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A Comparison of Technological Systems for Industrial Robots in Korea and Sweden

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<목 차>

요 약

이 논문은 Carlsson and Stankiewicz(1991)가 창안한 기술시스템(technological systems)의 개념을 한국과 스웨덴의 산업용로봇에 적용하여, 양자를 비교 분석하고자 하였다. 먼저 기술시스템의 개념을 재구축하고, 동태적인 측면에서 시스템의 진화과정을 보강한 다음, 한국과 스웨덴의 산업용로봇에 대한 기존 연구를 활용하여 양 기술시스템의 중요한 특징들을 비교하고 그 성과를 측정하였다. 한국과 스웨덴에 있어서 산업용로봇 기술시스템의 진화과정은 공히 미국, 일본 등 기술선도국을 모방하는 입장에 있었음에도 불구하고 '학습기간'이 20여 년 이상 소요됨을 보여주었다. 뿐만 아니라 양 시스템의 진화과정, 특히 태동기(embryo stage)에 있어서 정부의 역할이 매우 컸던 것으로 분석되었다. 그러나 기술시스템의 구성요소인 산업네트워크, 기술하부구조, 그리고 제도적하부구조 면에서 강약점 및 특징의 차이가 있음을 발견하였다. 기술시스템의 동태적 성과면에서는 한국의 경우가 스웨덴의 경우보다 상대적으로 더 우월한 것으로 평가되었다. 이는 스웨덴 시스템에서는 초기에 우위를 누렸던 기계, 전기, 그리고 메카트로닉스 기술의 우위와 사용자 능력이 점차 약화되어온 반면에 한국의 시스템은 기술하부구조 등이 취약하였지만 해외시스템과의 연계, 재벌 내에서의 기업간 연계, 산학연 협동, 그리고 지역내 연계 등 시스템내의 연계성이 기술적으로 취약한 부분을 보전해 주었기 때문인 것으로 분석되었다. 따라서 어느 한 기술시스템이 자생적으로 생명력을 이어가기 위해서는 시스템 구성요소의 개별적 형성 및 발전보다는 구성요소간 그리고 시스템내의 다양한 활동주체들의 상호작용과 연계성이 중요함을 강조하였다.

Key words : evolution, technological systems, industrial robots, performance

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Ⅰ. Introduction

Today the Japanese market is the largest and Japanese firms dominate the global robot industry, producing around 80% of global output and holding around 50% of world robot stock. Nevertheless, a number of European firms have grown to become quite successful. The most prominent of these is the Swedish firm ABB(Asea Brown Boveri Ltd.) Robotics, now a market leader in the robot industry. A number of Korean industrial robot firms have also grown large and successful. Korean firms such as Samsung Electronics have been catching up with other leading countries' firms and moved to the frontier in specific products and are now becoming major players in the global market.[1] Korea recorded the third highest robots stock density in the world in 2002, following Japan and Germany(Table 1).

<Table 1> Robots stock density for Korea, Sweden, Japan, Germany, and the U.S.

	No. of robots end of 2002 (units)	Share of world stocks(%)	No. of robots per 10,000 manufacturing employees
Japan	350,169	45.5	308
Germany	105,217	13.7	135
Korea	44,265	5.7	128
Sweden	6,846	0.9	91
U.S.	103,515	13.4	58
Total world stock	769,888	100.0	-

Source: International Federation of Robotics(2004)

How can we explain these two counties' catching-ups, and what lessons can be learned for policy? Recognizing that there may be many other factors in attaining these industrial developments, the paper focuses on the network or system of technological change as the most important one. In other words, we take a systems view of innovation.So far, various systems

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[1] Samsung Electronics announced in 2000 that it recorded 8,000 units of industrial robots in terms of cumulative production(The Electronic Times, Dec. 19, 2000). This figure is equivalent to that of foreign advanced companies.

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 industrial robot industries in Korea and Sweden using the technological systems approach, which was first introduced by Carlsson and Stankiewicz(1991). The approachmay 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.2)

The paper is organized as follows. In section 2, we reconstruct the concept of technological system, focusing on a product(industrial robot) as the unit of analysis. Section 3 compares the salient features of technological systems for industrial robots in Korea and Sweden in terms of system evolution, components, and their linkages. Section 4 measures the performance of the two countries'technological systems in an internationalcomparison. Finally, in section 5 the findings are summarized and policy implications drawn.

II. The Technological Systems Approach

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

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

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) 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,[3] the actors and institutions are all within a given industry. While the unit of analysis in standard industrial economics is the 'sector' ideally composed of firms with products addressing the 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 includeuser-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).[4]

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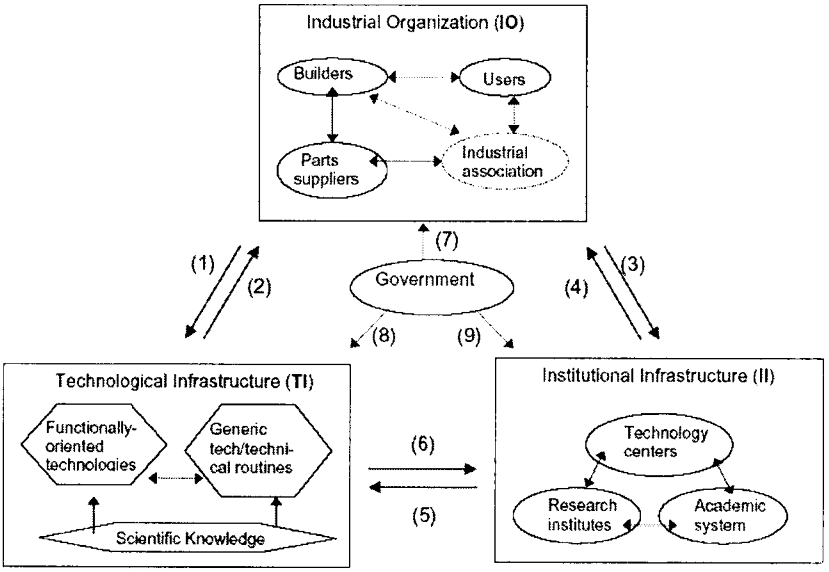
[3] The main focus in the analytical framework of technological systems is certainly on a technology or technologies. However, in applying the framework, several methodological alternatives are available. Concerning the level to which the analysis is applied, we have found that the system approach may 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), Holmen and Jacobsson(1998) as well as by 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(industrial robots) as the initialseed from which the system is defined. This is why we named it the technological system for industrial robots.

[4] 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.



Note: □ structure or organization ⬭ agent, actor, or institution
⬡ knowledge, technologies, or capabilities
→ flow of information or interactions among infrastructures, actors, and institutions

<Figure 1> The technological system focused on a product

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) Technological infrastructure as a hard core

Given a product, the industrial organization supports and is supported by technological infrastructure(relation 1 and 2). 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) 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). 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 enhancingthe dynamic efficiency of the technological system. In many cases, networks are formed as a result of spontaneous actions onthe 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 molding of technological systems. Therefore, government can be another bloc of a technological system.

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 withthe 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).

Alongthis time axis, the change in the system is characterized by the kinds of actors or institutionsinvolved 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

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

[6] An entrepreneur, government, or criticalmass(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.

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 mechanismswhich 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.

3. The technological infrastructure for industrial robots

Since a technological system is defined by a product, there are many technological systems within any given nation. The technological system for industrial robots is one of them. Based on the above discussion, Figure 2 shows the technological infrastructure, which is a core part of the system for industrial robots. According to International Standard Organization(ISO), an industrial robot is an automatically controlled, re-programmable, multipurpose manipulator programmable in three or more axes which may be either fixed in place or mobile for use in industrial automation application. An industrial robot consists of four sub-systems; the mechanical arm(with its transmission system, gears and internal sensors), the control system, external sensors, and the end-effectors. The control system stores information on how and when

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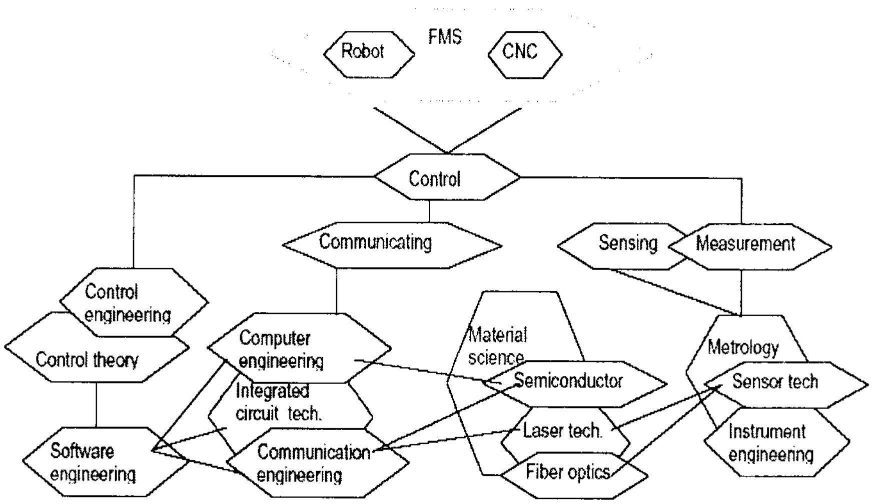
[7] Bridging institutions refer to arrangements and/or organizations that establish and maintain interaction among various actors in the system such as firms, academic or research institutions, and government agencies. The role of bridging institutions is not only to disseminate technological knowledge 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 a result of innovative activities, which otherwise tend to be highly firm-specific, and make them useful and available to other firms as well.



Note: FMS, Flexible Manufacturing System
CNC, Computer Numerical Control

<Figure 2> The technological infrastructure for industrial robots

different tasks should be performed. External sensors provide the control system with information about the surroundings, such as the approach of a workpiece and its position. The sensors can be based on vision, touch, sound or magnetism. The end-effectors are positioned at the very end of the robot arm and can be grippers, holding a workpiece, tools like a welding set, or a mouth-piece for spray-painting.8) Therefore, robot technology depends on control engineering, mechanical engineering, electronic/electric engineering, and computer software engineering.

A successful industrial robot depends on a number of generic technologies, which are components of technological infrastructure. These include semiconductor technology, laser technology, and fiber optics. 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

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8) Robots can be classified in terms of several factors, for example, application(industrial robot, non-industrial robot, etc.), structure(serial robot, parallel robot, humanoid robot, etc.), and control technology(sequence controlled robot, numerical controlled robot, etc.)

on the level of material science, which in turn is based on physics and chemistry.

For robots to perform the basic tasks effectively and integrate into the broader automated factory system,[9] a number of functionally-oriented technologies are needed. These include sensor technology, communication technology, and measurement/test method. 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(seeing and feeling)', 'communicating', and 'measuring', respectively. Specifically, a task such as sensing depends on independently developed sensor technology that must be adapted to and integrated with other elements of the robot, for example, a controller. A sub-activity such as sensing is much less effective in terms of the robot's overall performance if the data generated cannot be efficiently transmitted to a controller and the appropriate instructions sent back. Therefore, communications between sensors and controller and between the robot and other machines play in important role in terms of the robot's overall productivity, regardless of how advanced are the technologies of the individual components.

Ⅲ. Comparison of Technological Systems for Industrial Robots in Korea and Sweden[10]

1. Overview of Technological Systems Evolution

The evolution of a technological system may be global in character, but we deal with local cases. The evolution of the technological system for industrial robots in Korea and Sweden refers to that of a local (national) part of the global technological system. Since the first

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[9] The industrial robots became the core machines of factory automation(FA) with computer numerically controlled(CNC) machine tools. FA consists of both the automation technology of individual machines(e.g., CNC lathes, robots, and automated materials handling) and that of production systems(e.g., flexible manufacturing system; FMS).

[10] Otherwise noted, this section is based on our earlier works, Carlsson(1989), Carlsson(1995), and Sung and Carlsson(2002).

industrial robot was invented in the United States in 1961, both the Korean and Swedish cases 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 2 presents each system's development stages.

<Table 2> The development of technological systems for industrial robots in Korea and Sweden

	Embryo stage	Infant stage	Adolescent stage
Global	~ 1961	1961 ~ late-1970s	early-1980s ~
Sweden	~ 1973	1973 ~ mid-1980s	late-1980s ~
Korea	~ 1984	1984 ~ 1992	1992 ~

1) Global technological system for industrial robots

The very first robot for industrial use(hydraulic machine) was installed by the Ford Motor Company in the United States in 1961(Rooks, 1983). Since then, the infant stage started both globally and locally. During the first thirteen years following that event, only 3,500 machines were sold throughout the world. After this slow start, the market in the OECD countries grew on the average by 25 percent annually during the 1970s and by 40 percent annually during 1980-85.

Since the mid-1980s, Japanese firms have been dominant in using industrial robots. As noted earlier, now Japan is in an extreme position in the robot stock density in the world. The diffusion had been influenced by two important factors: decreasing price of standard robots, which had enhanced their ability to substitute for human labor and fixed automation(see e. g., Tani, 1987), and the improvement of the overall performance of the machines driven by new innovation.

2) Sweden

As noted earlier, Sweden was a follower country in industrial robot 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

ABB Robotics has a significant presence in the technological system for industrial robots. ASEA(now ABB Robotics) developed the first industrial robot in 1973. The infant stage started. Since then, the firm has been a technological leader on the machine level. By 1989 ABB Robotics had installed more than 18,000 robots throughout the world; sales for 1989 stood around 2,300 units. More than 90 percent of the production is exported. The firm has many foreign affiliates including ABB USA, ABB Norway, ABB Korea etc.

The suppliers were not the initiator of change when the robot industry was developed and their products began to diffuse. In fact, ASEA developed its product in response to its in-house demand. As a user of robot, Volvo also integrated robot production vertically. Electolux, a consumer electronic company, developed vacuum-cleaning robot(named Trilobite).

In relation to the robot industry, the most important was the development of factory automation, including CNC machine tools. 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. By 1965 a rudimentary capability had been achieved in the production of numerical control units. In the early 1980s, it produced 250 CNC lathes annually.

3) Korea

In the history of the Korean robot industry, Daewoo Heavy Industries and Samsung Aerospace first developed an arc welding robot(named NOVA) and an assembly SCAR robot(Wiseman) for commercialization, respectively, in 1984.[11] Since 1992, when major builders initiated the development of 6-axes robot according to the government-sponsored

R&D projects, a multitude of applications of new technology have been implemented. Therefore, 1984 and 1992 constitute the historical turning points of the development of the Korean technological system for industrial robots. The historical development process of the system may be divided into three phases: embryo stage(before 1984), infant stage(1984-92), and adolescent stage(after 1992).

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

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

With the above initial conditions, Korea started to form its own technological system for industrial robots. Owing to HCI-drive policy in the 1970s, the user industries such as automobile, general machine, electronics, etc., developed rapidly. As seen in Table 3, the share of machinery firms(user firms) in manufacturing industry increased to 25.2% by 1984. At this stage(the late 1970s), Hyundai Motor, the largest automobile maker in Korea, started to use industrial robots for its production process through imports. Of the robot-related industries, the most important was the development of CNC machine tool industry. Since Hwacheon first produced CNC machine tools in cooperation with Korea Institute of Science and Technology(KIST) in 1977, many domestic firms entered into the CNC machine tool industry.

As noted earlier, the infant stage started in 1984. As a case of technological catching-up, this resulted from obtaining learning(or absorptive) capability from foreign advanced countries. Korean manufacturers such as Hyundai Motor had imported and used a large number of industrial robots before the first domestic one was produced. This helped Daewoo Heavy Industries and Samsung Aerospace design the industrial robots through 'learning by reverse engineering'. Another source of the technological competence was Japan, which is located near by Korea. During 1984-1992, 22 of 28 foreign technology agreements in the robot-related

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11) Even though before 1984, there were several efforts to develop industrial robots. For example, Gold Star Telecom had produced a fixed sequence robot in the late 1970s and Korea Institute of Science and Technology(KIST) developed a cylindrical robot in the early 1980s. However, these were not for full-fledged commercialization.

<Table 3> The development of the Korean industrial robot industry

	Embryo(~ 1984)		Infant(~ 1992)		Adolescent(~1993)	
	Chaebol affiliat	Non chaebol affiliat	Chaebol Affiliat	Non chaebol affiliat	Chaebol affiliat	Non chaebol affiliat
	4 firms: Gold Star Telecom, Gold Star Machinery, Daewoo, Samsung Aerospace		6 firms: Samsung Electronics, Samsung Aerospace, Daewoo, Hyundai, Doosan, Kia	56 firms, including Fanuc Korea	7 firms: Samsung Electronics, Samsung Aerospace, Hyundai, Daewoo, Doosan, Wia, LG	94 firms, including Fanuc Korea, Yoojin, Robostar, Dajin
Machine tool firms	239		642		1,180	
User firms (A)	10,487		26,359		46,034	
Manufact-uring(B)	41,549		74,679		91,156	
A/B(%)	25.2		35.3		50.8	

Source: Korea Machine Tool Manufacturers' Association(KOMMA)

fields were with Japanese companies(Lee et al., 1997).

At the end of the stage, the industrial robot industry consisted of 62 firms, including parts suppliers(Table 3). The production of industrial robots increased to 910 units by 1992(Table 4).

<Table 4> Production and trade of industrial robots in Korea, selected year, 1987-1999

($ Million, %)

Year	Production (A)		Exports (B)		Imports (C)		Domestic consumption(D)*		Exports ratio (B/A)		Imports ratio (C/D)	
	Unit	value	Unit	value	Unit	value	Unit	value	Unit	value	Unit	value
1987	80	2.3	na	na	na	na	-	-	-	-	-	-
1992	910	65.4	18	0.2	1,867	47.2	2,659	112.4	2.2	0.3	70.2	41.9
1997	3,270	146.4	352	7.8	3,735	82.1	6,653	220.7	10.8	5.3	56.1	37.2
1999	2,056	64.3	900	9.5	1,461	30.2	2,617	85.0	43.8	14.8	55.8	35.5

Note: * Production minus exports plus imports.
Source: KOMMA

The adolescent stage is distinguished from the previous one in that the efforts to localize the products were undertaken through two government-supported large-scale R&D projects, the Mid-term Technology Development Project and the 'G7'Project. The purpose of the Mid-term Technology Development Project, initiated in 1992, was to develop a new controller. The G7 Project, which was scheduled to be performing over a decade (1992-2002), included the development of advanced manufacturing system (AMS) technology.12) Along with these efforts, the applications of new technology began to increase rapidly. Various actors including universities, firms, and research institutions have developed new types of robots.

As seen in Tables 3 and 4, in 1999, the industry consisted of over 100 firms and produced 2,056 units. As the exports ratio increased, several foreign users, mainly British and Malaysian,13) entered into the system as a new type of actor. Through the adolescent stage, the networks of the Korean technological system for industrial robots became more intricate. Several functions such as bridging institutions, transferring knowledge, and supplying venture capital were enlarged.

2.Technological System Components

In this section, we compare the salient features of their technological systems' components for industrial robots in Korea and Sweden, based on our model. The main features in two technological systems are summarized in Table 5.

1) Industrial Organization

In the Swedish case, the market for industrial robot consists of few companies, including ABB Robotics, Volvo, and Electrolux. ABB Robotics is not only a dominant firm in domestic market but also one of the world's largest builder. This oligopolistic market structure seems to

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12) The project is broadly composed of 8 strategic technologies including AMS. In turn, the AMS includes industrial robot technology, CNC machine tool technology, and various kind of generic technologies

13) Major foreign markets include Britain (about 35% of the total exports) and Malaysia 25%), and China(12%).

<Table 5> Comparison of Technological Systems for Industrial Robots in Sweden and Korea

	Sweden	Korea
Industrial Organization	• Oligopoly consisting of few builders • Builders were not initiator. • Close user-builder collaboration	• Oligopolistic, but more competitive market structure • Close user-builder linkage within a chaebol
Institutional Infrastructure	• Not leading role but supportive role of academic infrastructure • Swedish Board for Technical Development assisted universities	• KIST/KAIST • Korea Institute of Machinery and Material • Korea Institute of Industrial Technology • Universities with mechanical and control technolog
Technological Infrastructure	• Strength in mechanical engineering • Strength in electrical and electro-mechanical engineering	• The accumulation of technological knowledge through technology transfer from foreign builders
Major interactions/ Connectivit	• User competence • User-builder collaboration	• Technological cooperation between domestic and foreign builders • Interactions within a Chaebol • Industry-Academia-Research organization collaboration • Industry/research district
Critical mas	• Close networking between highly advanced users and builders	• Chaebol system • Changwon Machinery Industrial District • Daeduk Science Par
Bridging institution	• NUTEK(Swedish National Board for Industrial and Technical Development) • Mekanforbundet (Mekan) • IVF(Swedish Institut eof Production Engineering Research	• KOMMA(Korea Machine Tool Manufacturers' Association). • MOICE(Ministry of Industry, Commerce, and Energy) • KITECH(Korea Institute of Industrial Technology
Government Policy	• Indirect suppor	• Direct support (HCI drive policy, 'G7' Project, Mid-term Technology Development Project)

be due to narrow domestic market.

However, there is a sufficiently large set of highly competent buyers including SAAB and Volvo. Their competence and user-builder collaboration are conducive to building a strong industrial network. There have been traditionally strong links between ABB Robotics and several leading users. The crucial aspect in such a close relationship was not the financial or ownership link but rather close collaboration with a technically advanced buyer.

Close user-supplier collaboration is important not only for the parties directly involved but also for others. Without the precisely articulated technical requirements by ASEA, it is unlikely that what is now ABB Robotics would have been started. And even though ABB robotics is now a large international company with a bulk of its operation elsewhere, it still maintains a denser dealer network in Sweden then elsewhere. Thus it is easier for a potential use in Sweden to buy and learn to use a robot than for potential users elsewhere.

Korean market structure for industrial robot is also oligopolistic. The market has been dominated by chaebol affiliates, including Daewoo Heavy Industries, Hyundai Heavy Industries, and Samsung Electronics. But the picture is changing. The market is getting more competitive. A number of small venture firms entered into the market successfully. These included Dajin System, Youjin Robotics, Iram-Tek, Mirae etc.

Korean industrial networking is similar to Sweden in terms of user competence and user-supplier collaboration. When major builders started to produce industrial robots, there had been successful automobile firms such as Daewoo Motors and Hyundai Motors. These companies are relatively all high profile firm in the world. Since these users have the strictest standard requirements for the product, the Korean builders have to upgrade their technological level. Thus, buyer-supplier linkages became a source of technological capability.

2) Institutional Infrastructure

In Sweden, the academic infrastructure has played a supportive rather than a leading role in the technological system for industrial robots. Although academic infrastructure constitutes an important component by supplying competence and forming a part of thebridging 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 industrial robots(as well as in some other cases studied, see Carlsson(1995)), 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.14)

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14) 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

In Korea, however, institutional change was central to the evolution of the technological system for industrial robots. At the embryo stage, KIST, which is known to have developed a cylindrical robot in the early 1980s, already was established in 1966. The Korea Advanced Institute of Science and Technology(KAIST) and the Korea Institute of Machinery and Material(KIMM), which are known to have played a crucial role in developing new robots, were established in 1981, respectively. Through the infant and adolescent stage, the Korea Institute of Industrial Technology(KITECH), the Korea Association of Robots(KAR), and the Robotics R&D Association(consisting of 30 firms including Samsung Electronics, Terbo-Tek, and Kwangwoon University) were established. Various kinds ofR&D Associations in related generic or functionally-oriented technologies were also established: Computers(1985), Optics(1986), Semiconductor(1986), CNC(1987), FA(1988), Measurement Equipment(1988), etc.

Today 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 industrial robots, training engineers was no smalltask in a country in the process of catching up.

3) Technological Infrastructure

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 by then old mechanical engineering technology of the industrial revolution.15) Because of the strong orientation to mechanical engineering technology, this has been beneficial for industrial robots but not necessarily for other technological systems. Sweden is also strong in electricaland electro-mechanical engineering. As noted earlier, the first industrial robot developed by ABB Robotics was not a hydraulic machine but the machine

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orientation of education from old technologies(e.g. ship building technologies) to new(microelectronics).

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

with electrical microprocessor. After that, the product has dominated most of industrial robots. This means that the strength in electricaland electro-mechanical technology paved the way for the dominant technology in the industrial robots.

Korea is weak in technological infrastructure as well as science base. The firm-based manufacturing technologies had been obtained throughtechnology transfer. These technologies include the manufacturing technique of control technology and flexible manufacturing system(FMS)-related technologies. In the case of semiconductors, Korea is still specialized in general-use DRAM rather than customized products, more relevant to industrial robots. Thus Korean experience may be characterized as being TI(technological infrastructure)-assisted development rather than TI-led.

3. Connectivity within the system

1) Major linkages within the system

In the Swedish system, we can hardly find any linkages between actors, except close user-supplier collaboration. In contrast to Sweden, Korea has four major important links: linkages with foreign actors, Chaebol system, industry-academia-research institution linkages, and regional networks.

Linkages with foreign actors: The domestic-to-foreign builder links have been the major source of technological capabilities, especially learning capacity, in Korea. The learning capacity was obtained mainly through technology transfer from advanced countries. Figure 3 summarizes the technological connection between domestic and foreign builders. The figure shows that major builders depend on Japanese builders heavily. This seems to originate from the similarity of firm culture[16] as well as geographical closeness. All of these were implemented by technological agreements such as information and referral service, technological assistance and consultancy, transfer of skilled personnel, etc. These interactions through technological

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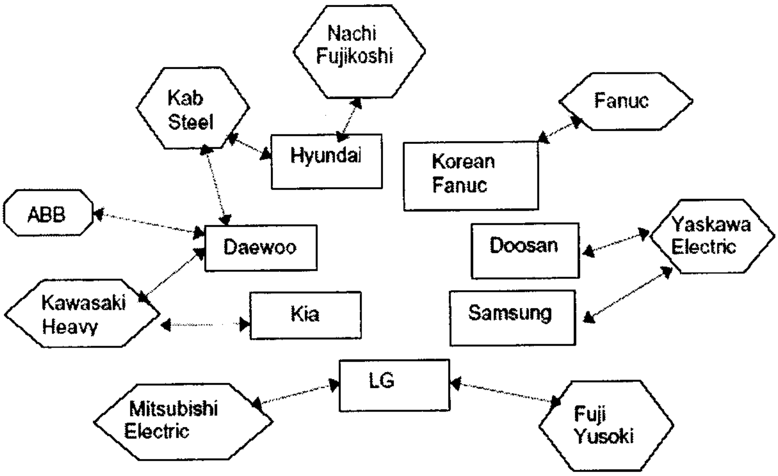
[16] It is well known in Korea that the Samsung business group has a Japan-oriented firm strategy.



Note: □Korean firm; ⬡Japanese firm; ⬭European firm
Source: KOMMA and Electronic Times

<Figure 3> Domestic-to-foreign builder networks(technology or marketing contracts)

agreements, however, helped Korean builders acquire capabilities in the design and development of new products. According to Barrow(1989), Korean builders were not passive recipients in such agreements: several actively prepared themselves to learn by experimenting with the new product, and a notable feature of the agreement was the exchange of skilled personnel.

Another link to foreign technological systems was through direct imports of trained personnel. KIST(and also KAIST), which developed a cylindricalrobot in the early 1980s, was staffed with Korean scientists who had been educated and were working overseas, mainly in U.S. The private firms also recruited those Korean engineers. In doing so, some Korean firms like Samsung offered engineers very high salaries, sometimes 3~4 times the salaries of their top managers(Chang, 1999). For example, Dr. Kim Sung Kwon, both a robot expert and vice president of Samsung Electronics,17) had worked for the University of Minnesota before he entered the company in 1988. This implies that the foreign educational system, specially that

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17) He is also the director of the Robotics R&D Association, which was established in 1999.

in the U.S., was a factor in modeling the Korean technological system for industrial robots

Chaebol system: The chaebol system, a nation-unique industrial organization in Korea, contributed to the building of technological capabilities by enhancing the connection of all kinds of linkages, including user-builder, domestic-to-foreign builder, domestic-to-domestic builder, etc. First of all, some affiliates within a chaebol, as a user, have developed, produced, and sold directly industrial robots. These include Samsung Aerospace and Samsung Electronics. Samsung Electronics constructed its own FA system in-house and then became a leader in the industrial robot industry.

The Chaebol systemalso helped users and builders cooperate with each other. DaewooHeavy Industries, Kia Heavy Industries, and Hyundai Heavy Industries, when they entered into industrial robots, each had their own automobile company within their business group. Because of similar manufacturing philosophy and corporate control of their own chaebol, related affiliates have cooperated with each other. At least, the users, affiliated to a chaebol, guaranteed the procurement of the new product produced by a robot builder within the same business group.

Furthermore, the highly diversified but centrally controlled chaebols also applied their experiences gained in one field of business to another, resulting in rapid diffusion of technological capability across subsidiaries(Kim, 1997, p. 197). The robot-related affiliates within a chaebol worked together in order to develop new technology. The cooperation between Samsung Heavy Industries and Samsung Electronics is atypical example. The two affiliates implemented the R&D partnership to develop a specific controller, which means the combination of mechanics and electronics. Through this effort, Samsung Electronics could produce a controller, PLC, and digital servomotor inhouse.

Industry-Academia-Research institution linkages: Industry-academia-research institution collaboration is an important part of technology policy in Korea. This is no exception in the field of industrial robot technology. The government has enhanced these through establishment of public research institutions and largescale R&D projects.

As for university-industry linkages, government-financed university research centers have performed these activities. These include the Engineering Research Center for Advanced Control and Instrument at Seoul National University, the Regional Research Center for Machine Tool Technology at Changwon National University, the Regional Research Center for Factory Automation at Keumho Institute of Technology, and Micro-robot Center of KAIST. Among these research centers, the Engineering Research Center for Advanced Control and Instrument at Seoul National University is the most prominent. The institution has been performing various activities, including 26 industry and government-sponsored R&D projects, faculty consulting, industrial associate program, and technology transfer. Of special importance is the so-called Industrial RoboticsConsortium Workshop, in which major builders such as Kia andDaewoo participate. As a result of these activities, 93 articles(66 in international journals, 27 in domestic journals) have been published, and 2 foreign patents have been applied for since its establishment(http://icat.snu.ac.kr: 4444/RnA/RnA_frame.html).

Regional networks: As noted earlier, the industrial district as a competence bloc wasdesigned to create a high degree of connectivity in the machinery industry. The Changwon Machinery Industrial District is a local sub-system, which consists of industrial organization, technological infrastructure, and institutional infrastructure. 5 of total 7 major robot builders and 592 user firms(385 firms in general machinery, 78 firms in electronics, and 129 firms in transportation equipment) are based in the District(Korea Industrial Complex Corp., Data Base). KIMM(Changwon affiliate), Regional Research Center for Machine Tool Technology at Changwon National University, R&D Association for FA, Daewoo's Factory Automation System Engineering Center, etc., support the industry and technological infrastructure in Changwon.

Another local sub-system is the Taeduk Science Park, which embodies various kinds of generic and functionally-oriented technologies. The science park consists of 16 government-supported research institutes, 26 private research institutes, 4 universities, and 17 government agents(Sul, 1999, p. 57). As for industrial robots, KIMM(Headquarter), Samsung General Research Institute, and KAIST are located in the Taeduk area. In sum, the 'connectivity' among builders, users, universities, and research institutes was facilitated by this geographical closeness.

2) Bridging institutions

In Sweden, NUTEK, Mekanforbundet(Mekan), and IVF have functioned as bridging institutions.[18] 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, Korea Machine Tool Manufacturers' Association(KOMMA), and KITECH in Korea, respectively. MOICE, the main government agency for implementation of industrial and technology policy, provides links among academia, industry, and research institutions. The incentive mechanism of this partnership was the allocation of funds via large-scale R&D projects. Our view is that the partnership arrangements explained above would not have come about without the funds supplied by MOICE, specially in a situation in which most Korean universities were not both pro-active and flexible.[19]

KOMMA, a kind of cartel, has arranged cooperation among its member firms. It helped the establishment of the Robotics R&D Association, which in turn arranged the Mid-Term Development Project.

KITECH, a public research institution, has linked firms, university, and government by arranging the robot-related task of the 'G7' project. In addition,

KITECH conducts technology scanning, monitoring, and diffusion as well as contract

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18) 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.

19) According to Kim(1997) and Lee et al.(1998), most Korean universities are still undergraduate teaching-oriented rather than research-oriented.

research and testing for individual firms, particularly small-sized manufacturing enterprises.

3) Critical Mass

In the Swedish case, the close networking between many highly advanced users(e.g., Volvo, SAAB, and Electrolux) and builders functioned as a critical mass.

The Korean case is more complex than the Swedish one. The close connection within chaebols functioned to provide a critical mass. The Chaebol system has enhanced the connection of various kinds of linkages, including user-builder, domestic-foreign builder, domestic-domestic builder, etc.Changwon Machinery Industrial District also functioned as an critical mass. The district gave the technological system geographical closeness. Another critical mass is the Taeduk Science Park, which embodies various kinds of generic and functionally-oriented technologies.

4. Role of Government Policy

In Korea, the role of government policy has been the most prominent in the molding the technological system for industrial robots. The Korean government gave legitimacy to the technological system for industrial robots 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. The Taeduk Science Park and Changwon Machinery Industrial District, created by the government, have also functioned as running devices. In sum, the Korean government, more specifically the Ministry of Industry, Commerce, and Energy(MOICE), played a 'macro-entrepreneurial' role in forming the technological system.

This is in contrast to Sweden 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.20)

Ⅳ. Comparison of Technological Systems Performance

Based on our model(section 2) and observations(section 3), we can construct a model determining the performance of technological system. Figure 4 presents such a model.

Along the line of this thought, we tried to measure the performance of technological systems for industrial robots in Sweden and Korea. 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 some measures we have are only partial indicators.21)

Under this limitation, the graphs in Figure 5present the dynamic changes in the twocountries' technological systems from 1987 to 1997 in an internationally comparative way. The three axes indicate the performance of components of the system, respectively: the robot stock share among major leading countries22) as a measure of industrial performance, the patent share as a technological infrastructure proxy, and the publication share as a measure of institutional performance.

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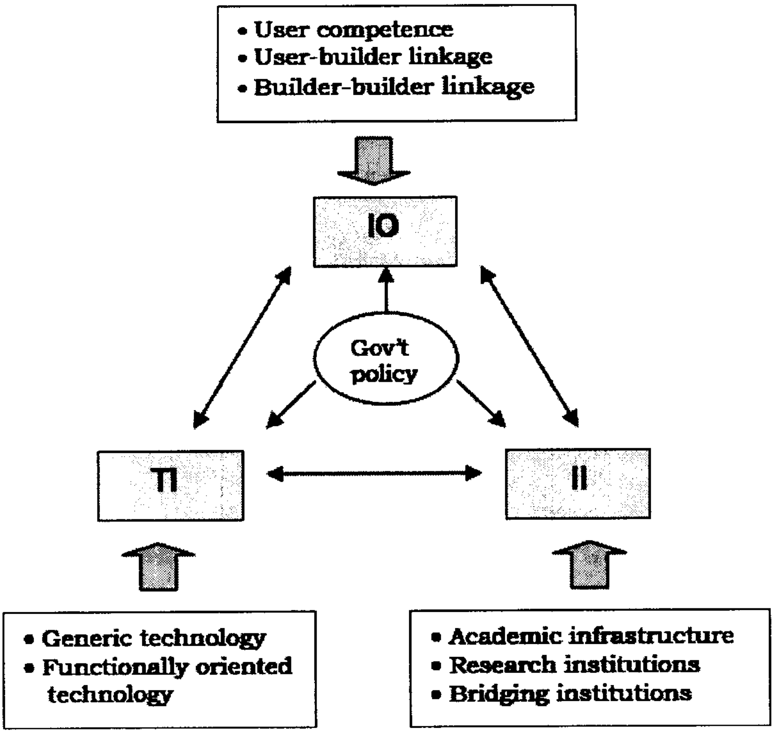
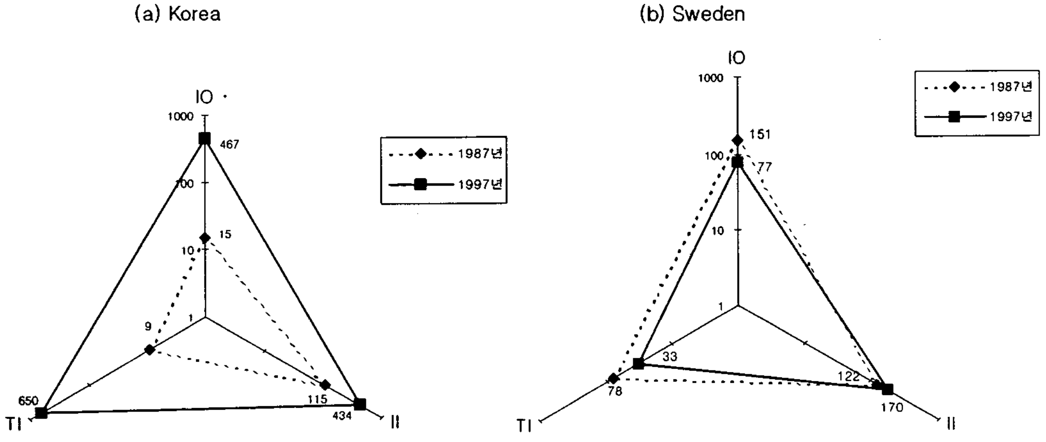
20) NUTEK is the main government agency for implementation of technology policy. IVF is a 50/50 partnership between the government and private industry.

21) See Carlsson et al.(2002) for methodological issues of the performance measurement of a technological system.

22) These include Japan, the U.S., Germany, the U.K. France, Sweden, and Korea.



<Figure 4> A Determinant model of Technological Systems' Performance


(a) Korea

(b) Sweden

Note: we multiplied the share(%) by 100 and took log scale in order to present the difference between two technological systems more clearly.

<Figure 5> Comparison of Technological Systems Performance

The patent share is computed from the number of patents assigned to countries by the U.S. patents and Trademark Office. The number of patents is based on the patent documents which have the phrases relating to generic or functionally-oriented technologies: robot, controller, sensor, semiconductor, laser, measurement, and optics(see <Figure 2>). The publication share is based on National Science Indicators(1981-1999) published by the Institute for Scientific Information. The field of articles includes robotics & automatic control.

Based on these criteria, the Korean technological system for industrial robots during the past decade seems to be more successful than that of Sweden.

As seen in Figure 5, all three values have increased. The robot stock share increased from 0.15% in 1987 to 4.67% in 1997. The publication share

and patent share increased by 3.19 percentage points(from 1.15 % in 1987 to 4.34% in 1997) and 5.41 percentage points(from 0.09 % in 1987 to 6.50% in 1997), respectively. These indicate that relative to other countries, the Korean

technological system for industrial robots has been gaining strength during the past decade. In the case of Sweden, the directions of change are mixed. While the robot stock share and the patent share decreased by 0.74 percentage points(from 1.51% in 1987 to 0.77% in 1997) and 0.45 percentage points(from 0.78 % in 1987 to 0.33 % in 1997) respectively, the publication share increased by 0.50 percentage points(from 1.22 % in 1987 to 1.70 % in 1997). This means that because of relatively lower paper to patents ratio, i.e., weak technological infrastructure, the Swedish technological system for industrial robots has been losing strength.

How can we explain these dynamic changes in two systems? Korea, as a follower, was weak in technological infrastructure, industrial organization, and institutional infrastructure. But these weaknesses have been compensated by various connectivity/linkages among actors/components within the technological system, including linkages with foreign builders, Chaebol system, industry-academia-research institution collaboration, industrial districts, and government policy. On the other hand, Sweden was strong in technological infrastructure, especially mechanical and electrical engineering. User competence, close user-supplier relationship, and the development of factory automation technology have been key success factors, at least over theearly stages. However, 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.

Ⅴ. Conclusions and Policy Implications

Taking a product(industrial robots) as the unit of analysis, the paper reconstructedthe concept of technological systems. Based on the model and our earlier works, we discussed similarities, contrasts, and insights from the experiences of Korea and Sweden. 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 process of formation of the technological system for industrial robots seems to have spanned over two decades.

Second,in both cases, the government played an important role in the molding 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.

Third, although Korea was clearly a latecomer in the field of industrial robots and control technology, the performance of the Korea's technological system for industrial robots during the past decade(1987-1997) seems to be better than that of Sweden. The main consequence of this is likely to be various and strong connectivity/linkages among actors/components in the technological system. Although Sweden developed the first robot with electrical microprocessor, based on the strength in mechanical, electrical and electro-mechanical technology, the country has lost its relative strength due to the weakened industrial networking, especially user competence.

The implications for public policy are as follows. First, the Korean case shows that 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.

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. This policy may be called technological infrastructure policy(TIP). See Teubal et al.(1996). In other words, institutions 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.

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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