Digital Development: Challenges and Prospects

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1. Introduction:

The digital age has been heralded with great fanfare. However, if hyberboles are set aside and a sober assessment is made, we find the beginnings of a technological revolution that has already created much uncertainty and a huge amount of personal wealth. So far the benefits have also been largely confined to the developed countries. Even the newly industrialized economies (the NIEs) have found it hard to catch up and maintain the pace required for not falling behind. The so-called developing economies are clearly at a great disadvantage in such a fast paced technological race. Thus there is a digital divide that is growing and through a cumulative causation the gap will widen further unless coordinated action is taken. This paper will discuss some of the most important economic issues conceptually and offer some modest policy advice. The field is vast and the issues are complex. Therefore, even this modest agenda may be too ambitious for a short paper.

Specifically, in the next section, the basic problem of adoption of a new technology system such as the ICT(information and communications technologies) is explored via the Schumpeterian concept of creative destruction. Section 3 sketches out the links between the ICT sectors, innovation, growth and development. Section 4 briefly outlines some special economic features related to the ICTs. Most important among these are the increasing returns to scale, network externalities and a disequilibrium process that can result in multiple possible equilibria at the end. Section 5 is the most substantive part of the paper. Here innovation as a positive feedback loop process is studied further, and a case study of such process is presented. The South Korean case study is a detailed investigation at both micro and macro levels of the requirements of an innovation system that can include ICTs as an integral part. The study leads towards a recognition of the limits of purely national efforts and suggests that a supranational institutional structure based on the principle of regional cooperation may be the optimal strategy for the developing economies.

2. ICTs and Creative Destruction:

Writing in another era, Joseph Schumpeter seems to have been quite prescient in terms of describing the essence of what is happening globally today. In his book *Capitalism, Socialism and Democracy*, he averred:

> The fundamental impulse that sets and keeps the capitalist engine in motion comes from the new consumers' goods, the new methods of production or transportation, the new markets,.... (This process) incessantly revolutionizes the economic structure *from within,* incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism.[1]

The ICT revolution in progress today is indeed a Schumpeterian process of creative destruction. The essence of capitalism in this view, is the constant revolutionizing of the economic structure from within. Marx had made a similar observation about the endogenous nature of technical change (Marx, 1867, 1945). Aghion and Howitt (1992) have proposed a model of creative destruction by treating the innovation process as intense inter-firm rivalry, as in the patent-race literature.

The present approach assumes, following Schumpeter, and Aghion and Howitt, that innovation in specific firms can have economy-wide effects. The expected growth rate of the economy depends on the economy-wide amount of research; but the process of this growth, precisely because research leads to the development of new products and processes, is characterized by creative destruction.

The relationship between R&D and growth is therefore both intimate and complex. An economy-wide model intending to capture this complex relationship will need to posit non-linearities and complex feedback rules. In the main body of this paper, no formal attempt is made to achieve this by endowing production functions and correspondences with some of these nonlinear and complex feedback features. However, it can be done---in particular, by defining non-linear production structures so that increasing returns and endogenous innovations are possible, one can explore the properties of fixed points that define equilibria at any point in time. A sequence of such equilibria over time, picked by an appropriate selection procedure, can then show the evolution of the system.[2] In the appendix, a prototype model is presented with two different existence proofs, first on a vector lattice, and then on the Banach space.

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[1] Schumpeter (1942) p. 83

[2] For an extended formal treatment , see Khan (1998) and Khan(2001a). Existence proofs for multiple equilibria are also given in these sources.

The problem of the developing countries in this ICT revolution is precisely that they face the destructive side of this process without being able to benefit necessarily from the creative side. The prospects for benefits exist but to realize them will require cooperation from the developed countries and domestic policy maneuvers. But what are these ICT sectors precisely?

3. ICT, Innovation, Growth and Development:

Before discussing the relation between ICT sectors and economic growth, innovation and development, it is first necessary to have a clear definition of the ICT sectors. The most widely accepted definition so far is the one agreed to at the April 1998 meeting of the Working Party on Indicators for the Information Society (WPIIS) and subsequently endorsed at the September 1978 meeting of the Committee for Information, Computer and Communication Policy of OECD. The following principles underlie the definition.

For *manufacturing industries*, the products of a candidate industry:

- Must be intended to fulfill the function of information processing and communication including transmission and display.
- Must use electronic processing to detect, measure and/or record physical phenomena or to control a physical process.

For *services industries*, the products of a candidate industry:

- Must be intended to enable the function of information processing and communication by electronic means.

Based on these principles the ICT sectors are identified within the revised classes of the International Standard Industrial Classification (ISIC). In manufacturing and services the following four digit sectors are included:

Manufacturing

- 3000-Office, accounting and computing machinery
- 3130-Insulated wire and cable
- 3210-Electronic valves and tubes and other electronic components
- 3220-television and radio transmitters and apparatus for line telephony and line telegraphy
- 3230-Television and radio receivers, sound or video recording or reproducing apparatus, and associated goods

- 3312-Instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process equipment
- 3313-Industrial process control equipment

Services

- 5150-Wholesaling of machinery, equipment and supplies
- 7123-Renting of office machinery and equipment (including computers)
- 6420-telecommunications
- 7200-Computer and related activities

In short, roughly there are three broad categories of the new ICTs: (1) computing (2) communicating (3) Internet-enabled communication and computing.

Strictly speaking, not all of ICT sectors are digital, or at least not yet. Even within the digital part, the pre- and post- internet distinction is historically important and relevant for the developing economies, as Tschang(2000) points out.

We can roughly dissect the digital economy's infrastructure into its pre-Internet and Internet eras. Before the Internet, a host of information technologies came into existence, which provided computing power on a platform-specific system, usually centralized (e.g. a central mainframe with terminals) or distributed within a local area. The advent of the Internet (and its precursors, the U.S. government-funded research networks like the defense research network - ARPANET) was a critical event because it set up the basic infrastructure, standards (e.g. protocols for communication) and technologies, that enabled large scale, distributed and platform-independent information exchange and manipulation. This "single" system allowed the introduction of literally unlimited sources of information, or access points to it, in a *scaleable* fashion, i.e., without increasing numbers of constraints or decreasing economic "returns to scale". The first computing functions consisted of basic email and file transfer capabilities like *ftp* and *gopher*, but these were soon coupled with basic "Web" technologies, like the development of the first browsers and the standards and technologies of the "World Wide Web". This latter further improved the remote accessing and manipulation of information, and ensured that all information could be "web-based", and therefore potentially viewable/downloadable by anyone connected to the Web. All these set the stage for electronic commerce to take place, since the connection of such large numbers of people to all the sources of information provided a potential market never possible in the history of markets.

Today, the developing countries may be able to leapfrog, as Soete (1985) had earlier conjectured for microelectronics; but there is a real danger of just lagging behind.The situation can be summarized by simply looking at the state of e-commerce infrastructure. OECD (1999) offers a classification of the infrastructure sectors for e-commerce: (1) hardware (PCs, routers, servers etc.), (2) software to run the hardware and e-commerce packages, (3) network service providers (e.g. providing Internet access), and (4) enabling services (e.g. e-payment, authentication/certification services, advertising and delivery). The revenue for these four categories have been estimated as follows:

Table 1. Value of E-commerce (billions of U.S. dollars)

	1995-97	2000-02
Hardware	11-30	43-72
Software and computer services	0.9	3.8-5.1
Network service providers	0.3-6.3	5-46.4
Enabling services	0.5-1	7.6-10
E-commerce		
Total e-commerce (median of multiple studies)	0.7	155
Business-to-business e-commerce (average over various years: 1996-2002)	78	

Source: (Tschang (2000), OECD (1999))

The state of the developing economies is underlined by the fact that this table does not even include them as a category via a breakdown into developed and developing economies. One reason why this idea may not even have crossed the minds of the OECD volume authors is that even if the suggested breakdown were to be carried out, the percentage share within each category (in table 1 above) for the developing economies would have been less than one per cent. Along the key dimensions of a digital economy such as computers per capita, internet providers, telecommunications infrastructure and cellular telephony etc. also the developing countries are far behind the developed ones. Even advanced developing countries, i.e., NIEs and other large economies such as the Asian tigers, China, India, Brazil or Mexico are in danger of falling further behind. What can explain this tendency and how best can the developing countries catch up? A conceptual clarification of the basic economics involved will help guide policy discussions in this area. It is to this task that the rest of the paper is devoted.

4. The (not entirely) New Economics of ICT and Knowledge Sectors:

The key to understanding the economics of ICT and knowledge sectors is to realize that a disequilibrium process has set in within the world economy and the advanced countries of the world that is leading to rapid economic changes. These changes include intersectoral shifts toward the ICT and knowledge sectors, changing skill requirements, high volatility of wages, profits and financial variables and consequent increase in uncertainty about the future states of the economy. The dynamics of this disequilibrium process must be studied through methods of understanding complexity.Clearly, our knowledge of such dynamic systems is still in its infancy; but much can be learned by studying some known features.

In the last twenty years, the frontiers of economics have moved far beyond the standard models of decreasing or constant returns where costs can not be decreased beyond a certain point, unless factor markets behave in a peculiarly decreasing marginal cost fashion. Leaving the perfectly competitive world behind, economists at the frontiers have been focusing on increasing returns to scale, economies of scope and network externalities.[3] The world of high technology in general and the ICT and knowledge sectors in particular, are characterized much better through these approaches than the old perfectly competitive models. Many models of imperfect competition have also been developed to study interesting and relevant phenomena such as R&D rivalry and R&D expenditures. The upshot of these developments is that economists at the frontiers of their discipline are much closer to understanding many aspects of the digital economy than they were ten years ago. In this paper I want to illustrate this point by discussing informally a recently developed theoretical and modeling approach. The policy implications for the ICT and knowledge sectors of developing countries are quite striking.

5. Positive Feedback Loops, Innovation and Intellectual Property Rights in Developing Countries:

The concept of NIS or National Innovation System, like many other concepts in the field of economics of innovation was originally proposed for analyzing developed technological systems in the advanced industrial

[3] Among the sources cited in the references see in particular, Arthur(1994), Matsuyama (1991), Khan(1998) among others.

countries (Freeman:1987;Nelson: 1993;Anderson and Lundvall: 1992;). As a systems-oriented, holistic way of thinking about technological change it has undoubted strengths. By drawing the link between R&D, human resources development, formal education and training as well as innovating firms,

NIS presents an analytical schema for relating a cross cutting array of activities that lead to a dynamic innovative economy. The proponents of this approach also advocate an `evolutionary' as opposed to a mechanistic approach based on classical physics type study of equilibria for studying the economics of innovation.

Given the obviously sincere and serious intentions of the theorists of NIS and the intellectual break with neoclassical economics, the study of NIS held out promises of both retrospective understanding of economic history and a prospective, prescriptive approach to help countries innovate. Nowhere was this promise more eagerly believed than in the developing countries. No one was more excited by the prospects of NIS than the avid modernizers in the governments, universities and international organizations and think tanks. I have documented in great detail elsewhere (Khan, 1997; 1998; forthcoming) the reach and sweep of NIS in newly industrializing countries such as South Korea and Taiwan.

Yet, so far the thinking about NIS, and its connections to modernity and development have been entirely technocratic. The argument always proceeds in terms of the function of technologies and their role in increasing GDP/capita in the most efficient manner. The intense and inconclusive debate raging with respect to whether East Asia has really grown because of a simple accumulation of labor and capital or because of productivity increase through genuine technical progress and learning illustrates neatly this technocratic bias. Neither side is willing to step beyond the economic inputs and outputs, production functions and technology as a black box. It is, of course, important to know whether learning has taken place in, for instance, textiles or electronics sectors. But there is no recognition of the point made by Feenberg and others, namely that "…design responds not only to the social meaning of individual technical objects, but also incorporates broader dimensions about social values" (Feenberg 1999, p. 86).

This "cultural horizon" of NIS which legitimately can be said to constitute a hermeneutic, interpretive dimension, should offer some interpretative flexibility. A recent paper by Murata (1999) illustrates the relevance and importance of such interpretative flexibility by simple but elegant examples such as the go-slow street barriers(to restrict speed) and harnessing the driver of a car to the key to prevent her from leaving it in the car in a fit of forgetfulness.When an underdeveloped economy accepts an NIS whose components come from abroad, a society-wide hermeneutic process is unleashed. Yet this is where the interpretative flexibility is frequently blocked by the closure imposed undemocratically over the rest of the population by the technocratic elite and their modernizing allies from the outside.

Such premature closures can certainly produce success stories. In Taiwan, for example, NIS has succeeded to the extent that it has been able to capture market shares in various high technology areas.The swift capture by the Taiwanese manufacturers the lion's shares of world information technogy hardware markets is nothing short of amazing. In most relevant product categories Taiwan has more than 50 percent of market share. In some categories such as scanners it has almost cornered the whole market. Yet further progress requires both a deeper understanding of the diseqilibrium processes at work leading towards multiple equilibria, and the social-cultural implications of the complex economics of **the production and distribution** aspects of NIS. It is with a view towards capturing these complexities leading towards multiple equilibria that an alternative conceptualization of technology systems transition has been formulated by some economists (Khan 1993; James and Khan 1997; Khan 1998, 2001a,b) . In addition to capturing both equilibrium and disequilibrium features of technological transitions, this broad approach can illuminate distributional issues as well. Since poverty alleviation remains on the agenda of the national governments of developing countries and the international development agencies, it can be argued that from this perspective at least the new approach has obvious relevance for the developing countries.

Khan(1998, 2001a) has formalized this approach and has coined the abbreviation POLIS to emphasize both the disequilibrium positive feedback loop features and the politico-social dimensions of the technological transitions. For the current ICT transitions in developing countries this model has been applied to South Korea, Taiwan, China and India, with work underway for Indonesia. The key results for policy purposes will be described shortly; but first let us take a closer look at the concept itself.

Complex Technological Systems and Models of POLIS

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It has been known for some time that technological systems are complex structures with many types of feedback loops and nonlinear relations. In this context, strategies of technological development assume new importance. As the debate on the "East Asian miracle" underlines, the key strategic question for a country that has made a technological transition from a traditional to a modern system concerns the prospects for long-term economic growth. Ultimately, it is the sustainable long-term rate of growth that will determine the wealth that can be distributed among personal consumption, investment, government spending on infrastructure and public services, etc.

Therefore, it is the creation of an innovation system that will determine the viability of a technology-based growth process. This process of building an innovation system is very much an evolutionary and path-dependent process.(Nelson 1981, 1989, 1993, 1994; Nelson and Winter 1974, 1977, 1982) The central idea is that the provision of appropriate types of capital, labor and forms of organization for high value-added industries will lead to rapid productivity increases. However, to sustain such an increase, a domestic innovation system must be set up. There is a further requirement that this innovation system must fulfill. This is the requirement of a positive feedback loop or a virtuous cycle of innovations.

This problem, as I have emphasized, is intimately connected with the existence of multiple equilibria in complex economies. A positive feedback loop leading to a virtuous cycle of growth and technology development is one particular sequence of equilibria in this context.[4] In general, such a sequence also involves increasing returns. In the remainder of this section a theoretical exploration of innovation with increasing returns and multiple equilibria will be undertaken.

In a market economy, 'success' is often cumulative or self-reinforcing. Typically outcomes are not predictable in advance. However,

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[4] If there is more than one such sequence, we may be tempted to choose from among them, the "optimal" sequence, according to some well-defined criterion, e.g., present value maximization.

once an equilibrium gets selected out of a number of long-run equilibria, there is a tendency to be locked in. Technically, economic processes exhibit non-convexities -- violating the generic assumption of competitive equilibrium economics. The presence of self-reinforcing mechanisms sharing common features found in fields as far apart as enzyme reactions and the economics of technical change underlines the importance of such mechanisms in governing the dynamics of self-reinforcing processes regardless of the field in which they occur.[5]

In order to give the reader some informal idea of the problem of formalizing complex technological systems I summarize here the basic structure of a 'simple' non-linear model embodying distinct technological systems. At any single point in time, the model can be presented as a Social Accounting Matrix (SAM) representation of the socio-economic system. The key distinction here is the explicitly non-linear nature of the economy-wide functional relationships. The key theorem shows the existence of multiple equilibria. Some further considerations lead to the specification of definite technology sectors such as the ICT sectors, productivity enhancement and income distribution. Thus a closed loop feedback sytem including all the production and distribution mechanisms can be set to work. The attractiveness of such an approach to the proponents of a holistic perspective should be readily apparent. What is even more intriguing is that apparently a way has been found to move beyond the annoying vagueness of the proponents of the systems approach to a precise and even mathematically and statistically formal way of describing complex technology systems. I now move towards a brief description of the key results obtained so far for the ICT sectors and their policy implications.

ICT Sectors in a POLIS and Policymaking in Developing Economies: What Have We learned?

The empirical work done so far on the ICT sectors in the NIEs and some other developing economies reveals the presence and importance of increasing returns to scale, economies of scope, network externalities and strategic complementarity between R&D and human resource development. This line of work also reveals the problems of building a POLIS when many

[5] See the essays in Arthur(1994) for some illuminating discussions.

of its ingredients are either missing or are underdeveloped.The example of South Korea is illustrative and instructive.

Whatever the record in the 1960s and 1970s, by the 1980s Korea did enter a largely modern technology-centered era (Khan, 1997a). Therefore, we need to investigate the situation during the last decade and a half in order to see the source and role of this modern technology system. First, it is necessary to look at the transfer of technology from abroad to Korea. In the process we also will have an opportunity to examine Teitel's characterization of the three phases of technological development. According to Teitel (1984 a, b) the first phase is the acquisition of technology from abroad; the second phase involves the modification of borrowed technology. The final phase is the generation of technology at home. This acquisition-modification-creation process can be observed in the history of economic evolution of the advanced industrial countries.

The government of Korea passed the Technology Development Promotion Act (TDPA) in 1972 the purpose of which was to facilitate technology imports. This coincided with the establishment of Technology Imports Counseling Center at the Korea Institute of Science and Technology. At the same time the Korea Development Bank's ‘technology development fund’ originated as a source of financing. The following year the TDPA was further liberalized to relax the approval criteria for imported technologies.

The third and fourth five-year economic development plans emphasized the role of heavy and chemical industries. A form of industrial policy can be seen to be at work here. Table 2 summarizes the changes in Technology import policy since 1978. The financial assistance facilities also played important roles. These are presented in table 3. Table 4 shows the declared industrialization and technology strategies during the decade of 1960s, 1970s and 1980s. It is important to note that promotion of high-tech industries became a goal only in the 1980s.

Table2: Changes in Technology Import Policy during the decade of creating the modern technology system since 1978 (1978- 1988)

Period	**Contents**	**Industry**
First Step (April 1978)	- Automatic approval items: • advance payment less than $30,000, royalty rates less than 3%,license period less than 3 years • Total royalty less than $100,000	Machinery, shipbuilding, electrical goods, electronics, fabricated metal products, chemicals, textiles.
Second Step (April 1979)	- Automatic approval items: • Advance payment less than $50,000, royalty rate less than 10%, license period less than 10 years	All industries, except nuclear energy and defense industry.
Third Step (July 1980)	- Automatic approval items: royalty rate less 10%, license period less than 10 years	All industries.
Fourth Step (September 1982)	- Delegation of approval authority to the competent ministry	All industries.
Fifth Step (July 1984)	- Transition from the approval system to a reporting system	All industries.
Sixth Step (July 1986)	- Transfer of trademarks only permitted	All industries.
Seventh Step (July 1988)	- Delegation of approval authority to Class A foreign exchange banks under the Foreign Exchange Control Act, except in cases where the license period exceeds 3 years and the total royalty exceeds $100,000 or the royalty rate exceeds 2% (or initial payment exceeds $50,000)	All industries.

Source: Korea Industrial Technology Association, Surveys on Technology Imports, 1992, p.9.

As Table 2 shows, changes in technology import policy since 1978 have become more liberal. The openness that existed with respect to trade in consumer goods can be said to have been extended to capital goods with embodied technology. Table 3 shows the general structure of the financial assistance system. Clearly, without such financing, technology imports would be hampered. These policies are consistent with the general development strategies by stages of development as shown in Table 4.

Table 3: Financial Assistance System during the period of creating a high technology system

Government Subsidy	Direct subsidy to private firms or industrial technology research association who participate in special R&D project or industrial basic technology development project for 40-80% of R&D fund.
Loan by Policy Fund	Annual 5.0-10.5% interest rate loan on R&D and commercialization of new technology.
General Loan	Loan assistance to R&D and commercialization of new technology by Korea Development Bank, Small-Medium Firm Bank, and other banks. The same interest rates as bank loans.
Assistance to Venture Capital	Korea General Technology Fund (Inc.)
Technology Credit Guarantee	Technology Credit Guarantee Fund

Source: KIET, Program for Technology Banking System Improvement, 1992.

Table 4: Development strategies by stages of development for three decades leading to the creation of the high technology system

Period	Direction of Industrialization	Technological development strategy
1960s	1. Establishment of the foundation for industrialization. 2. Fostering of import-substitution industries. 3. Expansion of export-oriented light industries (mainly labor-intensive industries).	1. Expanding education in science and technology and training in skills. 2. Establishment of the legal and institutional basis for the promotion of science and technology. 3. Facilitating the importation of advanced technologies.
1970s	4. Enhancing the sophistication of industries and fostering the heavy and chemical industries. 5. Promotion of small- and medium- sized industries. 6. Strengthening the competitiveness of industries in the international market.	1. Upgrading technological and scientific training in priority areas. 2. Facilitating the adaptation and improvement of imported technologies through the establishment of research entities in private industries. 3. Strengthening industrial technology research and development capability.
1980s	7. Enhancing the quality of export goods. 8. Promotion of skill-intensive industries (high-tech industries). 9. Fostering of information industry	1. Providing the large-scale recruitment from abroad and training of highly qualified scientific and technological manpower. 2. Liberalization of technology imports. 3. Preparation for an information-oriented society.

Source: Excerpted from Khan (1997a).

It is interesting to note that as the Korean economy has grown it has progressively imported more technology. More than 75 per cent of all foreign technologies imported between 1962 and 1991 came from Japan and the U.S.

Table 5 shows TI (technology imports), FDI (Foreign Direct Investment) and capital goods imports by Korea. The growth in imported technology and capital goods is noticeable throughout the 1980s.

Table 5: TI, FDI, and Capital Goods Imports: 1962-91(upto the creation of high technology system)

year	**TI payment (A, $million)**	**TI case**	**FDI• (B, $ million)**	**FDI• case**	**A/B (%)**	**Capital Goods Imports (C, $million)**	**C/total imports (%)**
62-66	0.8	33	47.4	39	1.7	486.0	18.9
67-71	20.4	285	218.6	350	9.3	2668.0	30.8
72-76	96.5	434	879.4	851	11.0	8106.0	27.3
77	58.1	168	83.6	54	69.5	3008.1	27.8
78	85.1	297	149.4	51	57.0	5080.3	33.9
79	93.9	291	191.3	55	49.1	6314.0	31.0
80	107.2	222	143.1	40	74.9	5125.0	23.0
81	107.1	247	153.1	44	70.0	6158.2	23.6
82	115.7	308	189.0	56	61.2	6232.7	25.7
83	149.5	362	269.4	75	55.5	7814.7	29.8
84	213.2	437	422.3	104	50.5	10106.3	33.0
85	295.5	454	532.1	127	55.4	11078.9	35.6
86	411.0	517	354.7	203	115.9	11340.2	35.9
87	523.7	637	1063.3	362	49.3	14552.4	35.5
88	676.3	751	1282.7	342	52.7	19033.4	36.7
89	888.6	763	1090.2	336	81.5	22370.3	36.4
90	1087.0	738	802.5	296	135.5	25451.3	36.4
91	1183.8	592	1396.0	287	84.8	30092.0	36.9
total	6109.3	7526	9268.8	3672	65.9	195016.0	33.3
ratio (%)	(3.1)		(4.8)			(100)	

- approval basis.

Sources: Korea Industrial Technology Association, Major Indicators of Industrial Technology, 1992; Ministry of Finance, The Status of Foreign Direct Investment, Dec. 1991; The Korean Statistical Association, Major Statistics of Korean Economy, 1992.

The adoption and diffusion of technology (imported or otherwise acquired), inevitably requires various lengths of time. On the demand side, the profitability of imported technology must be a major factor. However direct measures are impossible to get. A proxy that follows the strategy of Khan (1997a) is obtained by considering the profitability of the large and medium sized enterprises which are assumed to use imported technology. Adaptabilities of technologies also matter. The extent to which imported technologies can be adapted to domestic needs and circumstances also depends mainly on the technological capabilities of the host firms. Here, too, the large- and medium- sized enterprises will generally have a better chance of adapting the foreign technology.

It is possible to collect the relevant information and to organize this information in an economy wide technology systems matrix (technically called SAM-TECH) format. Looking at the information organized as a SAM-TECH as well as closely within its components results in the following observations:

1. With the exception of heavy industries, large and medium firms import relatively new technologies. This is consistent with Khan's (1997a) finding that the production functions in different firm sizes within the same industry differ.
2. Large size firms also seem to have greater bargaining power. They have shorter waiting periods for adoption of foreign technology.
3. Industries with competitive structures import technology at a slower rate than those which are oligopolistic.
4. In its acquisition, the price of new technology seems less of a determinant than the perceived needs of the firm. In other words demand for technology imports has been inelastic in many cases.

Given the prevalence of foreign technology in a number of sectors, one should expect more productivity increase in these sectors than in the other sectors with less than state-of-the-art technology. On the whole, this does turn out to be the case. The average for the foreign technology-intensive sectors turns out to be 2.8 per cent TFP growth annually from 1980 to 1994.

If imported technology were the only source of technology for the modern technology system, then the question of whether Korea has a POLIS could be settled immediately. The short answer would be that indeed it has no POLIS. However, the policies of the Korean government and the efforts of large Korean firms to create an innovation system cannot be passed over in silence. In the next section, the Korean innovation system is examined.

Learning to Innovate: Efforts to Build A Korean POLIS

Larry Westphal, Howard Pack, Sherman Robinson and Hollis Chenery, among others, have emphasized the role of industrial policy in an export-led economy like South Korea. According to Westphal (1990):

> Korea provides an illuminating case of state intervention to promote economic development. Like many other third world governments, Korea's government has selectively intervened to affect the allocation of resources among industrial activities. It has also used similar policies: taxes and subsidies, credit rationing, various kinds of licensing, and the creation of public enterprises...but these policies have been applied in the context of a radically different development strategy, one of export-led industrialization.[6]

If one follows a Schumpeterian approach to technology creation as a cascade of interlinked systemic activities, the possibilities for economies of scale and scope leading to the establishment of a POLIS arise out of the conjunction of a market system open to the world economy and selective interventions. Promotion of targeted infant industries has been part of this strategy of selective interventions in Korea. Examples include cement, fertilizer and petroleum refining in the 1960s. These were followed by steel and petrochemicals. In the late 1970s, shipbuilding, other chemicals, capital goods and durable consumer goods appeared on the list. More recently, electronic and information technologies are being promoted. Do these industries innovate? Even if they individually do innovate, do the industrial, governmental and social institutions connected to the innovation process add up to an innovation system? Furthermore is the innovation system, if it exists, characterized by positive feedbacks?

One quantitative indicator of the possibility of an innovation system would be the trend in R&D. Table 6 shows the major R&D indicators in Korea. Between 1965 and 1990 the expenditures increased more than 500 times. However the major take off has really been since the mid-1980s. Noticeable also is the reversal of the roles of public and private sectors. In 1990 the private sector provided 84 per cent of R&D funds.

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[6] Larry Westphal (1990), 'Industrial Policy in an Export-Propelled Economy: Lessons from South Korea's Experience', The Journal of Economic Perspectives (summer), 41. See also, Khan (1985,1997) and Kim (1989, 1997).

Table 6: Major R&D Indicators in Korea during the key phases of creating the modern and ultimately the high technology system 1965-1990

	1965	1975	1980	1985	1990
R&D expenditure ($ Million)	8	88	321	1298	4481
Funds from government (A)	7.2	59	186	247	717
Funds from private sources (B)	0.8	29	135	1051	3764
A:B	90:10	67:33	52:48	19:81	16:84
R&D/Manufacturing sales (%)	n.a.	0.35	0.65	1.51	2.07
GNP ($Million)	2759	20,952	55,345	87,703	234,607
R&D/GNP (%)	0.29	0.42	0.58	1.48	1.91
R&D researchers (persons)	2765	10,275	18,434	41,473	70,503
Research institutes	n.a.	5308	4598	7154	10,434
Universities	n.a.	2312	8695	14,935	21,332
Companies	n.a.	2655	5141	18,996	38,737
R&D researchers per 10,000 pop.	1.0	2.9	4.8	10.1	16.4

Source: Ministry of Science and Technology, Report on the Survey of Research and Development in Science and Technology, various issues;

The number of research personnel is also an important indicator of the possibilities of a POLIS. In the case of Korea, the number of core scientists increased by more than 30 times between 1965 and 1990. Here again, companies and universities are now the first and second largest employers of researchers, respectively.

Another important indicator of an innovation system is the number of patents. In the late 1980s and early 1990s the number of Korean patents grew, on the average, at a rate of 17.1 per cent (see table 7). In absolute terms, however, Korea seems to be still far behind the advanced industrial nations.

Table 7: Trends of Industrial Property Rights Applied by Korean and Foreign Nationals during the crucial phase of creating a POLIS

(Unit: case, %)

	1986	1989	1990	1991	Average Growth Rate (1986-91)
Patents	12,759	23,315	25,820	28,132	17.1
Utility Models	22,401	21,530	22,654	25,895	2.9
Industrial Designs	18,731	18,196	18,769	20,097	1.4
Trade Marks	28,031	39,832	46,826	46,612	10.7
TOTAL	81,922	102,873	114,069	120,736	8.1
Korean Nat'ls	63,256	68,300	81,713	90,659	7.5
Foreign Nat'ls	18,666	27,271	32,356	30,077	10.0

Source: The Office of Patents Administration, Patents Annals, various issues.

One special feature of the Korean industrial system in general and its innovation system in particular, is the role played by its **chaebols**, the big business conglomerates in developing and improving industrial technologies. With a large endowment of capital and modern complex organizational structure the chaebol can recruit the best human resources, identify and purchase the best foreign technology and obtain preferential financing. They have also established R&D and technical training facilities recognizing the importance of in-house R&D capability.

The government established the Ministry of Science and Technology (MOST) in the 1960s. It also has initiated a long-term science and technology development plan. Most government ministries and bureaucratic strata have been involved in one way or another in formulating and implementing the science and technology policies. The government has also pursued a scientific and technical human resources management policy.

In the late 1960s, Kwahakwha Undong or the Science Movement was supported by MOST. The creation of a university system has certainly led to an increase in the stock and flow of human capital. However, Korea still has a long way to go before it can claim to have created a world class research university system.

At the microeconomic level R&D capacity building by a firm can be illustrated by discussing the example of Samsung Electronics Company (SEC).

SEC is Korea's largest integrated electronics company. Table 8 shows the diverse product lines of SEC.

Table 8: Major Product Line-up of SEC during the creation of the Korean POLIS

Business Sector	Product Line
Audio and Video Business	TV, LCD Projector, VCR, Camcorder, Component Audio, CDP, MD, DCC, LDP, MOD, CD-I, CD-ROM
Consumer Electronics Business	Refrigerator, Microwave Oven, Air Conditioner, Washing Machine, Vacuum Cleaner
Computer System Business	Mini Computer, Micro Computer, Desk-Top PC, Lap-Top/Note PC, Pen Base PC, Palm-Top PC, Network System, Work Station, Optical Filing System, Teleconference System, CTS, BAS
Telecommunication System Business	TDX, Modem, MUX, PAD, Facsimile, Typewriter, Copier, Key Phone, Pager, Car Phone, Hand-held Phone, Optical Communication System, Optical Fiber
Memory Devices Business	DRAM, SRAM, EEPROM, MASK ROM, Specialty Memory, TPH, TFT, LCD, CIS
Micro Devices Business	Discrete, MOSIC, Linear IC, ASIC, Logic IC, Micro Component, DSP

Source: Public Relations Office, Samsung Electronics, Creativity and Innovation (1993), p. 47.

In the semi-conductor field, Samsung developed 64K DRAMs in 1983. In 1990 it shared in the making of 16M DRAM. SEC also exports an electronic switching system (Time Division Exchange or TDX) to other LDCs. It also manufactures digital, cellular and satellite transmission systems. It is also active in fiber-optic communication systems. SEC offers a full line of products in the micro-computer field. Perhaps better known among consumers is the line of consumer electronics products of SEC ranging from TV to microwave ovens.

SEC has a three tiered R&D system shown in table 9. Samsung Advanced Institute of Technology (SAIT) carries out research into basic or core technologies. Application technology and mid-term projects are the responsibility of the research centers associated with SEC's four business sectors. Finally, on the production technology side research teams attached to each division unit work closely with production and marketing people to make new or improved products.

Table 9: SEC's Three-tiered R&D System

	Samsung Electronic Company		Samsung Advanced Institute of technology
	Integrated Research Centers	Research Team and Design Office attached to Business Sector	
ROLE	Establishment of technological foundation for growth of company Strengthening of Cooperation with SAIT	Maximization of company's profit	Establishment of technological foundation for the growth of the Group Technical supports to affiliate companies
RESEARCH AREA	New products development and commercialization on a short- and mid-term basis	Commercialization of new products on a short-term basis Diversification of models, improvement of functions and cost reduction of existing products	Development of new products on a mid- and long-term basis Development of core technologies, bottle-neck technologies, and new materials and parts

Source: Twenty Years History of SEC, 837.

The discussion so far shows the strengths and limitations of both the standard macro and micro approaches in addressing the question posed at the beginning of this paper. At the macro level, statistical results may overstate or understate the overall innovative capability. At the same time the results on the whole warn against a casual optimism regarding East Asian growth in general and Korea in particular. The micro considerations show that in contrast to macro-pessimism some companies such as SEC do have considerable innovative capabilities.[7] However, it is not obvious if the SEC experience is generalizable for Korea as a whole or even a few sectors. Thus, there is a great gap at the current stage of research on ICT. Many more sectoral and firm level studies are necessary before firm conclusions could be drawn.

In terms of ICT development, ownership of personal computers and the number of internet hosts as well as telecommunications facilities increased several folds between 1993 and 1998(Tschang 2000). For example, in1998, Korea had a total of 7,252,000 personal computers, or on the average 157 PCs per thousand people. This put S. Korea ahead of most Asian economies except for Japan and Singapore. Korea also had 4,015 internet hosts per million people, much further along the way of building a digital economy than the rest of developing Asia.

At the microeconomic, firm level the emergence of the so-called “venture companies” in the ICT sectors could challenge the hegemony of the chaebols.According to the Korea Venture Business Association, there will be about 40,000 such companies by 2005. The Ministry of Information and Communications reported 252 info-tech start up firms for 1999 with a total revenue of 4.9 trillion won. The overall size of the internet economy is estimated as 8 trillion won or two per cent of GDP.

The chaebols are experiencing some migration of human resource to some of these start up companies. In response, leading chaebols such as the Lucky Goldstar (LG)and Samsung have initiated strategic moves. These range from incentive pay via stock options etc. to acquiring stakes in ICT companies. In 1999, LG acquired a majority stake in Dacom, a leading ISP and the second largest telecommunications company. SEC has established a strategic alliance with Yahoo! Inc. It has also created a special team in order to identify promising entrepreneurs and to assist them in bringing their products to the market. Samsung now has an Internet Shopping Division. More generally, as a business strategy, the chaebols are establishing incubators to compete with the upstart newcomers. In the year 2000, Samsung had 9 incubators with US$ 17.6 million in start up funds.

However, graduating out of the ranks of developing countries and joining the OECD involved rapid liberalization of the Korean economy. According to

[7] In this connection Kim (1997) documents for several industries as well as for the e3conomy as a whole, the growth in technological capabilities of Korea.

some observers (e.g., Chang 1998). This was directly responsible for Korea's being caught in the Asian financial crisis. Even if one disagrees with the exact causes, there is no doubt that the massive deflation and corporate bankruptcies put Korea's ability to transform itself into a digital knowledge- based economy into question.[8]

Another relevant development for Korea in the international dimension was its signing the WTO agreements. This led to trade liberalization that made technological imports and exports more free and therefore, theoretically, would have resulted in net welfare gain. However, the cases brought against Korea through the dispute settlement mechanism and other bilateral actions, combined with the impacts of the financial crisis, seem to have diminished that hope in the short run.

In the long run, the provisions of TRIPs are the most important for the ICT sectors.[9] The TRIPs agreement with its seven parts and. seventy three articles is the most important international attempt to harmonize intelectual property rights(IPRs) globally. The coverage is intended to be comprehensive and contains, for example, integrated circuits designs, biotechnology and software protection in addition to the standard copyright, trademarks, patents and other related areas.There are enforcement provisions requiring civil and criminal measures and border enforcements that are likely to be costly for countries like Korea with ambition to build a POLIS through ICT sectors innovations. Institutionally, Korea's entry into the WTO in 1994 also meant agreeing to be monitored and reviewed by the TRIPs council and accepting the TRIPs dispute settlement mechanisms.The long run impacts of adhering to all these provisions on Korean digital economy are not clear. In the short run, importing technology would have been easier; but since the Asian crisis many firms have suffered from foreign exchange shortage. At the same time, the foreign currency payments of licensing fee and other IPRs-related expenses have posed additional foreign exchange burdens on the innovating firms.

[8] Consideration of such issues highlight the strengths and limits of the official international views of Korea's transition to knowledge-based economy. See for example Dahlman and Andersson (2000) study for OECD/ World Bank.

[9] See Maskus (2000), Lai (1997) and Khan (2001c)

Conclusions:

The digital age has brought new opportunities for the developing economies by presenting some of them with the prospects for leapfrogging. By investing strategically in physical, intellectual and other forms of human capital these economies may be able to forge a path not only in the ICT sectors, but also create innovation systems of their own. Under the emerging globally competitive market environment this will be the best way to compete dynamically. However, creating comparative advantage in this way requires capabilities that many developing countries lack at the moment. Without a mix of openness and strong governance, it is unlikely that even a start can be made.

The case study of Korea presented in this paper is instructive in several ways from this perspective. A strong state under Park Chung-hee, Korea was able to go through several stages of modernization during the 70s and 80s. It created a solid infrastructure and started to generate knowledge-based production and services in the 90s. However, the mix of domestic policy mistakes and exogenous developments in the second half of the decade resulted in the most serious crisis in the Korean economy since the second world war. The economy is yet to recover from the damage done to its capacity to develop dynamic innovative capability.[10]

Many developing countries seem committed to the path of ICT development. What seem to be lacking are the awareness of some of the pitfalls and the need for both economic resources and institution building. Strategically, developing world class education and training facilities on a regional basis and sharing the burden of ICT sectors development through various regional cooperation schemes may be the best alternative. Therefore, the time may have come to discuss seriously and practically how to develop POLIS and ICT, not for individual national economies, but for entire developing regions in a supranational manner.

[10] In this connection the observations made by Chang (2001) in Pulling Up the Ladder are particularly germane. The current neoliberal international environment may make such 'technological recovery' and restart most difficult, if not impossible. This is another reason for considering regional cooperation and institution building seriously.

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Appendix: formal models of POLIS---existence proofs

In order to give the reader some idea of the problem of formalizing complex technological systems, in this section, I present a 'simple' non-linear model embodying distinct technological systems. The model is presented as a Social Accounting Matrix representation of the socio-economic system that was first mentioned in an abstract form earlier. The key distinction here is the explicitly non-linear nature of the functional relationships. The key theorem shows the existence of equilibrium. It is important to underline that the equilibrium is not necessarily unique. Some further considerations (using Herbert Amann's theorems on fixed points of increasing maps) show that multiple equilibria are the natural outcomes in such models. There would seem to be some role for domestic policy in guiding the economy to a particular equilibrium among many.

As mentioned before, the virtue of an economy-wide approach to technology systems is the embodiment of various inter-sectoral linkages. In a SAM, such linkages are mappings from one set of accounts to another. If there are "n" production activities then there are mappings connecting each activity with as many relevant other accounts (including other production activities) as possible. In terms of technology systems, the production activities can be broken down into a production (sub-) system and a set of innovative activities. In practice, this presents considerable difficulties of classification and empirical estimation. But conceptually the distinction has been made clear.

One major component of the entire innovation system is, of course, the expenditures on R&D. In the SAM presented later, this can appear either as an aggregate expenditure along the column labeled R&D, or as a set of disaggregated expenditures.[i] In the latter case these may be specified according to productive activities (e.g., construction, electrical equipment, the "digital sectors" etc.) or by institutions (e.g., private R&D expenditures, government R&D expenditures, etc.). It should be emphasized that the dynamic effects of R&D on the economy can be captured only in a series of such SAMs over time. This approach is still at the conceptual stage, but appears to be quite appealing. One can contrast the possible policy experiments that can be undertaken within such a framework with the apparently ad hoc science and technology policies in many developing countries. In particular, the impact over time of a POLIS can be traced by building and maintaining such SAMs. Even without a complete SAM, partial (equilibrium or disequilibrium) analysis can be carried out that can approximate the system-wide results.[ii]

In the following model, the main purpose is to establish a multiplicity of equilibria when the innovation system exhibits a non-linear relationship between parts of the socio-economic system. Such a relationship may obtain simply because of the existence of increasing returns to scale in production. Other types of non-linearities may also be present. However, the non-linearities in the production relations are the most relevant ones from the perspective of POLIS. Among other things this creates the possibility of moving from a technologically stagnant equilibrium to an equilibrium that makes a POLIS possible.

Choice of new technology in a developing country is affected by research and development in at least three different ways. Such a country can attempt to develop new technology through R&D, as mentioned previously. This ultimately requires a positive feedback loop innovation system in order to be self-sustaining. Another alternative is to adapt existing technology. This too requires a production system geared towards innovation in a limited way. A third alternative is to import technology or to acquire it through attracting foreign direct investment. In practice, all these different forms may be combined.

The abstract model below may be thought of embodying all these different possibilities. However, the first option requires, among other things, a presence of multiple equilibria. In a unique equilibrium world the competitive equilibrium (under the assumption of complete markets) will always be the most efficient one. The presence of increasing returns usually destroys such competitive conditions.

We begin with a number of productive activities reflecting the existing technological structure. We also incorporate the possibility of R&D as a separate productive activity. At the level of abstraction we are working, it is always possible to break R&D down into as many finite components as we want. The key relationship in this context is that between the endogenous accounts (usually, production activities, factors and households) and the exogenous ones. It is this relationship that is posited to be non-linear and this together with some assumptions on the mathematical space can lead to the existence of multiple equilibria, as shown below. We now turn to the formal part of the analysis. The analysis is carried out in abstract function spaces. In the first part the relevant space is a vector lattice over a real field R. In the second part some results on ordered Banach space are discussed.

I. The Model on a Lattice

Define X as a vector lattice over a subring M of the real field R.

Let $x_+ = \{x \mid x \in X, x \geq 0\}$

A non-linear mapping N is defined such that $N : X_+ \rightarrow X_+, N_0 = 0$. Given a vector of exogenous variables d, the following non-linear mapping describes a simultaneous non-linear equations model of an economy, E:

$x = Nx + d$

(1)

for a given $d \in X_+$.

This non-linear system represents a socio-economic system of the type described previously. In order to specify the model further, the following assumptions are necessary.

1. X is order complete
2. N is an isotone mapping
3. $\exists \hat{x} \in$ such that $\hat{x} \geq N\hat{x} + d$

In terms of the economics of the model, the non-linear mapping from the space of inputs to the space of the outputs allows for non-constant returns to scale and technical progress over time. The 3 assumptions are minimally necessary for the existence of an equilibrium. Assumption 3, in particular ensures that there is some level of output vector which can be produced given the technical production conditions and demand structure.

Existence of Multiple Equilibria:

Theorem: Under the assumptions 1 - 3, there exists $x^* \in X_+$ so that x^* is a solution of

$x = Nx + d$

Proof: Consider the interval $[0, x] = \{\hat{x} \mid \hat{x} \in X_+, 0 \leq \hat{x} \leq x\}$ where $\hat{x}$ is defined as in assumption 3. Take a mapping F.

$F : x \in X_+ \to Nx + d$

F is isotone and maps $[0, x]$ into itself.

Define a set $D \equiv \{x \mid x \in [0, x], x \geq Fx\}$.

By assumption 3, D is non-empty.

We now show $x^* \equiv \inf D$ is a solution to $x = Nx + d$. $x^* \equiv \inf D$; therefore $x^* \leq x, \forall x \in D$. F is isotone; therefore $Fx^* \leq Fx \leq x$ for each $x \in D$ implying.

$$Fx^* \leq x^*$$

From (2) we have $F(Fx^*) \leq Fx^*$. Thus $Fx^* \in D$; hence $x^* \equiv \inf D \leq Fx^*$ so, $Fx^* \leq x^* \leq Fx^*$. Therefore $x^* = Fx^*$.

This is an application of Tarski's and Birkhoff's theorem. The key feature to note here is that the equilibrium is not necessarily unique. It should also be noted that under additional assumptions on space X and the mapping N the computation of a fixed point can be done by standard methods (e.g. Ortega and Rheinboldt).

II. Multiple Equilibria on Banach Space:

In this section the results for multiple equilibria are extended to functionals on Banach Space. We can define the model again for monotone iterations, this time on a non-empty subset of an ordered Banach space X. The mapping $f : X \to X$ is called compact if it is continuous and if $f(x)$ is relatively compact. The map f is called completely continuous if f is continuous and maps bounded subsets of X into compact sets. Let X be a non-empty subset of some ordered set Y. A fixed point x of a map $N : X \to X$ is called minimal (maximal) if every fixed point y of N in X satisfies

$x \leq y(y \leq x)$

Theorem: Let (E, P) be an ordered Banach space and let D be a subset of E. Suppose that $f : D \to E$ is an increasing map which is compact on every order interval in D. If there exist $y,\ \hat{y} \in D$ with $y \leq \hat{y}$ such that $y \leq f(y)$ and $f(\hat{y}) \leq \hat{y}$, then f has a minimal fixed point x. Moreover, $x \leq y$ and $x = \lim F^k(y)$. That is, the minimal fixed point can be computed iteratively by means of the iteration scheme

$$x_0 = y$$

$$x_{k+1} = f(x_k) \qquad k = 0,1,2,....$$

Moreover, the sequence (x_k) is increasing.

Proof: Since f is increasing, the hypotheses imply that f maps the order interval $[\bar{y}, y]$ into itself. Consequently, the sequence (x_k) is well-defined and, since it is contained in $f[\bar{y}, y]$, it is relatively compact. Hence it has at least one limit point. By induction, it is easily seen that the sequence (x_k) is increasing. This implies that it has exactly one limit point $\bar{x}$ and that the whole sequence converges to $\bar{x}$. Since f is continuous, $\bar{x}$ is a fixed point of f. If x is an arbitrary fixed point in D such that $x \geq \bar{y}$, then, by replacing y by x in the above argument, it follows that $\bar{x} \leq x$. Hence $\bar{x}$ is the minimal fixed point of f in $(\bar{y}+P)\cap D$. It should be observed that we do not claim that there exists a minimal fixed point of f in D.

We can also show that if $F : x \in X_+ \to Nx + d$ is an intersecting compact map in a non-empty order interval $[x, \hat{x}]$ and $x \leq Fx$ and $F\hat{x} \leq \hat{x}$ then F has a minimal fixed point x^* and a maximal fixed point x^{**}. Moreover, $x^* = \lim F^k(x)$ and $x^{**} = \lim F^k(\hat{x})$. The first of the above sequences is increasing and the second is decreasing.

The above results are applications and extensions of fixed point theorems for increasing maps on abstract spaces due to Herbert Amann (1976). It is intriguing that they find such natural applications in economics with evolving technology systems and non-constant returns to scale. Although those theorems provide some structure for the equilibria in the socio-economic structure with evolving technology systems, it is not specified a priori which equilibrium will be reached. The problem of equilibrium selection thus remains open. The idea behind POLIS can now be stated more formally. It is to reach a sequence of equilibria so that the maximal fixed points that are attainable are in fact reached through a combination of market forces and policy maneuvers over time. It is also to be understood that path-dependence of technology would rule out certain equilibria in the future. Thus initial choices of technologies can matter crucially at times.This highlights the need for choosing the appropriate types of ICTs and creating complementary human and knowledge capital right from the beginning.

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i. Both types of specifications are possible in principle. In practice, as in the case of South Korea, the availability of data will often determine what type of specification will be used.

ii. If SAMs are available at regular intervals (Indonesia is one such country), then models with flexible prices, different closure rules, etc., can be constructed over time.