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Innovation and Growth:

A Schumpeterian Model of Innovation

Applied to Taiwan

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Abstract

Following Schumpeter we assume that innovation in specific firms, or groups of firms, can have economy-wide effects. Models based on this idea can be shown to have multiple equilibria. The idea of a positive feedback loop innovation system or POLIS is formalized by picking an appropriate sequence of equilibria over time. It is shown that POLIS has empirical relevance by applying the formal model to an actual economy. The 1997-98 financial crisis in many Asian countries, most notably South Korea, seemed to have reversed the conventional wisdom regarding the East Asian miracle". This paper applies the concept of a POLIS to the case of Taiwan to show that at least in this case, neither the view that the miracle was a mirage nor the view that the growth was a result of factor accumulation only is correct. Ultimately technological transformation — in particular the creation of a positive feedback loop innovation system is what makes the difference between sustained growth and gradual or sudden decline. Although various problems remain in both the real and the financial sectors, the successes of Taiwan in building the preconditions for an innovation system are worth examining. Upon careful examination of Taiwan's system of innovation within the above Schumpeterian model it is found that Taiwan has a fighting chance of building a POLIS in the near future. An interesting feature of the Taiwan POLIS is the modular organizational architecture of some of the high technology firms in Hsinchu science-based industrial park and other centers.

1. Introduction

How can we evaluate the industrialization experience of East Asian economies like Taiwan from a long-term growth perspective? Many have questioned the role of technical progress in these countries. Lau and his co-authors as well as Young in particular have been unable to find any role for technical progress in explaining the growth rate. Is this really the case for an economy like Taiwan? The answer to this question, it will be seen, depends at least partly on methodology. In this paper an economy-wide modeling approach consistent with Schumpeter’s emphasis on creative destruction is followed. It turns out that this allows one to examine aspects of the relations between growth and innovation that the aggregate meta-production function approach and the standard growth accounting procedures fail to observe directly at an appropriate level of dissagregation.

In Capitalism, Socialism, Democracy Schumpeter characterized creative destruction in the following way:

> 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]

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1 Schumpeter (1942) p. 83

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, 1946). Aghion and Howitt (1992) have proposed a model of creative destruction by treating the innovation process as a rivalry following the patent-race literature. Iwai (1984a,b; 1991;200;2001) explores the dynamics of Scumpeterian models in a variety of ways. A macroeconomic model of growth, consistent with innovations at the micro-level through productive investments, was presented in Scott (1989)---particularly in chapters 5 to 9--- with much necessary detail and patient elaboration. The present work is very much in that spirit, with the focus being more explicitly on a disaggregated"micro-structure" at the sectoral and groups of firm level. Theoretically, both firms and groups of firms can engage in innovation with potential macroeconomic impact; but empirically, for Taiwan the focus here will be on groups of firms in specific sectors.

The present paper assumes following Schumpeter, Scott, and Aghion and Howitt, that innovation in specific firms, or groups of firms can have economy-wide effects. The expected growth rate of the economy depends, among other things, on the economy-wide amount of research[2]; but the process of this growth, precisely because research leads to the development of new products and processes, is characterized by creative destruction.

[2] Not just research, but other factors such as overall investment, complementary human capital formation etc. are also important. In the multisectoral model of POLIS considered later, both R&D and other factors can be included in principle. However, R&D in a broad sense is still a necessary condition for innovation that can have economy-wide impact. But historically, there are stages where, as in Taiwan, an economy begins with very little R&D, goes through output expansion in an export promotion regime, and then gradually begins

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 this paper, an attempt in this direction is made by endowing production functions and correspondences with some of these features. 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. [3]

Section 2 presents the idea of technological complexity and two relevant models motivated by this discussion. The existence and characterization of multiple equilibria show the possibility of creating a positive feedback loop innovation system (POLIS) in a model economy on an abstract function space. Section 3 is an initial attempt to apply the abstract theorems to a real world economy through a series of linear approximations. The economy chosen for this purpose is that of Taiwan. As mentioned before, recent controversy between contending perspectives on technological change makes Taiwan an interesting case. Potentially, a modeling approach embodying POLIS offers an alternative to the standard growth accounting approach to assessing the presence and impact of

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imitative and innovative R&D processes. I am grateful to an anonymous referee for suggesting clarifications regarding the complex relationship between R&D and growth.

[3] One interesting aspect in proceeding as I do in showing the theoretical possibility of constructing a temporal sequence of equilibria(fixed points) is that it not only preserves the spirit of Kaldor's critique of neoclassical equilibrium analysis, but also allows for increasing returns to play the kind of central role that Kaldor had intended. At the same time, it eschews the problems of a full-fledged disequilibrium analysis

technical change. The results presented here are preliminary but promising enough to establish the empirical relevance of the alternative models of growth through creative destruction.

Thus, this paper attempts to offer a new perspective on the productivity debate in East Asia by going beyond the growth accounting or production function fitting approaches used by the participants. It can be seen as belonging to attempts, most notably by Nelson and Pack (1996), to eschew the conceptual problems arising from the standard methodologies. It also begins from the idea that while technology is the key issue, for judging performances of entire economies we should begin with consideration of systems of technologies (James and Khan, 1997; Stewart 1977) and ask ourselves how modern systems of technology can replace more traditional systems during the process of development. We should then ask ourselves if East Asian economies such as Taiwan have in fact made this transition. This paper argues that indeed a transition has been made by Taiwan in a limited but analytically and empirically relevant fashion and goes further in investigating how permanent this transition is likely to be. In this sense also, the approach and conclusions are consistent with what Nelson and Pack call the assimilationist interpretation of the East Asian growth.

2. Technological Complexity and Models of POLIS

2.A. Technological Systems as Complex Structures

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which can become intractable very quickly in the context of a complex, multi-sectoral economic model. For an evolution of Kaldor's own thinking on these and related issue see the theoretical essays in Kaldor(1978).

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.[4]

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.[5] 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 we will see soon, 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. In general, such a sequence also involves

[4] The role of government, in general, is both important and complex. Simple etatist or, at the other extreme, the neoliberal doctrines can be misleading. For a nuanced and detailed empirical investigation at the institutional level for Taiwan see Wade(1990)

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, 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.

2.B. A 'Simple' Non-linear Model of Complexity[6]

In order to give the reader some 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 of

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5 In this context, especially with respect to the building up of technological capabilities Lall has been a pioneer. See Lall (2001) for an up-to-date discussion.

6 Khan (1997c and forthcoming, 1998) contains technical discussion and proofs of Existence of multiple equilibria for an entire class of models of this type.

complexity and increasing returns show that multiple equilibria are indeed the natural outcomes in such models. Thus, there would seem to be some role for domestic policy in guiding the economy to a particular equilibrium among many.

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. 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.

One major component of the entire innovation system is, of course, the expenditures on R&D. In the SAM for Taiwan used here, this can appear either as an aggregate expenditure along the column labeled R&D, or as a set of disaggregated expenditures.[7] In the latter case these may be specified according to productive activities (e.g., construction, electrical equipment, 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

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[7] Both types of specifications are possible in principle. In practice, as in the case of South South Korea (Khan 1998), the availability of data will often determine what type of specification will be used.

countries. In particular, the impact over time of a POLIS can be traced by building and maintaining such SAMs.

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 embodies all these different possibilities. However, the first option requires, among other things, a presence of multiple equilibria.[8] 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. This activities are defined on the input-output subspace of the general and abstract mathematical space X. In addition to the values of inputs and outputs, points in this space could also represent household and other institutional income and expenditure accounts. We also incorporate the possibility

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[8] This could be considered a modern mathematical representation of Schumpeter's idea that perfectly competitive firms were singularly unmotivated to innovate.

of R&D as a separate productive activity. Formally, 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 and technologies, 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 relevant mathematical space can lead to the existence of multiple equilibria.

Although the existence theorems for these multisectoral models provide some structure for the equilibria as sequences of fixed points 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 a POLIS can now be stated somewhat more formally. It is to reach a sequence of equilibria so that in the non-linear models of the entire economy 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.

2. C. 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 s.t. N: $X_+ \rightarrow X_+$, $N_O = 0$. Given a vector of exogenous variables d, the following non-linear mapping describes a simultaneous non-linear equations model of an economy, E:

$$x = Nx + d \qquad (1)$$

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. $\exists x^* \in X$ s. t. $x^* \geq N x^* + d$

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

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

F is isotone and maps $[0, \hat{x}]$ into itself.

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

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 $x^* = \inf D \leq Fx^*$ so, $Fx^* \leq x^* \leq Fx^*$. Therefore $x^* = Fx^*$.

This is an application of Tarski and Birkhoff 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).

2.D. 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: $X \rightarrow X$ 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: $X \rightarrow X$ is called minimal (maximal) if every fixed point y of N in X satisfies

$x \le y$ ($y \le x$).

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

$x_0 = y$

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

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 $x \ge \bar{y}$, then, by replacing y by x in the above argument, it follows that $\bar{x} \le x$. 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: $x \in X_+ \rightarrow Nx + d$ is an intersecting compact map in a non-empty order interval $[x, \bar{x}]$ and $x \le F\bar{x}$ and $Fx \le x$ then F has a minimal fixed point x* and a maximal fixed point x**. Moreover, $x^* = \lim F^k(x)$ and $x^{**} = \lim F^k(x)$. The first of the above sequences is increasing and the second is decreasing.

2.E. Translating the Non-linear Model

These models, interpreted with due caution, demonstrate the theoretical possibility for a (Schumpeterian) positive feedback loop innovation system. However, it is far from transparent how such a system can be represented in actuality. In the next section, an attempt will be made to first define precisely what technological systems are from an empirical standpoint for a specific NIE such as South Korea or Taiwan. Based on this, an operational way of capturing such systems empirically will be presented. The vehicle chosen for such a representation is the Social Accounting Matrix or SAM. SAMs are elaborate quantitative constructions based on social and economic data that can show the economy at a point in time with the necessary detail. How do we depict different technology systems in a SAM? How can we show the evolution of a technology system in such a construction? How do we incorporate R&D and other factors of significance in understanding innovation in a SAM? These are some of the questions we need to raise. At the end, through a series of approximations the non-linearities and complexities of an innovation system can be approached meaningfully by using empirical SAMs for particular countries.[9]

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9 Khan (1997c, and 1998) offers a technical description of the exact empirical methods and computational details.

3. Taiwan: Building a POLIS

In this section an East Asian “miracle” country--Taiwan--is studied with the help of the Schumpeterian model developed above. The history of development of Taiwan shows a greater reliance on direct foreign investment, more direct government ownership of enterprises and the greater role of small and medium enterprises in the manufacturing sector than the other large East Asian ”miracle” economy, South Korea.

The early development policy in Taiwan was aimed at increasing agricultural output and developing an infrastructure. Light manufacturing industries were also promoted. Import-substitution policy was pursued till the mid-sixties. U.S. foreign aid played a crucial role in financing imports and early capital formation.

The switch to a regime of export promotion took place in the mid-sixties, as in the case of South Korea. Initially exports of the light manufacturing industries such as textiles and consumer electronics were stimulated. At the same time, Taiwan pursued a long-term strategy of building a more complex industrial structure including steel, petrochemicals, machine tools and electronic equipment.

The new outward-looking strategy was accompanied by a series of financial and fiscal measures to facilitate export financing and to help establish export processing zones. From the beginning, Taiwan made a special effort to promote high technology sectors through publicly funded research laboratories.[10] Later, an industrial park was created specifically for high technology industries.

In the wake of the 1973 oil crisis a policy of major infrastructure projects was introduced. Subsequently, capital goods producing sectors were promoted heavily. As a result Taiwan broadened its export base to include machinery and related equipment.

The second oil shock also led to substantial changes in Taiwan's industrial policies. Overcapacity and the lack of competitiveness in a number of firms were addressed by a strategy of scaling-down industrialization plans. Strategically selected firms, however, were aided by special grants and loans. Foreign investment in capital-intensive sectors was encouraged further in order to effect a transfer of technology and knowledge.

The new orientation in the 1980s has meant an emphasis on high technology and skill-intensive activities. Specifically, three areas--information, electronics, and machinery--were identified as strategic. Precision instruments, machine tools, VCRs, telecommunications equipment and computers are products that were targeted for special treatment (Liu 1993).

[10] Ofcourse, this 'government laboratory view' of Taiwan's technological capability should not be overdone. Many pioneering firms, as discussed shortly, acquired their technology through sub-contracting, joint ventures, licensing etc.. Government programmes seem to have been valuable only in selected areas of R&D. But even that is no mean achievement.

Inspite of the openness, flexibility and strategic vision of the Taiwanese economy there may be problems in creating a POLIS. The predominance of small firms may be a handicap where large R&D expenditures may be necessary for high-tech ventures. The strategic complementarity of R&D and skilled human components may also create a bottleneck in some sectors. Thus, whether Taiwan has succeeded in creating a POLIS is an open and non-trivial question. However, there is one particular sector in which Taiwan may have achieved a mature capability to innovate. This is the electronics sector. A discussion of the state of the electronics sector can serve as a prelude to a discussion of an economy- wide capability to innovate.[11]

The Electronics Sector in Taiwan

From a humble beginning in the 1950s--when Taiwan first started producing transistor radios--to the 1990s, the electronics sector has grown to include many advanced products. Among them are the various components of personal computers, advanced work stations and other microelectronic products. Companies such as Tatung and ACER have sales exceeding one billion dollars. A number of small firms such as Sampo Corporation and United Microelectronic Corporation have shown tremendous growth in recent years. The share of

[11] Of course, it is not being claimed that having an apparently self-sustaining innovation structure in one sector is sufficient for a POLIS. For this we must examine the economy-wide linkages.

foreign-owned firms also declined during the 1980s and 90s. However, even now the foreign-owned firms account for more than 25 percent of the industry output.

Small- and medium-sized firms (defined as firms with less than 300 employees) dominate the industry. This means that unlike South Korea the innovation occurs in relatively small firms. Modifications that take this fact into account are therefore necessary in building a SAM-Tech for Taiwan as is shown in the following section.

Table 1 shows the plans for the year 2000 for the electronics industry. Information products are forecast to be the leading edge in the industry. According to O'Connor and Wang (1992) nearly US$ 6 billion of total computer production was exported. Of this 40 percent went to North America and 41 percent to Europe. Japan imported only 2 percent of the computer exports; but Asia-Pacific accounted for about 14 percent.

Table 1: **Electronics and information technology, production values and forecasts (US$ billions)**

	Output 1990	Revised growth rate forecast 2005 (%)
Information products	6.9	3.2
Automation	2.8	5.1
Consumer electronics	2.3	3.2
Telecommunications	1.9	4.6
Semiconductors	1.5	6.2
Total	15.4	22.3

(Source: Hobday, 100, My calculation for growth rate for 2005)

Although the take-off in the electronics sector appears to be a market phenomenon government policies also played a role. In May 1979, the Executive Yuan put forth the Science and Technology Development Program. This program identified information technology systems as an area of emphasis for future R&D. The idea for establishing the Institute for Information Industry was also hatched during this period.

The Ministry of Economic Affairs moved quickly. In July 1979, the implementation plan for computer technology was contracted out to the Industrial Technology Research Institute. The Council for Economic Planning and Development prepared a ten-year plan, 1980-1989. The plan provided targets for R&D expenditures and human capital supply among other things. The Electronics Research Services Organization was given responsibility for coordinating the transfer of technology from foreign companies.

By all indicators the ambitious plans succeeded for the most part. By the 1990s Taiwanese firms took their place among innovative designers of PCs, electronic notebooks, and circuit boards. Many new companies such as Datatech were started in the 1980s. Several of them (including Datatech) grew to be successful. During this time Taiwan also surpassed Great Britain to become the fifth largest producer of semiconductors in the world. The major industrial policy pursued by Taiwan was directed credit from the formal lending institutions to the large and growing firms in this sector.

Under an overall imitative strategy (Chiang, 1990) Taiwan decided to follow the leaders in already established technologies. The objective has been to compete by cutting costs through productive efficiency. The government has taken the responsibility for acquiring technology from abroad. It has also fostered advanced research. The government-supported research institutes, utilizing skilled scientists and engineers, have been crucial for carrying on such research. The results of the research are then transferred to the private sector.

Furthermore, economic incentives are provided to the strategic sectors through favorable tax and credit policies. In terms of complementary human capital accumulation, many Taiwanese went abroad and continue to do so in order to acquire advanced education and skills in science and technology. A number of local employees were also trained in the foreign multinationals where they were employed as engineers, technicians and managers. Lucrative financial incentives were offered to attract skilled Taiwanese living abroad.

As Hobday (1995) points out, there seem to be a least five types of strategic firms in the electronics industry. These are: foreign corporations and joint ventures; the major local manufacturing groups; high technology start-up firms;

government-sponsored ventures; and the traditional small and medium enterprises that cluster together in special market niches. The combined effect of strategic interactions among these actors has been the rapid growth and expansion in the industry as a whole even when some individual firms have declined. There is an almost classic Schumpeterian scenario unfolding before our very eyes in this sector.

It may not be out of place to discuss the role of the major private manufacturing groups and government-sponsored start-ups here. Both Chapponniere and Fouquin (1989) and Hobday (1995) have discussed the activities of these actors in Taiwan. The following brief discussion highlights the actions of these diverse economic agents in creating the conditions for a "POLIS" at least within the electronics sector.

The Electronics Sector: Firms

The progress of Tatung in the development of their electronics industry, according to Hobday, is representative of the entire electronics industry in Taiwan. In the 1970s, electronics became the industrial group's largest operation. The following table 2 shows Tatung's progress in electronics. The electronics maker began to produce black and white TVs by 1964 and fourteen-inch color monitors for computers by the early 1990s. The company also currently produces other household electronics and electric goods in its manufacturing plants around the world.

Table 2: **Tatung's Progress in Electronics: Towards the Construction of POLIS**

Product	Introduction date
Black and white TVs	1964
Colour TVs	1969
Black and white TV picture tubes	1980
VCRs	1982
High resolution colour TV picture tubes	1982
Colour TV tubes	mid-1980s
PCs	mid-1980s
Hard disk drives	mid-1980s
TV chips/ASICs	late 1980s
Sun workstation clones	1989
Fourteen-inch colour monitors	1991

Tatung, like the typical South Korean *chaebol*, first gained its manufacturing knowledge through technical cooperation deals. By investing capital in joint venture projects with foreign companies the Tatung group gained further through licensing agreements while learning technological skills through OEM deals. Tatung absorbed and adapted foreign technology, learning to modify, re-engineer and re-design consumer goods to fit customer needs. While production initially involved little R&D, the group did employ more than 500 R&D staff by 1990. However, the job of this mainly engineering staff was in advanced engineering rather than "blue sky research." Finally, just as production technology has been passed to industries in Taiwan by the more advanced manufacturing nations, by the mid-1980s Tatung was transferring its production technologies to its subsidiaries in lower cost East Asian countries.

ACER is representative of the high technology start-up companies which began to appear in Taiwan in the late 1970s and early 1980s. ACER relied on product innovation and original equipment manufacturing (OEM) with experience gained by individuals who had worked overseas in US firms or universities. Many of the other recent start-ups, like ACER, have used OEM to some extent, and most were unknown outside of Asia despite brand name sales. The following table 3 shows the development and innovations of ACER.

Table 3: **ACER-Behind the Frontier Innovations:Towards A POLIS**

1984	developed its own version of the 4 bit microcomputer (later followed by 8 bit, 16 bit and 32 bit PCs)
1986	launched the world second 32 bit PC, after Compaq but ahead of IBM
1988	began developing supercomputer technology using the Unix operation system
1989	produced its own semiconductor ASIC to compete with IBM PS/2 technology
1991	formed a joint company with TI (and the Taiwanese Government) to make memory chips (DRAMs) in Taiwan
1992	formed alliances with Daimler Benz and Smith Corona to develop specialist microelectronics technology
1993	produced a novel PC using a reduced instruction-set (RISC) chip running Microsoft Windows NT operating system
1993	licensed its own US-patented ChipUp technology to Intel (in return for royalties)
1993	received royalties from National Semiconductor, TI, Unisys, NEC and other companies for licensing out its PC chipset designs

ACER, according to many observers of technology in Taiwan, exemplifies many of the strengths and weaknesses of Taiwan's high technology start-ups. ACER started with only 11 engineers in 1976 with total sales reaching some US$1.4 billion by 1993. ACER led the local computer industry in the 1980s with 60 percent of sales being name brand through OBM. The company began to distribute directly to customers abroad during this period in order to challenge other brand leaders and move beyond OEM. However, the company began to retreat from OBM to OEM and ODM sales after heavy losses between 1990 and 1993.

The above discussion shows that there are strengths or advantages and weaknesses or disadvantages of companies like ACER. The strengths or advantages of these companies have been that they were able to benefit tremendously from the improving technological infrastructure and established market channels; they were able to bypass the consumer electronics phase of the

1970s thus allowing them to enter the market at a higher technology level, and they have received greater benefits from managers and engineers educated abroad. The weaknesses or disadvantages for these companies has been mainly the difficulty they have encountered as latecomers. Specifically in the ACER case, the company sustained heavy losses in own-brand sales. This forced the company to move from OBM back to OEM, once again making ACER dependent on the global leaders of core technologies. Unless and until these latecomers make the full transition to OBM and develop in-house technologies, they will be dependent on the global leaders and unable to compete on an equal basis.

The final grouping to be discussed here is the government-sponsored start-ups. The following table 4 shows the companies working at the government-developed Hsinchu facility and their relationship with international companies. [12]

[12] While I agree with Saxenian(1994;2000) regarding both conglomeration and network of relations in creating "regional advantage", the Taiwan case is more complex than just accumulating private sector agglomeration economies. My interviews at Hscinchu and other locations with firm managers and at other times and locations with the relevant government officials point to a complex interaction between the proivate sector and the government in high technology sectors in Taiwan.

Table 4: **High-technology Start-ups in Hsinchu Science-Based Industrial Park (Government/firm/market interaction towards a POLIS)**

Firm	Start date	Sector	Sources of senior staff, technology and training
Microelectronics Technology Inc.	1983	Telecom	HP, Harris, TRW
United Fibre Optics Communications Inc.	1986	Telecom	Sumitomo (J), Philips (H) AT&T, STC (UK)
TECOM	1980	Telecom	Bell Labs, IBM
Macronix	1989	Semiconductors	Intel, VLSI-Tech
Winbond Electronics Corp	1987	Semiconductors	RCA, HP
Taiwan Semiconductor Manufacturing Corp.	1987	Semiconductor foundry	Harris, Burrows, RCS, Philips (H), IBM

(Source: Hobday, 118; verified by the author during a visit to the Hsinchu facilities in 1998))

In one case of government-sponsored start-ups, the government has taken a "hands on" approach offering direct and indirect assistance, to include tax incentives and loans, and the use of science park facilities at Hsinchu to entice overseas Taiwanese to return to Taiwan. MTI, a telecommunications equipment maker, is one example. The government was greatly responsible for initiating this firm.

In another example, the Winbond Electronics Corporation, the government arranged for technology transfers for Winbond. Winbond founder and eventually many of its employees came from the Industrial Technology Research Institute, a state controlled organization that trained engineers in advanced semiconductors and transferred technology. The company took advantage of the needs and demands for technology in the local market. With technological transfers and innovation, Winbond was able to compete in a number of areas not only locally but internationally as well. However, shortages in investment capital, poor brand name recognition, and uncertain distribution arrangements meant that the company remained dependent on international leaders for technological innovation and capital goods.

A final example of a government-sponsored start-up is United Fibre Optic Communications Inc (UFOC). The government, specifically the Ministry of Economic Affairs Industrial Development Bureau, felt that Taiwan needed an indigenous fibre optic producer. This government agency called together the four largest copper producers and the local telecommunications operator within Taiwan to form a joint venture company, UFOC. The new venture attempted to obtain licensing agreements with four other international companies, finally deciding on one of them, AT&T.

UFOC is representative of the other start-up companies in Taiwan. Faced with the option of continuing to purchase its know-how from international competitors or investing heavily in its own in-house technology these companies have usually had to rely on the former for continued learning and technology. This suggests some of the difficulties of latecomers in overcoming the OEM path to further development (Hobday, 1995). Nevertheless, innovation can be carried out with support from the state.

But, Does Taiwan have a POLIS?

The foregoing discussion leads to the conclusion that at least in the electronics sector the Taiwanese firms have become innovators on an ongoing basis. It may even be said that there is a localized "POLIS" in the sector, as it were. But are the linkages with the rest of the economy sound enough to generate an overall "POLIS" effect? Are the R&D activities elsewhere in the economy being stimulated in such a way that an ongoing economy-wide positive feedback loop leading to a virtuous cycle of innovation and growth can be said to exist?

Let us recall that both Lau and Kim and Young separately arrived at the conclusion that for Taiwan also, in terms of total factor productivity growth the macroevidence does not support the hypothesis growth through technical change. In the terminology developed here those findings may be read as a rejection of the hypothesis that a POLIS exists in Taiwan at present.

As in section III, the approach followed here is to construct two successive SAM-Techs with the modern high-tech sectors included. The same approximation strategy used previously can once again be utilized in order to apply the insights of the non-linear theoretical model of POLIS to the Taiwanese case. The years used are 1990 and 1992. The intention here is to capture the structural change in the modern technology system as completely as possible.

The production, household and factors in Taiwan all have somewhat different classifications from those of South Korea[13]. This is inevitable in a study of

[13] For the South Korean SAMs please see Khan (1997a) and particularly chapter 5 in Khan(1998). The household and factor classifications are deliberately kept simple and similar to the Korean SAM-Tech. Thus

comparative economic structures in two different countries. In both the SAMs, however, R&D could be included as a separate activity. Classifications of factors (fewer in numbers in Taiwan) in both cases includes a separate category for engineers, technical and professional personnel. The total number of households in Taiwan is ten. On the production side the activities have been disaggregated more for the non-agricultural sectors. A separate disaggregated sector for the electronics industry has been created in order to pinpoint and test the importance of this sector for the Taiwanese economy. The dualistic breakdown of activities has not been pursued for Taiwan. The reason for this is that we are solely interested in sectors which are primarily modern R&D intensive. We also focus exclusively on the high technology sectors within manufacturing. Thus the range of analysis is narrower for Taiwan than for South Korea. But future extensions may be possible if one is interested, for example, in agricultural technologies.

Table 5 below gives a complete description of endogenous accounts for the Taiwan SAM.

Table 5: **SAM-Tech classification for Taiwan:**

1990 and 1992

1	Engineers
2	Technicians
3	Skilled workers
4	Apprentices
5	Unskilled
6	White collar
7	Self-employed (manufacturing)
8	Self-employed in service
9	Capital

the focus is on productivity and technical change, and only incidentally on consumption and distribution. If the focus changes from production to these other aspects then more detailed household and labor and capital classification may be necessary.

10	Agricultural workers
11-20	same as 1-10 except that they now refer to households as opposed to factors
21	Cereals
22	Other agriculture
23	Fishing
24	Processed food
25	Mining
26	Textiles
27	Lumber and furniture
28	Chemical products
29	Energy
30	Electronics (including computers)
31	Cement, non-metallic mineral products
32	Metal products
33	Machinery
34	Transport equipment
35	Beverages and tobacco
36	Other consumer products
37	Construction
38	Real Estate
39	Transportation and communication
40	Trade and banking
41	Education
42	Medical, personal and other services
43	Research and Development

In the above table the modern SAM-TECH (ModSAM-TECH) is constructed by adding R&D rows and columns according to the scheme identified before. Thus, a 43X43 endogenous account SAM is formed in Taiwan. The basis of the SAM is the updated input-output table specially modified for the SAM-TECH. The factors and household classification systems have enough detail for our purposes here; they include the most relevant categories for the formation of a POLIS. The focus here is on identifying productivity and value added changes; but some attention always needs to be paid to the distributional characteristics of the innovation system.

As mentioned before, in line with the strategy outlined in the last section two successive approximations for two different scales are made. One is for 1990 GDP and the second is for the increment in two years. In the latter case coefficients are changed **in proportion** to growth. In all probability, this procedure embodies a conservative increasing returns assumption because of the particular linear approximation scheme used.

For Taiwan, the simple multiplier exercises indicate a somewhat greater effect than South Korea as found in Khan (1998). For each one percent injection of R&D output in the ModSAM-TECH increases by about 3 percent. The modern technological system shows a range of increase varying between 2.5 percent and 4 percent. The electronics sector also shows the expected increasing returns effect. It should be recognized that the assumption of excess capacity is significant here. If the economy is near full employment additions to capacity will need to be made. In fact, such additions have occurred for both Taiwan and South Korea. To capture the capacity building effect a series of projected ModSAM-TECHs for Taiwan will be necessary. It should be pointed out that some inflation has accompanied the growth process, although the anti-inflationary policies of the Central Bank of China has kept it within bounds.

On the distributional side, the engineers, managers, technicians, and in general skilled workers gain disproportionately from the POLIS effect. As in the case of South Korea in Khan (1998), future trade increases of Taiwan with other LDCs with relatively more unskilled workers may bring factor-price equalization (according to the factor-price equalization theorem in standard trade theory) into play. Under such circumstances skilled/unskilled remuneration ratio will further deteriorate for Taiwan. Thus on the distributional side, in Taiwan as in South Korea, for the less skilled anyway, POLIS may turn out to be a mixed blessing.

In summary, this section has considered carefully the empirical evidence regarding innovation in Taiwan. Signs that Taiwan is building a POLIS are somewhat stronger than the South Korean case. In keeping with the caveats of the evolutionary approach, however, we must not hasten to pronounce Taiwan as a mature innovating country yet. There are still weaknesses even in the high technology sector. For example, inspite of the government's efforts, by and large, Taiwan still follows the imitative strategy. There remains several open questions as to if, when and how Taiwan can follow an autonomous innovation strategy. Beyond the high technology sector, the rest of the economy is not as well integrated as it needs to be before a POLIS can be self-sustaining. But clearly, more than a mere beginning has been made.[14]

Conclusions

In this paper, I have allowed theoretically the technological aspect of growth in East Asia to take the next logical step beyond imitation. That is to say, I have tried to go beyond the study of catch-up technology and to raise the question of innovation processes--Schumpeterian or otherwise--in countries like South Korea and Taiwan.

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14 The 1998 and 1999 issues of Asian Development Outlook Taipei, China country chapter also recognized the impressive achievements and outstanding problems of transition with respect to the high technology sector. Conversations of the author with leaders in R & D sector in Taiwan also pointed to some bottlenecks. In particular the plans for Asia Pacific Regional Operations Center (APROC), which among other things, are supposed to facilitate the economy□ transition to high technology may be over-ambitious.

The analysis of growth in Taiwan (that could be carried out for other economies in East Asia as well) here relies crucially on a number of emerging concepts with regards to the operation of complex production economies. Our understanding of complex economic systems in particular is still in its infancy. Therefore, the concepts developed here and their empirical applications can only be provisional and tentative.

Such qualifications notwithstanding, the present approach does reveal that analyzing complex technological systems can be a rewarding exercise, even at the current crude level of our knowledge. However, the already substantial literature on East Asian growth shows a schizophrenic state of affairs in this regard. At the detailed institutional level of description and analysis complexities are often acknowledged and their implications are explained. With a few important exceptions, in the formal, theoretical work simplifying assumptions regarding technologies are made. Such simplifications, it can be argued, are necessary and inevitable. It is certainly understandable that as theoretical economists, we want to keep our models tractable. Yet, quite often we forget that such tractability is often purchased at a price. In the immortal words--at least among economists--of Milton Friedman, “there is no such thing as a free lunch.” Forgetting this fact has led some to make claims about the East Asian growth process that ignore crucial and fairly well-known features of the East Asian economies.

The concrete results obtained so far which are summarized in the section on Taiwan show how the idea of a POLIS can be operationalized. Although this operationalization in the present instance has involved linear approximations to a non-linear model, future work can attempt to overcome this problem. The tentative interpretation of the results is that Taiwan shows a modest POLIS effect. In other words, Taiwan beginning to build structures of innovation that could possibly prove to be self-sustaining. Whether such self-sustaining virtuous positive feedback loops in the innovation systems will become a reality is not certain, however. Much more patient work at the micro level on specific sectors and industries may be necessary for a definitive answer to the question of a sustainable POLIS.

A small beginning in this direction has been made. Attempts by the electronics sector in Taiwan to build an innovation-led production systems can not be ignored. In particular, the efforts of firms such as Tatung and ACER seem to be headed in the direction of creating a domestic innovation structure. However, the economy-wide effects are still not clearly noticeable. It will perhaps take some time before such effects become discernible. There are also financial and other problems ahead that must be solved.

At the same time there are good reasons to believe that in an economy-wide sense also there is some movement towards a POLIS. This could be encouraging news. This overall effect is clearly not caused by just one company; there are many sectors of Taiwan's economy using modern technology that are trying to innovate. Once again, lasting success can only be measured as time passes.

In judging the potential for lasting technological success for a country like Taiwan (or for any other country, for that matter) financial factors can not be ignored. Sudden pressures on immature financial systems called upon to support the building of a POLIS may lead to a shortage of funds. On the financial side itself, quick liberalization or lack of prudential regulation can lead to excess volatility affecting long-term financing of projects crucial to the building of a POLIS. A detailed discussion and analysis of the complex issues involved here are beyond the scope of this paper. However, it may be noted that the relatively slower pace of liberalization seems to have insulated Taiwan's economy from the Asian financial crisis in 1997. More importantly, unlike South Korea, Taiwan can address the problems of building a POLIS without having to be distracted by immediate problems of insolvency and illiquidity of firms.

What may be happening in the Taiwan example discussed here is that small and medium scale firms, as well as some large firms are utilizing bold catch-up strategies and are using human resources to complement R&D at the same time. The study of the electronics sector shows that to a great extent this may be true. Here again, it would be foolhardy to predict an ongoing sustained cycle of innovations. All one can say is that in the absence of major political upheavals, capital flight, or labor unrest, etc. Taiwan stands possibly the best chance of forming a genuine positive feedback loop innovation system among all the newly industrialized economies.

On the theoretical side this paper has shown the relevance of creative destruction in an overall economy-wide setting. Growth depends on both technical progress and creation of additional capacity in response to changes in aggregate demand over time. Extensions of the model exploring the relationship between technical change, business cycles and long-run growth could build a bridge between short-run and the long-run. Such models would have great relevance for studying not just the NIEs such as Taiwan, but advanced economies as well.[15]

[15] Another intriguing possible implication of the theory developed here is that it undercuts a mechanical 'stages' approach to economic history. In that sense it is consistent with Gerschenkron's(1962) critique of Rostow, and the importance of analyzing 'backwardness' in a non-deterministic and historically nuanced manner. I am grateful to an anonymous referee for drawing this intriguing connection between Gerscenkron's concerns and the broader implications of POLIS.

Selected Bibliography

Abramovitz, Moses (1986), "Catching Up, Forging Ahead, and Falling Behind," *Journal of Economic History*, June, 46:2, 385-406.

----- (1989), *Thinking About Growth. Cambridge*: Cambridge University Press.

Aghion, P. and Howitt, P. (1992), "A Model of Growth Through Creative Destruction," *Econometrica*, p.323-51.

Arthur, Brian (1988), `Competing Technologies: An Overview', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds), *Technical Change and Economic Theory*, London: Printer Publishers.

----- (1994), *Increasing Returns and Path Dependence in the Economy*, Ann Arbor: University of Michigan Press.

----- (1989), "Competing Technologies, Increasing Returns, and Lock-In by Historical Small Events," *Economic Journal,* 99: 116-31.

Boskin, M. J. and L. J. Lau (1990), "Post-War Economic Growth of the Group-of-Five Countries: A New Analysis." Centre for Economic Policy Research Technical Paper No. 217. Stanford University Press.

----- (1991), "Capital Formation and Economic Growth." In *Technology and Economics: A Volume Commemorating Ralph Landau's Service to the National Academy of Engineering*, pp. 47 - 5 6. Washington, D.C.: National Academy Press.

----- (1994), "The Contributions of R&D to Economic Growth: Some Issues and Observations." Paper presented at the Joint American Enterprise Institute--Brookings Institution Conference on the Contribution of Research to the Economy and Society. Washington, D.C.

Chaponnier, J.R. and Fouquin,M. (1989), "Technological Change and the Electronics Sector-Perspectives and Policy Options for Taiwan'. Report prepared for Development Centre Project, May, Entitled: 'Technological Change and the Electronics Sector - Perspectives and Policy Options for Newly-Industrializing Economies', Paris: OECD.

Chiang, J.T. (1988), 'Technology Strategies in National Context and National Programs in Taiwan', *Technology in Society*, 10, pp. 185-204.

----- (1990), 'Management of National Technology Programs in a Newly Industrializing Country-Taiwan', *Technovation*, 10, No. 8, pp. 531-54.

Dahlman, Carl J., and Ousa Sananikone (1991), "Technology Strategy in the Economy of Taiwan: Exploiting Foreign Linkages and Investing in Local Capability," mimeo, The World Bank, Washington D.C..

Gershenkron, A. (1962). *Economic Backwardness in Historical Perspective, a Book of Essays*, Cambridge, the Belknap Press of Harvard University Press.

Ho, Samuel (1980), "Small-Scale Enterprises in Korea and Taiwan," World Bank Staff Working Paper No. 384, The World Bank, Washington D.C.

Hobday, Michael (1995), *Innovation in East Asia: The Challenge to Japan*. Aldershot, England: Edward Elgar Publishing Ltd..

Hou, Chi-Ming and Gee San (1993), "National Systems Supporting Technical Advance in Industry: the Case of Taiwan," in Richard R. Nelson, ed., *National Innovation Systems,* New York, Oxford University Press.

Iwai, Katsuhito (1984a)"Schumpeterian Dynamics: An Evolutionary Model of Innovation and Imitation", Journal of Economic Behavior and Organization, 5(2), June 1984, pp. 159-190.

---------------------(1984b)"Schumpeterian Dynamics, Part II: Technological Progress, Firm Growth and 'Economic Selection'", Journal of Economic Behavior and Organization, 5(3), Aug.-Dec. 1984, pp. 321-351.

---------------------(1991)"Towards a Disequilibrium Theory of Long-run Profits," Journal of Evolutionary Economics, 1(1), pp. 19-21.

----------------------(2000)"A Contribution to the Evolutionary Theory of Innovation, Imitation and Growth," Journal of Economic Behavior and Organization, 43 (2), Oct. 2000, pp. 167-198.

_______________(2001)"Schumpeterian Dynamics: A Disequilibrium Theory of Long-run Profits," in Lionello Punzo ed. Cycles, Growth and Structural Change (London: Routledge, 2001).

James, Jeffrey and Khan, Haider(1997a), "Technology and Income Distribution," *World Development*, 25-2 (February): 153-65.

James, Jeffrey and Khan, Haider (1997b), *Technological Systems, Employment and Income Distribution*, London: MacMillan.

Kaldor, N. (1978), *Further Essays on Economic Theory*, London, Duckworth.

Khan, Haider A. (1985), "Choice of Technology in Energy and Textiles Sectors in South Korea," in A.S. Bhalla ed. Technology and Employment in Industry, 3rd Edition, in Geneva ILO.

----- (1993), Faust I or Faust II? Some Observations on U.S.-Japan Trade Conflicts and Implications for Trade and Technology in Asian NICs," paper presented at the conference on Japan as Techno-economic Superpower, Santa Fe, New Mexico.

----- (1997a), *Technology, Energy and Development: The South Korean Transition*, Cheltenham, U.K.: Edward Elgar.

----- (1997b), "GIN and TONIC: Technology in Globally Integrated Networks for NICs," unpublished, manuscript.

----- (1997c) "*The Future of Miracles: Interpreting East Asian Growth"* Economics and Development Resource Center, Asian Development Bank, Manuscript.

----- (1998), *Technology, Development and Democracy:: Limits to National Innovation Systems in the Age of Postmodernism,* Cheltenham, U.K.: Edward Elgar.

----- (1998) *A Quick Note on Financial Crisis,* Economics and Development Resource Center, Asian Development Bank, Manuscript.

Khan, H. A., and Thorbecke, E. (1988), *Macroeconomic Effects and Diffusion of Alternative Technologies within a Social Accounting Matrix Framework*, Aldershot, U.K.: Gower Publishing.

----- (1989), Macroeconomic Effects of Technology Choice: Multiplier and Structural Path Analysis," *Journal of Policy Modeling* 11, no. 1: 131-59.

Kim, J.I., and L. J. Lau (1992a), "Human Capital and Aggregate Productivity: Some Empirical Evidence from the Group-of-Five Countries." Stanford University Department of Economics working paper. Sept.

----- (1992b), "The Importance of Embodied Technical Progress: Some Empirical Evidence from the Group-of-Five Countries." Center for Economic Policy Research Working Paper No. 296. Stanford University, June.

----- (1992c), "The Sources of Economic Growth of the Newly Industrialized Countries on the Pacific Rim." Paper presented at the Conference on the Economic Development of the Republic of China and the Pacific Rim in the I99Os and Beyond. Taipei, May 25-28.

----- (1994a), "The Role of Human Capital in the Economic Growth of the East Asian Newly Industrialized Countries." Paper presented at the Asia-Pacific Economic Modeling Conference-94. Sydney, Aug. 24 - 26.

----- (1994b), "The Sources of Asian-Pacific Economic Growth." Paper presented at the Annual Meeting of the Canadian Economic Association. Calgary, June.

----- (1994c), "The Sources of East Asian Economic Growth Revisited." Stanford University Department of Economics working paper.

----- (1994d), "The Sources of Economic Growth in the East Asian Newly Industrialized Countries." Journal of the Japanese and International Economies, 8, 35-71.

----- (1995), "The Role of Capital in the Economic Growth of the East Asian Newly Industrialized Countries." In B. Kapur, E. Quah, and H. H. Teck, eds., Festschrift in Honour of Professor Lim Chong Yah.

Krugman Paul (1996a), *The Self-Organizing Economy*, Oxford: Blackwell Publications.

----- (1996b), *Pop Internationalism*, Cambridge: The MIT Press.

Lall, Sanjaya, (2001) *Competitiveness, Technology and Skills*, Cheltenham, UK: Edward Elgar.

Lau, Lawrence J. (1996), "The Sources of Long-Term Economic Growth: Observations from the Experience of Developed and Developing Countries." Ralph Landau, Timothy Taylor and Gavin Wright (eds.) *The Mosaic of Economic Growth*, Stanford, Ca.:Stanford: Stanford University Press.

Lau, L. J., and P. A. Yotopoulos (1989), "The Meta-Production Function Approach to Technological Change in World Agriculture." *Journal of Development Economics*, 241-69.

Levine, Ross (1997) Financial Development and Economic Growth: Views and Agenda, Journal of Economic Literature, Vol XXXV (June): 688-726.

Liu, Chung-Yuan (1993), "Government's role in developing a high-tech industry: the case of Taiwan's semiconductor industry," *Technovation*, 13(5), 299-309.

Matsuyama, K. (1991), "Increasing Returns, Industrialization and Indeterminancy of Equilibrium", *Quarterly Journal of Economics,* 106:616-650.

Nelson, Richard R. (1964), "Aggregate Production Functions and Medium-range Growth Projections," *American Economic Review*, September, 54, 575-606.

----- (1968), "A Diffusion Model of International Productivity Differences in Manufacturing Industry," *American Economic Review*, 58:1219-48.

----- (1980), 'Production Sets, Technological Knowledge, and R and D: Fragile and Overworked Constructions for Analysis of Productivity Growth?', *American Economic Review*, 70: 62-7.

----- (1981), 'Research on Productivity Growth and Productivity Differences: Dead Ends and New Departures', *Journal of Economic Literature*, 19/3: 1029 64.

----- (1989), ”What is Private and What is Public about Technology?” *Science, Technology and Human Values*, 14(3): 229-41.

----- (1992), ”U.S. Technological Leadership: Where Did It Come from and Where Did It Go?” Scherer, Frederick M. and Mark Perlman (1992), *Entrepreneurship Technological Innovation. and Economic Growth: Studies in the Schumpeterian Tradition* Ann Arbor: The University of Michigan Press: 25-50.

----- (1993), “Technical Change as Cultural Evolution,” Ross Thomson, ed., *Learning and Technological Change*. New York: St. Martin Press.

-----, ed. (1993), *National Innovation Systems: A Comparative Analysis*. Oxford: Oxford University Press.

----- (1994), “What has been the Matter with Neoclassical Growth Theory,” Silverberg and Luc Soete, eds. (1994), *The Economics of Growth and Technical Change: Technologies, Nations, Agents*, Aldershot, U.K.: Edward Elgar: 290-324.

----- (1995), “Recent Evolutionary Theories About Economic Change” *Journal of Economic Literature*, pp. 48-90.

Nelson, Richard R and S. Winter (1973), “Recent Exercises in Growth Accounting: New Understanding of Dead End?”, *American Economic Review*, 73:462-468.

----- (1974), 'Neoclassical vs. Evolutionary Theories of Economic Growth: Critique and Prospectus', *Economic Journal*, 84: 886-905.

----- (1977), "In Search of a Useful Theory of Innovation." *Research Policy* 6: 36-76.

----- (1982), *An Evolutionary Theory of Economic Change*, Cambridge: MA, Harvard University Press.

Nelson, Richard R., and Edmund Phelps (1966), "Investment in Humans, Technological Diffusion, and Economic Growth," *American Economic Review*, May, 56, 69-75.

Pack, Howard (1987), Productivity, Technology, and Industrial Development. New York: Oxford University Press.

----- (1988), "Industrialization and Trade," Chenery, Hollis B., and T. N. Srinivasan, eds., *Handbook of Development Economics*. Amsterdam: North Holland, 333-80.

----- (1992), "Technology Gaps between Industrial and Developing Countries: Are there Dividends for Latecomers?" *Proceedings of the World Bank Annual Conference on Development Economics*. Washington, D.C.: The World Bank.

----- (1994), "Endogenous Growth Theory: Intellectual Appeal and Empirical shortcomings. " *Journal of Economic Perspectives*, Winter, 8, 55- 72

Pack, Howard and, Fang Ye Wang and Larry E. Westphal (1997), "Exports and Learning in Taiwan," unpublished ms.

Pack, Howard and Larry E. Westphal (1986), "Industrial Strategy and Technological Change: Theory vs reality." *Journal of Development Economics* 22: 87-128.

Pack, Howard, and John M. Page (1994a), "Accumulation, Exports and Growth in the High Performing Asian Countries," Carnegie-Rochester Papers on Public Policy, Winter.

----- (1994b). "Reply to Alwyn Young." Carnegie-Rochester Papers on Public Policy, 40: 251-57.

Perez, C. and Soete, L. (1988), 'Catching up in Technology: Entry Barriers and Windows of Opportunity', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds), *Technical Change and Economic Theory*, London: Frances Pinter.

Redding, Stephen (1996), "The Low-skill, Low-quality Trap: Strategic Complementarities between Human Capital and R & D," *Economic Journal*, Vol.106, No.435: 458-70.

Rodrik, Dani (1992) "Closing the Productivity Gap: Does Trade Liberalization Really Help?" in: G. Helleiner, ed., *Trade Policy. Industrialization and Development: New Perspectives.* Oxford, Clarendon Press.

----- (1993) "Trade and Industrial Policy Reform in Developing Countries: A Review of Recent Theory and Evidence." *NBER Working Paper #4417*

----- (1995) "Getting Interventions Right: How South Korea and Taiwan Grew Rich," *Economic Policy.*

----- (1996), "Understanding Economic Policy Reform." *Journal of Economic Literature* 34 (March): 9-41.

------ (1994), "King Kong Meets Godzilla: The World Bank and the East Asian Miracle." In Albert Fishlow, et. al. *Miracle or Design? Lessons from East Asia*. Washington, DC: Overseas Development Council.

Romer, Paul M. (1986), "Increasing Returns and Long-run Growth," *Journal of Political Economy*, October, 94:5, 1002-1037.

----- (1987), 'Growth Based on Increasing Returns due to Specialization,' *American Economic Review*, 77, 56-62.

----- (1990a), "Endogenous Technological Change," Journal of Political Economy, October, 98, S71-102.

Saxenian,Anna Lee(2000),"Transnational Entrepreneurs and Regional Industrialization: The Silicon Valley-Hschinchu Connection", in Rueyling Tzeng and Brian Uzzi eds. Embeddedness and Corporate Change in the Global Economy, N.Y.: P. Lang.

----------------(1994) Regional Advantage:Culture and Competition in Silicon Valley and Route 128, Cambridge, Ma.: Harvard University Press.

Scitovsky, Tibor, "Economic Development in Taiwan and South Korea, 1965-1981." In Lau, Lawrence J., ed., *Models of Development: A Comparative Study of Economic Growth in South Korea and Taiwan.* San Francisco: ICS Press, 1986, pp. 135-95.

Schumpeter, Joseph A. (1942). *Capitalism, Socialism, and Democracy.* New York and London: Harper & Brothers Publishers

Scott, Maurice F. (1989). *A New View of Economic Growth*, Oxford, Clarendon Press.

.

Stiglitz, Joseph E. (1996), "Some Lessons from the East Asian Miracle," The World Bank Research Observer, Vol. II, No. 2:151-77

Stewart, Frances, (1977) *Technology and Underdevelopment*, Boulder: Westview Press.

Svejnar, J., and Thorbecke, E. (1980), "Determinants and Effects of Technological Choice." Paper presented at the Annual Meeting of the American Association for the Advancement of Science, San Francisco.

------ (1982), "The Determinants and Effects of Technological Choices." In Barbara Lucas, ed. *Internal and External Constraints on Technological Choice in Developing Countries*. London: Tooley-Bowker Publishing Company.

Wade, Robert (1990). *Governing the Market: economic theory and the role of the government in East Asian industrialization*, Princeton, NJ, Princeton University Press.

World Bank (1993), *The East Asian Miracle: Economic Growth and Public Policy*. World Bank Policy Research Report, New York: Oxford Univ. Press.

Young, A. (1991), ”Learning by Doing and the Dynamic Effects of International Trade”, *Quarterly Journal of Economics*, 106:369-405.

----- A. (1992), "A Tale of Two Cities: Factor Accumulation and Technical Change in Hong Kong and Singapore." In O. J. Blanchard and S. Fischer, eds., *National Bureau of Economic Research Macroeconomics Annual*, pp. 13-5 4. Cambridge: MIT Press.

----- (1995), The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience, *Quarterly Journal of Economics* 110, 641-680.

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