC machine tools. Thus Korean experience may be characterized as being TI (technological infrastructure)-assisted development rather than TI-led.

3.3 Role of Government Policy

In Korea, the role of government policy has been the most prominent in forming the technological system for CNC machine tools, although some policy measures, e.g., trade restrictions, were inefficient socially.[22] The Korean government gave legitimacy to the technological system for

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20) The mechanical engineering industry is the bulk employer in Swedish manufacturing. If it fails, employment and real wages will suffer significantly.

21) For example, the spindle speed and precision level were to be increased to 3000-5000 rpm and (+/-) 10μm, respectively (Korean Industrial Bank, 1991).

22) As noted earlier, all products below a certain size limit had to be supplied by domestic builder due to import restrictions for CNC lathes. However, local machine tool users had to accept a less differentiated supply of the

CNC machine tools through its heavy chemical industry (HCI)-drive policy at the embryo stage and large-scale R&D projects (e.g., G7 Project) at the adolescent stage, respectively. The government also supported the industrial organization (clusters of firms) by mobilizing the *Chaebol system,* a nation-specific (or unique) one, and compensated the weakness of universities by enhancing the academia-industry-research institution links. In sum, the Korean government, more specifically the Ministry of Industry, Commerce, and Energy (MOICE), played a 'macro-entrepreneurial' role in building the technological system.

This is in contrast to Sweden and the U.S. as well as some other technological systems in Korea, such as semiconductors, in which a specific entrepreneur got the system started and a few competing firms developed the new technology independently (Chang, 1999). In the Swedish case, the government has supported the system indirectly. The government (particularly the Swedish National Board for Industrial and Technical Development, NUTEK) has allocated resources to academic programs and participated in bridging institutions such as IVF (the Swedish Institute of Production Engineering Research) which is a collective research institute financed jointly by the government and private industry.[23)]

In the U.S., the government provided the economic incentive for developing the technological system in demand side through 'targeted' government policy. That is the support provided by the U.S. Air Force to the development of NC technology. Even in this case, the technology ultimately diffused to other sectors and promoted the emergence of the flexible manufacturing methods. However, while the U.S. Air Force hastened the development of NC technology, it also contributed to the factors behind the U.S. firms' neglect of the segment of market demand, which formed the basis for entry in the U.S. market by Japanese builders of low-cost CNC machine tools. At any rate, the U.S. government supported indirectly the technological system in demand side. But U.S. policy direction was changed from discouragement to active support for collaboration among firms in R&D and other business activities. For example, the National Cooperative Act of 1984 permitted inter-firm cooperation in R&D. Thanks to this act, the major R&D collaboration involving CNC machine tool firms, the National Center for Manufacturing Sciences (NCMS), was formed, enlisting the participation of a large number of U.S. machine tool builders as well as users.

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machines, since Korean builders produced mainly low-performance machine tools and the restrictions was applied to all CNC lathes below a certain size irrespective of their performance.

23) NUTEK is the main government agency for implementation of technology policy IVF is a 50/50 partnership between the government and private industry.

3.4 Connectivity Between Blocks

There are two aspects of connectivity between blocks which seem noteworthy in regard to an international comparison: bridging institutions and critical mass.

3.4.1 Bridging Institutions

In Sweden, NUTEK, Mekanforbundet(Mekan), and IVF have functioned as bridging institutions.24) IVF and NUTEK provide links between academia and industry, while Mekan bridges the gap between government and industry. According to Granberg (1995), although the cases of direct and voluntary university-firm collaborations are exceedingly rare, indirect collaborative links have been formed via IVF. The Korean system has similar institutions that played such a role. NUTEK, Mekan, and IVF in Sweden appear to correspond to MOICE, KOMMA, and Korea Institute of Industrial Technology (KITECH) in Korea, respectively. However, KOMMA and KITECH are more focused on machine tools than those in Sweden. In the U.S., Air Force has played a similar role but more limited role through financial support. The NCMS also arranged various R&D partnerships.

3.4.2 Critical Mass

In the Swedish case, the close networking between many highly advanced users (e.g., Volvo, ABB, SAAB, and Electrolux) and builders functioned as a critical mass. In the U.S., the military sector (U.S. Air Force) played such a role.

The Korean case is more complex than the Swedish one. An entrepreneur, the *Chaebol system,* and Changwon Machinery Industrial District all seem to be a kind of critical mass together. In initiating the infant stage, the role of an entrepreneur should be noted. Mr. Seung Kwan Kwon, founder of Hwacheon, was pivotal.25) He first developed a 'conventional' lathe in 1958 and a CNC lathe in 1977. He had been aware of the importance of machine tools in Korean industrial development and the global technological opportunities since he started his business. The close connection within chaebols functioned to provide a critical mass. The *Chaebol system*

24) Mekan is the branch organization of the Swedish engineering industry. In addition to the duties normally performed by a branch organization, Mekan plays a significant role in the diffusion of technology as well as the formulation of technology policy in Sweden. IVF, a private organization, conduct technology scanning, monitoring, adaptation, and diffusion as well as contract research and testing for individual firms.

25) It is known that his vision for CNC technology had been influenced by Mr. Inaba, the former Chairman of Fanuc (Electronic Time, Feb. 11, 1999).

has enhanced the connection of various kinds of linkages, including user-builder, domestic-foreign builder, domestic-domestic builder, etc. The Korean government also functioned as a critical mass. The government gave the geographical closeness by creating the Changwon Machinery Industrial District. 10 of total 31 builders and 592 user firms (385 firms in general machinery, 78 firms in electronics, and 129 firms in transportation equipment), Korea Institute of Machinery and Material, and Changwon National University are based in the district.

4. Performance Comparison of Technological Systems

The graphs in Figure 3 present the dynamic changes in the three countries' technological systems from 1981 to 1987 and 1997 in an internationally comparative way.[26] The three axes indicate the performance in different dimensions of the technological system: the revealed comparative advantage (RCA) as an indicator of industrial performance, the revealed technology advantage (RTA) as a technological infrastructure proxy, and the revealed publication advantage (RPA) as an indicator of institutional performance (see Figure 1). The RCA is the well-known Balassa index. The value of RCA of country i in industry j is given by $(X_{ij} / \Sigma_i X_{ij}) / (\Sigma_i X_{ij} / \Sigma_i \Sigma_j X_{ij})$, where X_{ij} is the exports volume of country i in industry j. If the index is greater than 1, it gives evidence of commercial specialization. The RTA and RPA are the application of RCA, respectively.[27] The RCA is based on the exports of all kinds of CNC machine tools.

The RTA index is computed from the number of patents assigned by the U.S. Patent and Trademark Office. The number of patents is based on patent documents which have phrases relating to CNC technologies, generic technologies, and functionally-oriented technologies - 'computer numerically controlled', 'numerically controlled', 'microprocessor-based numerical control', 'microcomputer-based controller', 'servomotor', 'surface and cutting edge test', 'speed test', or 'sensor' - anywhere within the indexed text. The RPA is computed from the number of scientific articles published by various kinds of institutions, i.e., universities, research institutions,

26) Because of the size and complexity of technological systems and the variety of ways in which they interact with other systems, it is difficult to measure the performance of a technological system. Thus, it should be kept in mind throughout this exercise the measures we have are only partial indicators. See Carlsson *et al.* (2002) for methodological issues of the performance measurement of a technological system.

27) We calculated the indexes for major countries such as the U.S., Japan, Sweden, the U.K., France. The RTA and RPA are calculated by dividing the country's share in a specific field by its national average to measure the comparative advantage of the technological and institutional strength, respectively. See Laursen (1998) for a comparison among different measures of trade specialization.

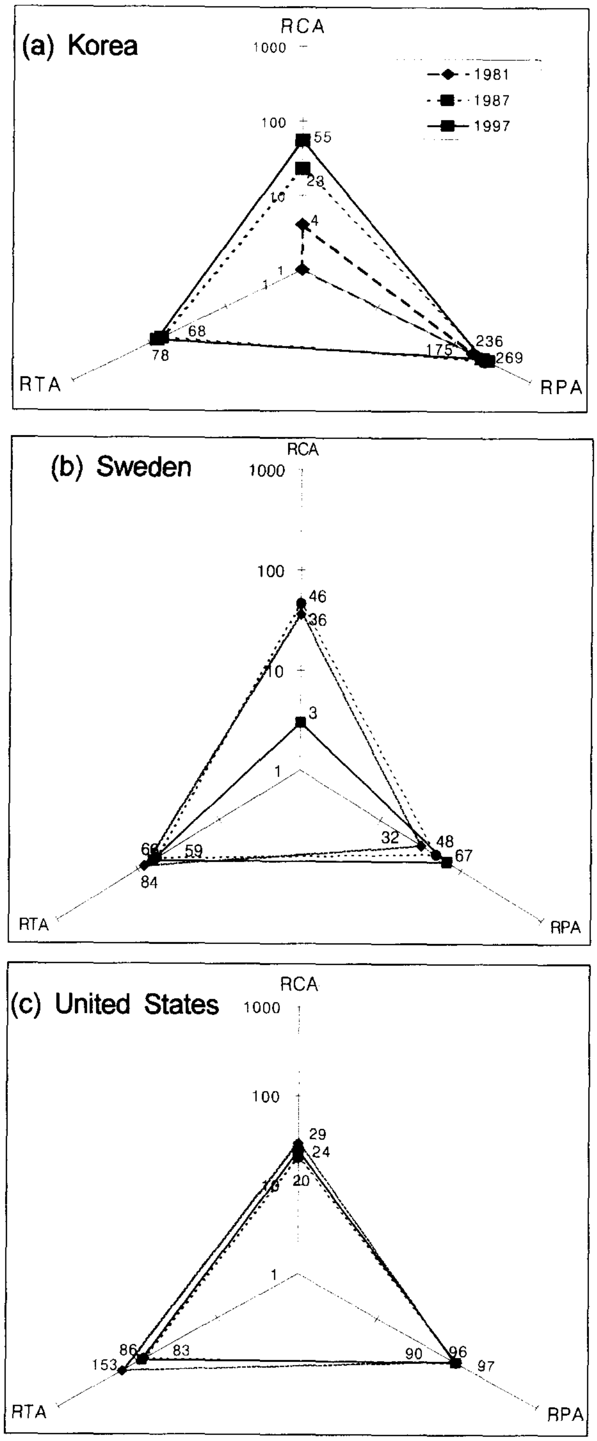

Fig. 3 : Performance of Technological Systems for CNC machine Tools in Korea, Sweden, and the United States

and technological centers. Thus, our view is that the index reflects the performance of institutional infrastructure. The RPA index is based on National Science Indicators published by the Institute for Scientific Information. The fields of articles include automatic control, mechanical engineering, computer science & engineering, electronics engineering, and instrumentation/measurement.

Based on these criteria, the performance of the Korean system during the past about two decades (1981-97) seems to be better than that of Sweden and the U.S. All three indexes in Korea increased over the period. The RCA was less than 10 in 1981 and then it rose to 55 in 1997.[28] The RTA was zero in 1981 and then it rose to 68 in 1987 and 78 in 1997. The RTA increased from 175 in1981 to 237 in 1997. These indicate that relative to both other countries and other fields in Korea, the technological system for CNC machine tools has been gaining strength during the past two decades. In our view, this is accomplished by increasing the connectivity/linkages among actors/components within the technological system, rather than the development of individual infrastructures. However, it should be noted that both the RCA and RTA are still less than 100. Although the RPA is greater than 100, this is due to strong position of CNC machine tool-related fields relative to other fields in Korea, rather than to other countries.

On the other hand, the U.S. system experienced very little change in its position. It can be seen that the U.S. trajectory is moving in opposite direction to Korea, except in the RPA. This may be due to the entry of many other countries, especially Japan, into the CNC machine tool industry and research activities. However, the U.S. system is still the strongest position in terms of absolute value.

Sweden has the same directions of change with the U.S. While the RPA index increased by 36 (from 32 in 1981 to 67 in 1997), the RTA index decreased by 17 (from 83 in 1981 to 66 in 1997). Especially, the RCA decreased from 46 in 1981 to 4 in 1997 sharply. This means that because of relatively low paper to patents ratio, i.e., weak technological infrastructure, and weak industrial infrastructure, the Swedish technological system for CNC machine tools has been losing strength. Especially, the ability of less competent user firms to acquire up-to-date technology geared by their specific needs has been weakened. Another factors are likely to be problems in the domestic economic environment having to do more with institutions: the welfare state with high taxes and poor incentives, too much of the economy being guided by non-market principles and lack of EU membership.

28) In order to show the difference among three countries graphically, we multiply the index by 100 and take log operation.

5. Conclusions and Policy Implications

Taking *a product* (CNC machine tools) as the unit of analysis, the paper reconstructed the concept of technological systems. Based on the model and our earlier works, we discussed similarities, contrasts, and insights from the experiences of Korea, Sweden and the U.S. We also presented the performance measures of the systems in an international comparison.

Our major findings are as follows. First, the 'learning period' for local (national) technological systems takes long time, even though it is a catching-up case. In Korea and Sweden, the whole evolution process of the technological system for CNC machine tools seems to have spanned over two decades.

Secondly, the key success factor of the technological system appears to be the connectivity among various actors or infrastructures, rather than just the existence or formation of those. The three cases show that various bridging institutions (MOICE, KOMMA, and KITECH in Korea; NUTEK, Mekan, and IVF in Sweden; NCMS in the U.S.) enhanced the connectivity of the system and therefore increased the competitiveness of the CNC machine tool industry.

Thirdly, another distinct factor in the evolution of technological system is the role of government. In all cases, the government played a important role in the formaing of each system. Especially, the Korean case shows that a technological system can be created and evolved by government, although the government utilized the *Chaebol system* which is a nation-specific (or unique) industrial organization as well as a critical mass.

Fourthly, although Korea was clearly a latecomer in the field of CNC technology, the performance of Korea's technological system for CNC machine tools during the past two decades (1981-97) seems to be better than that of Sweden and the U.S. Korea has been catching up with other leading countries and is now becoming major player in the global market. The main consequence of this is likely to be various and strong connectivity/linkages among actors/components in the technological system In contrast, Sweden has lost international market share due to weakened industrial networking, especially user competence.

The implications for public policy are as follows. First, the policy perspective should be changed from rectifying individual market failures to reinforcing the technological system or at least prescribing the remedies of system failure. The important role of government policy is to make the system as a whole well functioning rather than to subsidize particular firms or industries, to supply temporary technical solutions, or to support individual R&D projects. The policy measures may include creating and improving institutions that provide capital, research, managerial and technical education, etc.

Second, a well-functioning technological system doesn't mean 'equal' treatment of the three system components. Since technological infrastructure as a set of knowledge is embodied in a variety of institutions and linkages within the system, the policy should be designed on the basis of the technological infrastructure.[29] In other words, institutions (e.g., technology centers) and linkages embodying relevant technological infrastructure should be established, and the knowledge produced in these institutions must be accessible to other actors in the system.

Third, while both 'localized' technological learning and global learning were important, global or 'distance' learning played an important role in the process of catching-up. A main task of policy was to identify globally new technological opportunities at a very early stage and to contribute to raising the awareness of these opportunities as broadly as possible in industry, academia, and other institutions.

Fourth, the timing of policy becomes essential. Korean policy had a strong anticipatory element, and the government must have an appropriate mechanism for early identification of potential or actual policy problems. Since it is obvious that the length of the 'learning period' is substantial, even in a catching-up case, it also needed to have a long-term view.

As for private businesses, they can contribute to strengthening the technological system of which they are a part, by increasing their firm-based capabilities, by increasing their R&D efforts, by initiating and building new bridging institutions while strengthening existing ones, and by articulating the requirements to which the academic sector can respond.

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29) This policy may be called technological infrastructure policy (TIP). See Teubal *et al.* (1996).

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