JOURNAL OF ECONOMIC DEVELOPMENT
Volume 19, Number 2, December 1994

Limited Diffusion of Technology, Learning Incentives and A Low Level of Industrialization*

Been-Lon Chen**

In this paper we attempt to answer the question of poor industrialization in a dynamic model with limited diffusion of technology and costly learning in which individuals make an effort to adopt technology. We find that there are generically multiple interior steady states such that the economy can find itself in a steady state with a low, but not zero, level of industrialization. Entrepreneurs' lack of incentives to learn technology are the reasons for this poor industrialization. Policy implications for a takeoff from this low level of industrialization are analyzed by drawing on successful histories of economic development.

I. Introduction

During two hundred years since the Industrial Revolution, while some countries became highly industrialized, many countries still only have low levels of industrialization. Given the evident economic gains from a higher level of industrialization, there must exist reasons that these less developed countries cannot highly industrialize.

In this paper we attempt to answer this question in a model with limited diffusion of technology and costly learning. We underscore the role of learning incentives. Specifically, we model the process of diffusion of industrial technology into less developed countries to be limited; meanwhile, entrepreneurs are allowed to make an effort to learn the

* The author has benefitted from valuable comments of Sebastian Edwards, Arnold Harberger, John McCall, Sule Özler, Federic Sturzenegger, and workshop participants at UCLA, Academia Sinica, and National Taiwan University. He is also grateful to an anonymous referee for helpful suggestions. The conventional disclaimer applies.

** The Institute of Economics, Academia Sinica, Nankang, Taipei, Taiwan.

technologies to hasten the process of acqusition but are subject to costs incurred. Depending on the learning costs and the expected returns obtainable from acquiring the technology, entrepreneurs decide their optimal effort to learn the technology. In steady state, either retarded or great industrialization results.

There have been some related papers in the literature recently. Among these are the works by Murphy, Shleifer and Vishny (1989a, b), Krugman (1991) and Matsuyama (1991). The former authors presented one line of research about the conditions under which both a zero and a full level of industrialization coexist. In these models, a zero level of industrialization results solely from self-fulfilling prophecy. These models, however, are treated in a static framework and therefore treated with difficulty the possibility of a takeoff.

Krugman (1991) and Matsuyama (1991) presented an another line of research, in which their models being variants of sector adjustment are thus dynamic. In their equilibria, there exist both a zero and a full or high level of industrialization in the steady state and their economy can lock into the state with a zero industrialization. As Krugman's setting is linear, there exists no interior steady state. Although by improving Krugman's setting in the direction of non-linearity Matsuyama attained an interior (high) level of industrialization, he still obtained a non-interior (zero-level) steady state. The latter state implies that the developing economy under issue uses no industrialized technology; this implication is not shared by most developing or less developed economies that have generally a non-negligible fraction of modern manufacturing sector, e.g., India and Pakistan. This result rests in part upon the assumption that an agent must decide in which sector to work at the beginning of his life and is not permitted to switch sectors after making such a decision. Moreover, sector choice in Matsuyama takes no time, whereas in real world technology choice takes time as the availability of industrialized technology is not instantaneous; time is typically required to employ more advanced technology as the proper technology must be chosen first and engineers need to learn the operation or to be trained next. As this characteristic of the process of technology adoption is prevalent especially in less developed countries, it should be incorporated in modeling. We try to model in this direction.

Our model features both limited diffusion of industrial technology into a developing country and incentives of entrepreneurs to make the effort to hasten the diffusion. Moreover, in contrast to Matsuyama, an agent in our model is permitted to switch sectors after he works in the traditional sector. According to our modeling strategy, an economy has a more productive modern technology coexisting with a less productive traditional technology; the traditional technology is subject to constant returns to scale, whereas the modern technology is subject to an external economy. Hence, as there is greater modern industry, there is a greater productivity per capita within this industry.[1] An entrepreneur in question invariously has a traditional technology available; meanwhile he may choose to make an effort to match or to adopt a modern technolgy for himself. This matching or adopting process may be complex instead. To simplify matters, we represent it by a Poisson process with a mean rate of arrival. This rate is not constant, but an increasing function of the level of learning effort. Technically, this process of learning a modern technology is modeled as a search process in which individuals choose optimal levels of effort when learning or adopting the technology.[2] The level of optimal learning effort depends upon both costs and expected benefits of learning the technology. Insufficient learning incentives thus explain the result of a low level of industrialization.

We find that as there are multiple interior steady states generically, there coexist both a low and a high level of industrialization. In analyzing what leads the economy to choose this low-level steady state, our analysis indicates that, as in Krugman (1991) and Matsuyama (1991), both history and expectations are relevant for the result of a low level of industrialization. This result is not surprising given the assumption that the expectations of future incomes are perfect foresight. We must point out, however, the underlying factor in this current model is different from that of both Krugman and Matsuyama. For Krugman, it is the adjustment cost that is crucial as to an agent's sector decision, whereas for Matsuyama, an agent must decide in which sector to work and the decision is irreversible. In our work, as an individual is permitted of switching sectors after working in the traditional sector, it is an entrepreneur's incentive to learn the modern technology of limited diffusion that is critical to a decision to adopt technology and therefore the level of industrialization. Moreover, our result of a low level of industrialization makes actually more practical sense compared with a zero (non-interior) level in both Krugman and Matsuyama.

1 This externality is a sort of learning by doing in which an individual entrepreneur invests in private knowledge that concomitantly contributes inadvertently to a public pool of knowledge. See Arrow (1962).

2 In literature, a search equilibrium model is mainly applied to explain high unemployment. See among others, Diamond (1982a,b) and Howitt and McAfee (1987). The use of a search equilibrium model for economic development in this work thus represents a new application.

This paper is organized as follows. After building a basic model in the next section, we consider an individual's problem of optimal learning in section III; the equilibrium and its properties are analyzed in section IV. We investigate policy implications for a takeoff by drawing casual historical examples in section V, and conclude in section VI.

II. Basic Model

We consider an economy that is populated by a continuum of identical, risk-neutral and self-employed entrepreneurs, of which the size, for simplicity, is normalized to unity. There are overlapping agents (Blanchard, 1985): each agent throughout his life confronts a constant probability of death b,[3] and at any instant, a cohort of size b is born. Each entrepreneur owns one unit of labor endowment.

A. Preferences and Technologies

We assume that individuals consume what they produce. This assumption is made to avoid the effects of demand spillover which is the principal mechanism that generates multiple steady-state equilibria according to Murphy, Shleifer and Vishny (1989b). We assume for simplicity the instantaneous utility to be linear. The instantaneous utility can be relaxed to concavity without altering the analytical results.

There are technologies of two kinds that produce homogeneous commodities called the traditional and modern technology for convenience. Both technologies use labor as the only input. The traditional technology is operated under constant returns to scale, with one unit of labor input producing y units of output. Each entrepreneur has a free access to traditional technology. He can choose to learn a *more productive* modern technology, subject to an external economy due to learning by doing. The productivity of modern technology depends on the size of this industry in the sense that, if there is greater modern technology adopted, there is more human capital accumulated and people know how to use the technology more efficiently. As a result, the technology becomes more productive. In terms of evidence for external economies, Caballero and Lyons (1990, 1992) who examined the external economies of two-digit manufacturing industries in four European countries and

3 This setting of an instantaneous rate of death captures also bankruptcy of firms due to structural shifts. This condition reflects the fact that the turn-over rate of firms is typically non-negligible in many countries. The structural shifts are assumed to cause randomly a fraction b of firms to become bankrupt.

US found significant evidence of external economies for most industries. These manufacturing industries in Europe and USA exemplify the modern industry in this work.

Formally, we assume that the modernized production function has the functional form g(m), in which $m \epsilon [0,1]$ is the fraction of entrepreneurs in this industry, or the size of this industry. This production function means that one unit of labor input can produce on average g(m) units of output. Individual productivity depends thus externally on the size of the industry. We assume that g(m) is differentiable and finite, and that $g'(m) > 0$ for all $m \epsilon [0,1]$. As we assumed that modern technology is *more productive* than its traditional counterpart, we need $g(0) > y$. This restriction is reasonable as the cost of adopting modern technology becomes embedded in an another term.

Under the condition that there is no transition of states from live to death and from using traditional technology to using modern technology, an agent's expected lifetime utility is then $V_y(t) = \int_t^\infty e^{-(\tau - t)} y d\tau$ when he uses traditional technology (y), where r is a constant rate of time-preference, and is $V_m(t) = \int_t^\infty e^{-(\tau - t)} g(m(t)) d\tau$ when he uses modern technology (g(m)). The expected lifetime utility is the sum of future output produced as we have assumed that an agent consumes what he produced and the instantaneous utility is linear.[4] If we take the derivative of $V_y(t)$ and $V_m(t)$ with respect to time, we get respectively

(1) $$rV_y(t) = y + \dot{V}_y,$$

(2) $$rV_m(t) = g(m(t)) + \dot{V}_m,$$

where a variable with a dot above it denotes its time derivative. Intuitively, equations (1) and (2) are arbitrage equations. To explain why, think of an agent using traditional technology as an asset. Contemplate holding this asset a period dt. This yields a dividend ydt and an expected capital gain $\dot{V}_y dt$ in equation (1). The sum of these two should equal the normal return $rV_y(t)dt$. Similar interpretation applies to equation (2). Later we will incorporate into equations (1) and (2) considerations of transition of states.

B. Technology Diffusion Process

The diffusion of modern technology is assumed to be a Poisson pro-

[4] If the instantaneous utility is convave, we just replace y in $V_y(t)$ and g(m) in $V_m(t)$ by u(y) and u(g(m)) respectively, where $u' > 0$ and $u'' < 0$.

cess with a parameter a, in which a is a function of the level of learning effort β. The greater effort β that an individual exercises, the more readily obtainable is the modern technology. Accordingly, we deduce a functional form $a=a(\beta)$. However, the greater learning effort that an individual exerts, the greater is the cost $f(\beta)$ incurred. We note that because the parameter of the Possion process ia a, it implies that the expected or mean arrival rate of a modern technology in a small time interval dt is a and 1/a is the expected waiting time.

We assume that both $a(\beta)$ and $f(\beta)$ are non-negative, finite, twice continuously differentiable, and strictly increasing for all $\beta>0$, that a is strictly concave for $\beta>0$, that f is strictly convex for $\beta>0$, and that $a(0)=f(0)=0$. These assumptions are conventional except the latter. The assumption $a(0)=f(0)=0$ is to make the law of motion in equation (5) emanating from the origin.

When expected capital gains (losses) due to death and transition of production type are taken into considerations, they should appear in equations (1) and (2) along with other expected capital gains. These two equations then becomes respectively

$$rV_y(t)=y+b[0-V_y(t)]+a(\beta(t))[V_m(t)-V_y(t)]-f(\beta(t))+\dot{V}_y, \tag{3}$$

$$rV_m(t)=g(m(t))+b[0-V_m(t)]+\dot{V}_m. \tag{4}$$

These two equations are standard in literature. See, among many others, Diamond (1982a, b) and Howitt and McAfee (1978) in the context of labor search, Shapiro and Stiglitz (1984) in that of efficiency wage, and Kiyotaki and Wright (1989) of the origin of medium of exchange. In equation (3), $b[0-V_y(t)]$ is the expected capital loss due to death, and $a(\beta)[V_m(t)-V_y(t)]-f(\beta)$ is the expected capital gain due to transition of production state. This latter capital gain consists of the income gap between using a modern technology (Vm(t)) and using a traditional technology ($V_y(t)$) times the expected arrival rate of a modern technology ($a(\beta)$) and the cost of making effort to adopt a modern technology ($-f(\beta)$). In equation (4), $b[0-V_m(t)]$ is the expected capital loss due to death. The arbitrage interpretations similar to those of equations (1) and (2) apply here.

C. Law of Motion for the Size of Modern Industry

As m(t) is the fraction of modern industry, 1-m(t) is the size of traditional industry. Therefore, increased size of modern industry signifies decreased size of traditional industry. The proportion of population in modernized industry satisfies the following law of motion.

(5) $\dot{m} = 1(1 - m(t))(1 - b)a(\beta(t)) - m(t)b.$

According to equation (5), the size of modern industry increrases as people transfer into from traditional industry and decreases due to death of people in this industry. $(1 - m)(1 - b)$ is the fraction of people alive in existing traditional industry and they make effort to adopt modern technologies and each has a mean probability $a(\beta)$ to adopt one technology in a small period dt.

III. Entrepreneur's Optimal Learning Problem

We proceed to examine the optimal learning of an entrepreneur. As a modern technology is more productive than its traditional counterpart, an entrepreneur currently in traditional industry may have an incentive to learn a modern technology. The intensity of incentives, however, may vary before a steady state is reached. An individual's intensity of learning incentives depends on both the expected income from acquiring a modern technology and the learning costs.

Denoting $V(t) = V_m(t) - V_y(t)$, we interpret V(t) as the value surplus of an entrepreneur who transfers into modern from traditional industry at time t. As a result, we obtain the relation $\dot{V} = \dot{V}_m - \dot{V}_y$. Subtracting equation (3) from equation (4), one derives

(6) $$V(t) = \frac{1}{r + b + a(t)} [g(m(t)) - y + f(\beta(t)) + \dot{V}].$$

V(t) in equation (6) forms the expected value surplus obtainable from working in modern industry, rather than in traditional industry, from t onward. According to this equation, a larger size of modern industry implies a greater expected value surplus. For any given expected V, we derive $V_y(t)$ from equation (3) in the following equation[5]

(7) $$V_y(t) = \int_{\tau=t}^{\tau=\infty} e^{-(r+b)(\tau-t)}[y + a(\beta(\tau))V(\tau) - f(\beta(\tau))]d\tau.$$

$V_y(t)$ in equation (7) is the expected lifetime income of an entrepreneur who is in traditional industry at time t, according to which

[5] As the right hand side of (3) is continuously differentiable (C^1), there exists a unique solution $V_y(t)$. See Hirsch and Smale (1974, pp. 163-169) for the proof. For a solution of this nonhomogeneous and nonautonomous differential equation, see also Hirsch and Smale (1974, pp. 99-102).

the expected lifetime income is constituted by both the instantaneous output produced using the traditional technology and the net expected income from making the effort to adopt a modern technology. Given the expected excess income V(t) and the size of the modern industry m(t), an entrepreneur in traditional industry maximizes his lifetime income ($V_y(t)$) by optimizing his learning effort $\beta(\tau)$ for $\tau \geqslant t$. The optimal level of learning effort β is found by pointwise maximizing equation (7). The necessary and sufficient condition is[6]

$$(8) \qquad a_\beta(\beta(\tau))V(\tau) = f_\beta(\beta(\tau)),\ \forall \tau \geqslant t.$$

According to equation (8), an entrepreneur in traditional industry makes an effort to learn the modern technology in every period $\tau \geqslant t$ up to the level at which the expected marginal excess income equals marginal cost. This equation characterizes an entrepreneur's optimal learning behavior. Equation (8) implies an interior β as long as $\lim_{\beta - 0} [a_\beta(\beta)V - f_\beta(\beta)] > 0$. We denote this β by $\beta(\tau) = \beta(V(\tau))$, $\tau \geqslant t$, with β strictly increasing in $V > 0$.

IV. Equilibrium: Low Level of Industrialization

We assume that the entrepreneurs' expectations of value surplus are perfect foresight. In equilibrium, the preceived V should equal the realized value surplus. Moreover, because our setup involves a representative individual setting, an entrepreneur's optimal level of learning effort β is equal to the average optimal level of learning effort β in equilibrium. With this understanding in mind, we analyze the perfect-foresight steady state as follows.

This perfect-foresight steady state is the set of values, $\{\beta, m, V\}$, that satisfies (5), (6), and (8), with $\dot{m} = \dot{V} = 0$. Recalling that equation (8) becomes reduced to the unique function $\beta = \beta(V)$ and inserting $\beta = \beta(V)$ into both equations (5) and (6), one obtains

$$(9) \qquad \dot{m} = (1 - m(t))(1 - b)a[\beta(V(t))] - m(t)b,$$

$$(10) \qquad \dot{V} = [r + b + a(\beta(V(t)))]V(t) - g(m(t)) + y - f[\beta(V(t))].$$

The steady states solve $\dot{m} = 0$ in equation (9) and $\dot{V} = 0$ in equation

6 In deriving the following equation, we evaluate $V_y(t)$ at β. Note that the permanent income from working in modern industry, $V_m(t)$, is common to all workers in this industry and is independent of β. This condition implies that $\partial V/\partial\beta = \partial V_m/\partial\beta - \partial V_y/\partial\beta = 0$.

(10) simultaneously to obtain m and V. Instead of solving these two equations algebraically, we use a diagrammatical tool for analysis. We find first their slopes in the (m,V) coordinates as

$$\text{(11)} \qquad \frac{dV}{dm}\Big]_{\dot{m}=0} = -\frac{-a-b}{(1-m)a_{\beta}\beta_{V}} > 0,$$

$$\text{(12)} \qquad \frac{dV}{dm}\Big]_{\dot{V}=0} = -\frac{-g_{m}}{r+a+b} > 0.$$

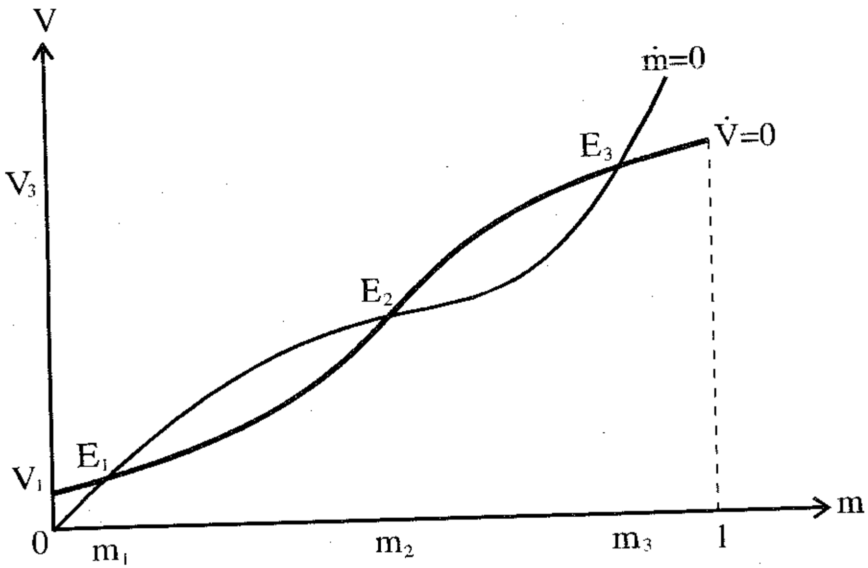
According to (11) and (12), the slopes of both curves are positive for the following reasons. For the curve $\dot{m}=0$, a greater modern industry implies, other things being equal, both more numerous entrepreneurs existing from the existing modernized industry and fewer entrepreneurs in traditional industry learning modernized technology. Under a given level of value surplus (V) and therefore an implied given level of learning effort (β) these two effects tend to shrink modern industry. The value surplus must increase in order to induce greater learning incentives. This effect increases the number of entrepreneurs (m) entering into modern industry in the steady state and thus prevents this industry from shrinking. Therefore, m and V are positively related on $\dot{m}=0$. As for the curve $\dot{V}=0$, a greater value surplus, *certeris paribus,* generates a positive capital gain for a unit of labor in modern industry and therefore creates chances for arbitrages. Entrepreneurs in traditional industry thus possess a large incentive to learn modern technology. As a result, modern industry expands to stop the arbitrages in the steady state. V and m on $\dot{V}=0$ therefore move in the same direction as well.

As these two curves have positive slopes, we need to ensure the existence of an interior steady state. This can be done by applying the intermediate-value theorem. We illustrate the idea for the proof as follows. We show that $\dot{V}=0$ starts from a value V greater than that at which $\dot{m}=0$ starts when $m=0$, and ends at a value of V less than that at which $\dot{m}=0$ ends when $m=1$. We note that on $\dot{m}=0$, $V=0$ when $m=0$ and V approaches infinity when $m=1$. This results in a convex curve $\dot{m}=0$. See Figure 1. As both $\dot{m}=0$ and $\dot{V}=0$ are continuous on $m\epsilon[0,1]$, there exists invariously an interior steady state.

As is obvious from Figure 1, the key difference between our figure and those of Diamond (1982a) and Matsuyama (1991) lies in the result that the curve initiating from the origin ($\dot{m}=0$) is convex in our model, whereas those in Diamond and Matsuyama are concave. This difference results in one or an old number of steady states in our model, but zero or an even number of steady states in Diamond and Matsuyama. As

Figure 1

Multiple Steady States



both $\dot{m}=0$ and $\dot{V}=0$ in Figure 1 are intrinsically as nonlinear as those in Diamond and Matsuyama, there are generically multiple steady states. Diamond and Matsuyama discuss the simplest case of multiple steady states where the number of steady states is two. In the following, we discuss the case with three steady states and denote the three steady states E_1, E_2 and E_3 in Figure 1. Among these states, E_1 represents an equilibrium with a low level of industrialization, E_3 symbolizes an equilibrium with a high level of industrialization, and E_2, a middle level. The economy hence can end at either the worse steady state E_1 or the better steady state E_3 if both E_1 and E_3 are not unstable. Note that E_1 corresponds to a low rather than zero level of industrialization. We make remarks on this point subsequently.

Given the underlying population and economic structure, our result indicates that this economy could end up varied states. If the steady state happens to be at E_3, the economy becomes highly industrialized; namely, modernized industry m_3 becomes large. As a consequence, the realized value surplus of V_3 from modern industry is large, and therefore the society becomes affluent. In contrast, if the steady state occurs at E_1, the economy has now only a low level of industrialization m_1. The corresponding value surplus, V_1, is small and the state of poverty prevails. The steady state at E_3 may represent the economic situation for countries in western Europe, North America and Japan, whereas the one at E_1 may represent the case for countries in southern Asia, Africa and Latin America.

Why are the results of economic development among these countries so extremely varied? If this variation was only a transient phenomenon, the blame for perturbations such as wars and natural disaster might be reasonable. Two hundred years have elapsed since the Industrial Revolution. We think that those perturbations are not proper reasons. Although the Industrial Revolution occurred originally in western Europe, why can the new industrial technologies not be fully transmitted to countries in southern Asia, Africa and Latin America whereas they were transmitted to North America, Japan and eastern Asia? This question is equivalent to asking why many countries selected E_1, instead of E_3 in Figure 1 as the steady state two hundred years after the Industrial Revolution. The answer of this question is related to the issue in the literature whereby history or expectations help to select an equilibrium (Krugman, 1991). We next analyze the local dynamic properties near each steady state and then envisage when and why the equilibrium moves to the state at E_1.

Let $E_i=(m_i, V_i)$, $i=1,2,3$, be the three steady states in Figure 1. If we linearize (9) and (10) around E_i, we obtain

$$\begin{bmatrix} \dot{m} \\ \dot{V} \end{bmatrix} = \begin{bmatrix} -(1-b)a-b & (1-m)(1-b)a_\beta\beta_V \\ -g_m & r+b+a \end{bmatrix} \cdot \begin{bmatrix} m-m_i \\ V-V_i \end{bmatrix}$$

From the above we obtain

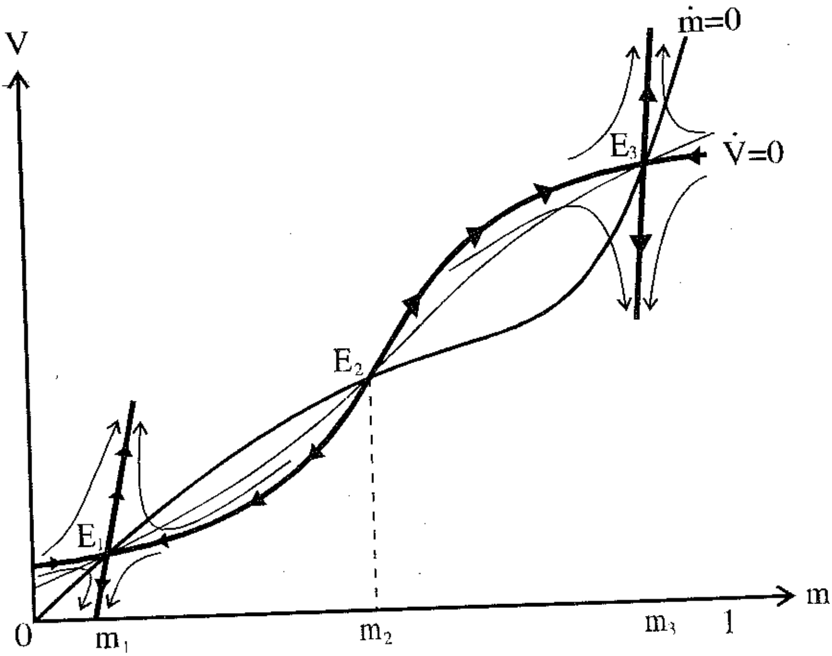
Trace $=r+ab>0$,

$$\begin{aligned} \text{Determinant} &= [-(1-b)a-b](r+b+a)-g_m(1-m)(1-b)a_\beta\beta_V \\ &= -(r+b+a)(1-m)(1-b)a_\beta\beta_V\{(\text{the slope of } \dot{m}=0) \\ &\quad -(\text{the slope of } \dot{V}=0)\}. \end{aligned}$$

As the slope of $\dot{V}=0$ is less than that of $\dot{m}=0$ at both E_1 and E_3 in Figure 1, the determinant (product of the two eigenvalues) is negative. This condition implies that the two eigenvalues have opposite signs and thereby E_1 and E_3 are saddles. Therefore, there exists a unique trajectory respectively that leads the equilibrium to converge toward E_1 or E_3. Analogously, E_2 is obviously a source as both the determinant and the trace (sum of the two eigenvalues) are positive and therefore the two corresponding eigenvalues are positive in sing; meanwhile, as the two eigenvalues at E_2 may be real or complex, the system may expand away from E_2 in a monotonic or oscillating manner. Combined with the fact

Figure 2

Heteroclonic Orbit will E_2 a Monotonic Source

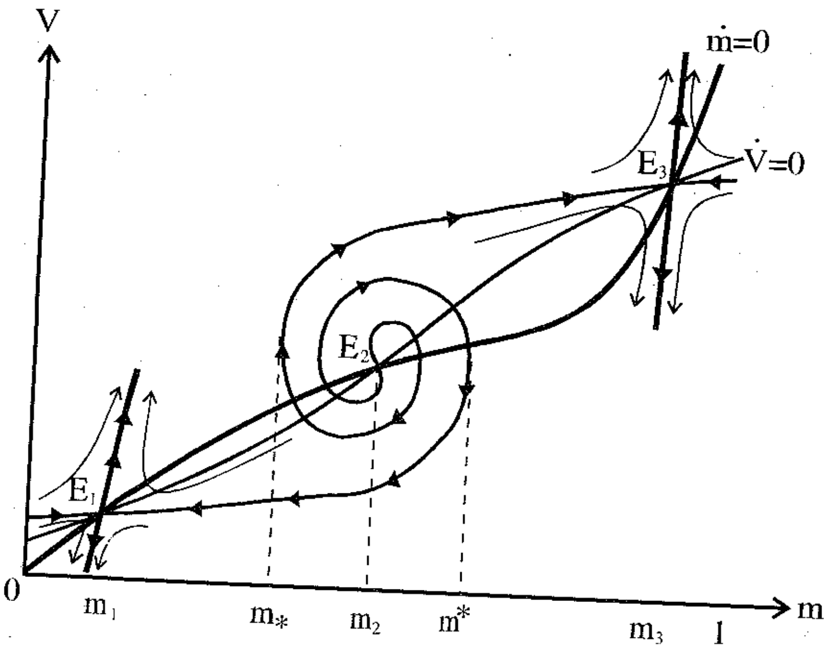


that both E_1 and E_3 are saddles, it then becomes evident that the paths emanating from E_2 are heterclonic orbits. These two cases are illustrated respectively in Figures 2 and 3.

Figure 2 depicts the case in which the paths emanating from E_2 are monotonic. This case defines a threshold of m_2. "History" plays a major role in selecting an equilibrium in this situation. The economy obviously converges monotonically and gradually toward the steady state E_1 with a low level of industrialization in the steady state when the economy starts with the size of modern industry smaller than the threshold m_2..Intuitively, when the size of the modern industry is below the threshold and thus the productivity of the modern technology is small, the expected value surplus obtainable from adoption of a modern technology is not greater than the learning cost. The learning incentive of entrepreneurs in traditional industry (β) is therefore diminished, and thereby the mean technology-adoption probability ($a(\beta)$) is lessened. The fraction of people entering into this industry, $(1-m)(1-b)a(\beta)$, is

Figure 3

Heteroclonic Orbit with E_2 an Oscilating Source



consequently smaller than that existing from it, mb. As a result, the modern industry shrinks and the economy moves to a steady state with a low level of industrialization.

When the path stemming from E_2 is oscillating, the story is more complicated. The orbits in figure 3 involve a range of values of m, from m_* to m^*, from which either E_1 or E_3 can be reached in the steady state. In this situation, even when the economy starts with m greater than m_2, the poor level of industrialization at E_1 may result as long as m is less than m^*. Here the "self-fulfilling prophecy" plays a pivotal role in selecting an equilibrium. Intuitively, although the productivity of modern technology is large currently when $m > m_2$, this fact may not ensure the result that the expected productivity of modern technology is also large in the future. This condition occurs when entrepreneurs expect that people outside the modern industry, due to pessimistic expectations about capital gains obtainable from adopting a modern technology, make insufficient learning effort such that the fraction of people entering into is smaller than that existing into this industry. These entrepreneurs then expend only a smaller learning effort; as a result, the modern industry shrinks, and the productivity of modern technology is diminished. Entrepreneurs' beliefs are thus self-fulfilled.

We must point out that, although both history and expectations play roles in selecting an equilibrium in our model as do in Krugman (1991) and Matsuyama (1991), the factors underlying the dynamic are different. It is the entrepreneurs' technology-adoption incentives that explain the underlying dynamic evolution in our model. In contrast to Krugman and Matsuyama, entrepreneurs in our model invariously make an effort to adopt modern technology, although the intensity of effort may be large or small. The reason is that in our model modern technology is assumed to be more productive than its traditional counterpart given that the installation or adoption cost of modern technology has been specified separately, and that entrepreneurs are allowed to transfer sector to produce after they have been already in one of two sectors. In this circumstance, the economy under question possesses at least a (non-negligible) small rather than zero fraction of modern industry in the steady state. This result is more nearly applicable to the real world as most developing countries obtain a proportion of modern manufacturing sector. For example, even the lowest fraction of manufacturing sector in term of GDP was 4% (Uganda) in the world in 1990; for industry as a whole as against agriculture and services, this fraction is even greater (7%).[7] This case exemplifies the situation that a manufacturing sector in even the least developed country is not zero but small.

This poor industrialization is an unfortunate result. This result may reflect phenomena in the real world; that is, while countries in Western Europe, North America and Japan have increased incomes per capita to high levels, less developed countries in Southern Asia, Africa and Latin America have remained at low levels. According to our model, an important reason for this result is that the cost of adopting new technologies in these less developed countries is great, so to diminish technology-adoption incentives. In the real world, one main ground resulting in this great learning cost may be the fact that average educational levels in these countries are generally low. As a consequence, it is more expensive and difficult for people in these countries to learn a given modern technology than for people in developed countries. Accordingly, most people in these less developed countries prefer to use traditional technologies instead of learning modern technology. This condition maintains poor industrialization, and the income per capita

7 See World Bank (1992), table 3.

remains small. In this situation, an economy cannot escape from this poor industrialization without a takeoff, the possibility of which we next investigate.

V. Policy Implications: Takeoff

According to the analysis above, the major reason resulting in poor industrialization lies in the fact that people are lack of incentives to learn modern technologies. Policies to escape from this poor industrialization should therefore be designed to enhance learning incentives.

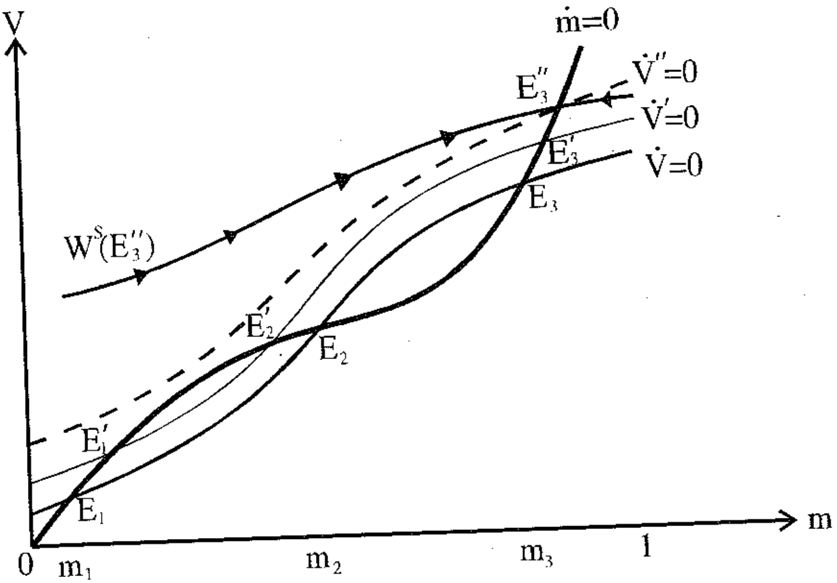
When analyzing implications of policy for economic development, it is worthwhile to learn from the experience of successful economic development. Japan and the "four Asian tigers," among others, are proper examples. Among these countries, we are familiar with the fact that Japan has expanded its economy from poor industrialization to the current advanced industrialization and these later comers have moved progressively from underdeveloped to the current "newly industrialized" levels. These countries have a common property, namely large rates of savings. In a dynamic model, a small rate of time preference, other things else equal, implies a large rate of saving. According to equation (6), a smaller rate of time preference indicates a greater value surplus obtainable from joining modern industry. And according to equation (8), a greater expected values surplus in turn launches entrepreneurs' incentives to learn the modern technology. People are hence willing to exert efforts more vigorously when learning a modern technology. In equilibrium, there is then a larger size of modern industry, and the reward from production is consequently greater becuse of a greater externality.

To draw policy implications from an economy with a small rate of time preference, the simplest way is to evaluate how the steady states are altered if the rate of time preference varies from a high level to a low level. This analysis involves a comparative statics. According to equations (9) and (10), as r is reduced, the curve $\dot{V}=0$ shifts upward for any given level of m whereas $\dot{m}=0$ is not influenced because r does not appear in this curve. Intuitively, a smaller rate of time preference results in a small value surplus according to equation (10). There is therefore a capital loss, i.e., $\dot{V}<0$, and thus a chance for an arbitrage. Under a fixed level of m, the value surplus must increase to avoid arbitrages in the steady state. Therefore, $\dot{V}=0$ shifts upward at any given level on m.

With an upward shift in $\dot{V}=0$ we obtain three new steady states denoted by E_1, E_2, and E_3 in Figure 4. According to the figure, both the new steady states at E_1 and E_3 are each obviously Pareto-dominating the old ones at E_1 and E_3 respectively as each corresponding value surplus is increased. Nevertheless, E_1 is still a low level of industrialization, and thereby the economy continues to stagnate and stays poor. Evidently, a small reduction in the rate of time preference is inadequate. The economy needs a takeoff to escape from this poor industrialization. Such a takeoff could be achieved if people in the economy become patient, namely if the rate of time preference r becomes sufficiently small. Intuitively, if r is small enough, the curve $\dot{V}=0$ may be pushed upward so much that there is only one steady state (E_3'' in Figure 4). The critical rate of time preference depends on the economic structure. Given the economic structure, the assumptions on g, a and f, and the optimal learning behavior, the critical value r* can be calcualted if we parametrize g, a and f. If the realized rate of time preference happens to be below the critical value r*, from whatever initial value of m, the economy moves along the "turnpike" $W^s(E_3'')$(Radner, 1961) and becomes industrialized gradually.

Figure 4

Possibility for a Takeoff



Although a small rate of time preference is beneficial to escape from a poor industrialization, there are difficulties of two kinds. First, if r* is negative there is no possibility for a take off by decreasing the rate of time preference. Second, even if r* is positive, the rate of time preference is not a policy that a government can easily control or alter in a brief period. These difficulties may explain why some Asian countries have taken off while most of the developing countries have not.

The learning incentives, and therefore to a certain extent the educational incentives, are important for adoption of a more productive technology; more importantly, the government has the ability to influence these incentives. If individuals expend greater effort toward technology adoption, the economy becomes industrialized more easily. However, because individuals cannot capture all benefits from modern technology when they pay the cost of technology adoption, they decline to exercise effort to the socially optimal levels when adopting the modern technology. As the net social benefit exceeds the net private benefit if the external benefit is taken into consideration, the government can intervene to subsidize individuals' cost of learning and technology adoption under this situation. The most apparently successful cases of this policy of subsidy are seen in Japan and South Korea in their early stages of development (see Shinohara, 1982; Song, 1990). Given the same expected income of V, this subsidy increases individuals' incentives to learn modern technology. As a consequence, the economy gains a larger modern industry. The economy finally benefits from the external expansion in productivity.

An another policy in a similar dirction is to diminish y. According to equation (6), a decreased y enlarges the income gap between modern technology and traditional technology and therefore launches incentives for technology adoption. Some newly industrialized countries utilized this policy when they started economic development. Kuo (1983) noted the use of a "hidden rice tax" from 1952 to 1960 in Taiwan when the share of rice over overall agricultural products was above 45%;[8] she found that the hidden rice tax diminished the share of rice and contributed to the development of food processing and other industries and to an early stage of industrialization in Taiwan.

We draw on some educational achievement among East Asian countries as educational accomplishment is related to ability (or cost) and incentives of technology adoption. In Japan, numerous foreign scholars and technological experts were imported and students were sent to the

[8] See Kuo (1983), chapter 3.

West after the Meiji Restoration. Moreover, Japan had a high enrollment rate in primary school since the late 1880. These factors allowed Japan to become industrialized quickly after World War II.[9] As for newly industrialized East Asian economies, because governments in these economies have devoted much budget to educational investment, these economies have accomplished high average educational levels. During the past thirty years many foreign undergraduate and graduate students from these economies, especially from Hong Kong, South Korea and Taiwan, studied in USA. Of these students many returned to their countries after graduation. These people helped either to adopt western advanced technologies into domestic industry or to teach the next generation at schools. This condition made people in these countries learn advanced technologies at smaller cost than in other developing countries, and made their country become industrialized quickly. Such achievement seems to indicate education to be a viable way to acquire more productive technologies.

VI. Concluding Remarks

We have constructed a dynamic model to address the issue regarding the causes of a low level of industrialization and the possibility of a takeoff from this poor industrialization. We feature a prolonged diffusion of modern technology, while allowing entrepreneurs to make a learning effort to hasten the process of obtaining modern technology. We find that this economy may attain a steady state with a low level of industrialization. Entrepreneurs' lack of incentives to learn technology is the key reason producing this poor industrialization. We discussed the possibility of a takeoff from this state, illustrated with successful achievement of economic development.

Some people may consider our supply-side setting to be special. However, we believe this consideration to be untrue. The specification of only the supply side is one common characteristic in most models of economic growth and development. The reason that in most work of growth and development this setting is employed is that the supply-side effect generally dominates other factors in the long run. Moreove, this simplified setting makes our model more intuitive and more easily tractable. Although we are aware that the demand in commodity market may have a sillover effect on the supply side,[10] and although we know that

9 See Easterlin (1981). See also Lockwood (1954, chapter 1) for similar arguments.

10 See the argument made by, for example, Leijonhufvud (1968) and by Murphy, Shleifer and Vishny (1989b).

some people advocate the importance of money and finance in the development process,[11] we excluded such consideration from the model. This deliberate omission, however, does not harm the purpose of this paper. Conversely, this omission sheds light on the roles of both a limited diffusion of technology and insufficient learning incentive that result in poor industrialization. We think that the specification of only the supply side is proper in this respect.

11 For example, McKinnon (1974) advocates that large real cash balances, held in portfolio equilibrium, enhance the rate of growth.

References

Arrow, K.J., "The Economic Implications of Learning by Doing." *Review of Economic Studies,* 29, 1962, 155-173.

Blanchard, O.J., "Debt, Deficits, and Finite Horizon," *Journal of Political Economy,* 93, 2, 1985, 223-247.

Caballero, R.J. and K.L. Richard, "Internal versus External Economies in European Industry," *European Economic Review,* 34, 1990, 805-830.

——— and ———, "External Effects in US Procyclical Productivity," *Journal of Monetary Economics,* 29, 1992, 209-225.

Diamond, P., "Aggregate Demand Management in Search Equilibrium," *Journal of Political Economy,* 90, 5, 1982a, 881-894.

———, "Wage Determination and Efficiency in Search Equilibrium," *Review of Economics Studies,* 49, 1982b, 761-782.

Easterlin, R.A., "Why Isn't the Whole Developed?," *The Journal of Economic History,* 41, 1981, 1-17.

Hirsch, M.W. and S. Smale, *Differential Equations, Dynamical Systems, and Linear Algebra,* Academic Press, New York, USA, 1974.

Howitt, P. and P. McAfee, "Costly Search and Recruiting," *International Economic Review,* 29, 1, 1987, 88-102.

Kiyotaki, N. and R. Wright, "On Money as a Medium of Exchange," *Journal of Political Economy,* 97, 4, 1989, 927-954.

Kuo, S.W.Y., *The Taiwan Economy in Transition,* Westview Press, Boulder, Colorado, 1983.

Leijonhufvud, A., *On Keynesian Economics and the Economics of Keynes,* Oxford University Press, New York, USA, 1968.

Lockwood, W.W., *The Economic*

Development of Japan: Growth and Structural Change, Princeton University Press, 1954, 1868-1938.

Matsuyama, K., "Increasing Returns, Industrialization, and Indeterminacy of Equilibrium," *Quarterly Journal of Economics,* 106, 1991, 617-650.

McKinnon, R., "Money, Growth and the Propensity to Save, in G. Horwich and P.A. Samuelson, *Trade, Stability, and Macroeconomics: Essays in Honor of Lloyd Metzler,* Academic Press, New York, USA, 1970.

Murphy, K.M., A. Shleifer and R. Vishny, "Income Distribution, Market Size, and Industrialization," *Quarterly Journal of Economics,* 104, 1989a, 537-564.

_____, _____ and _____, "Industrialization and the Big Push," *Journal of Political Economy,* 97, 1989b, 537-564.

Radner, R., "Paths of Economic Growth that are Optimal with Regard only to Final State," *Review of Economic Studies,* 28, 1961, 98-104.

Shapiro, C. and J. Stiglitz, "Equilibrium Unemployment as Worker Discipline Device," *American Economic Review,* 74, 3, 1984, 433-444.

Shinohara, M., *Industrial Growth, Trade and Dynamic Patterns in the Japanese Economy,* Tokyo, University of Tokyo Press, 1982.

Song, B.N., *The Rise of the Korean Economy,* Oxford University Press, Hong Kong, 1990.

World Bank, *World Development Report,* Oxford University Press, New York, 1992.