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A Model of Innovation, Emulation, and the Dynamics of Trade Patterns

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This paper intends to formalize the Product Life Cycle theory of international trade focusing on technological aspects, especially on how technological creation and diffusion cause dynamic changes in the trade pattern. Optimal control theory and dynamically changing nature of technology concept are employed as an analytical framework. Based on model results, this paper also explores the relationship between the static factor proportions approach and the dynamic technology approach of international trade patterns and concludes the former is a special case of the latter.

I. Introduction

Since the "Leontief Paradox" was posited, formulation and testing procedures in international trade theory have been in a state of flux. However, comparative advantage or international competitiveness is generally conceived to be the determining economic factor of international trade.

International economists recognize that comparative advantage is a dynamic rather than a fixed process. Technological advance, capital accumulation, acquisition of new skills, and introduction of new products are commonplace in all dynamic economies. There is a proliferation of empirical and policy literature which relies on simplified descriptions of these processes at work, notably Vernon's (1966) pioneering concept of the "product life cycle (PLC)," Krugman's (1979) simple general equilibrium model of product life cycle trade, and Sato's (1988) game theoretic international technology competition.

In spite of the simplicity, these studies have exhibited several deficien-

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cies. First, although the PLC theory attempts to explain the gradual shift of comparative advantage away from the innovating countries, theoretical inadequacy is apparent in its inability to explain the recent counter trend of internationally located U.S. firms moving back to the U.S. from overseas production. Second, the duration of the PLC has been mentioned in the literature, but factors affecting it have not been seriously analyzed.

The purpose of this paper is to formalize the PLC theory by focusing on various technological aspects, particularly on how technological creation and diffusion cause dynamic changes in the patterns of international trade in imperfectly competitive world markets. It will show how one country's comparative advantage shifts to another country over time and under what conditions shift of comparative advantage takes place. Related to this shift is the relationship between both countries' innovation and duration of the PLC. The analytical framework employed here is the dynamic limit pricing model which was initially formulated by Gaskins (1971) and extended in its application by Magee (1977a) and Sohng (1988). In using the model for the present purpose, some modifications and extensions are made: Technology is embodied in the new product and its nature changes dynamically from a private good to a public good, an analogy is made between a dominant firm and a dominant country from an empirical point of view, and the product market grows at a diminishing rate so as to fit the PLC theory. Through this reconceived model, the effect of technological creation and diffusion on export performance is examined for various rates of optimal product price-reductions over time. Implicit in the dynamic theory of comparative advantage is the assumption that the technological superiority of one country inevitably leads to comparative advantage. This is because of the advanced technology of that country results in low costs, which in turn lowers domestic and export prices. Low prices lead to comparative advantage and thus to superior export performance.

The conclusions of this paper are conceptual and suggestive, and the limitations of the analysis should be noted. An innovating developed country is implicitly assumed to remain as a dominant country, regardless of market share. But from a behavioral point of view, at some market share, the country will lose its identity as a dominant country. This model is not proposed to replace existing theories but proposed to supplement them.

The remainder of the paper is in three parts. Section II briefly discusses the concept of the dynamically changing nature of technology. Section III will introduce a dynamic limit pricing model with a linear demand curve in a static market situation and will apply the model to the growing market, where the new product market is allowed to grow at a diminishing rate. In Section IV, the implications of the model will be conflated with the PLC theory, and dynamic comparative advantage and policy implications of the analysis are discussed.

II. Technology in International Trade

The importance of technology in international trade is not limited to the changes it provokes in the size and the quality of factor endowment; it also influences the composition and growth of a country's pattern of trade by fostering new or improved products. The technological factor is crucial, especially in manufactured trade, for three reasons. First, the major share of the composition of world trade and the most rapidly growing sector of trade is in manufactured goods. Also, trade in newly developed products appear to be growing faster than trade in standardized products. Finally, manufactured exports from less developed countries are increasing rapidly as a result of dramatic technological progress in the past two decades.

In spite of the crucial importance of technology and technological change on manufactured trade discussions of technology factor in international trade have been few. Jones (1970) examines the effects of technological change in a Heckscher-Ohlin framework, while Dornbusch, Fischer and Samuelson (1977) discuss within a Ricardian model. Economic theory usually represents technology as a given set of factors' combination defined (qualitatively and quantitatively) by certain outputs. Technical progress is generally defined in terms of a moving production-possibilities curve, and/or in terms of the increasing number of producible goods. Krugman correctly points out why technological change has received so little emphasis in international trade theory. First, conventional models, although well suited to the analysis of once-for-all technological change, are less suited to the analysis of on-going technological change. Second, conventional models ignore the dynamically changing nature of technology.

The definition of technology introduced here is much broader. As suggested by Dosi (1982), technology is pieces of knowledge, know-how, methods, procedures, a history of successes and failures, and also, of course, physical devices and equipment. Technology is not a public good in the sense that it is available with search cost and that its use by one producer restricts its availability to others in the form of patents, licenses, and so on. Contrary to the standard assumption of international trade theory, such technology is a private good. Technological knowledge generally, however, cannot be kept secret forever by its innovator. Changing dynamically, technology is a private good at the outset and, through the diffusion process, becomes a public good. New technology gives its creator a temporary monopolistic power, which disappears when technology becomes a public good through diffusion.

III. Dynamic Pricing Behavior of Innovator

Because technological innovation and diffusion give rise to the limitation and the eventuation of the PLC, an innovating firm's behavior plays a crucial role in the product life cycle. Gaskins applied optimal control theory to maximizing the present value of future profit streams and attempted to determine the optimal pricing strategy for both a dominant firm and a group of profit-maximizing oligopolists threatened by potential entry in an imperfectly competitive structure of industry. Magee transposed this problem into an optimal pricing strategy for an innovating multinational corporation using Gaskins dynamic limit pricing model.

In transposing an industrial organization pricing model into an international trade model, it is necessary to make an analogy between countries and firms. If a single firm in a single country possesses the new technology, then the country will obviously behave as a dominant firm in trade because the firm will do so. But what will happen when a single country has the technology and it is shared among numerous firms within the country? Even in this case, an innovating dominant firm's behavior can bear some analogy with that of a technologically advanced country composed of a group of innovating multinational corporations; this analogy is justified by the observation that countries composed of multinational corporations compete in an imperfectly competitive world market to maintain and create technological superiority. It can be said that a large country that possesses technological superiority, such as the United States, behaves like a large dominant firm in some respects.[1]

A. *Static Market Model*

If we consider a multinational corporation that develops a new technological innovation in the world market, we may immediately assume

1 Such an abstraction is also made by Magee (1977a) that the U.S. is a logical candidate for the "dominant firm country" since the U.S. held 41 percent of the foreign held patents obtained in developing countries in 1972.

that the firm wishes to maximize the present value of its long-run profit. Several other simple assumptions help to establish the framework for the analysis of the static market model. These are: (1) The innovative component of the product is such that it cannot be priced separately from the product; (2) The innovating firm charges a uniform price. It neither price discriminates nor dumps the product; (3) Production is based upon constant returns to scale at any moment in time; (4) Competitors view the current price of the products as the future price; (5) The costs of production remain constant over time; and (6) the innovating firm does not engage in further technological development. Given these assumptions, the objective function of the innovating firm may be shown as follows:

(1) $V[P(t),C(t),q\{P(t),t\},t] = \int_0^t \{P(t)-C(t)\} q\{P(t),t\} \, e^{-rt} dt$

where $P(t)$ = price of new product

$C(t)$ = innovating firm's average total cost of product

$q\{P(t),t\}$ = quantity sold by the innovating firm as a function of its price and time

t = time

r = discount rate

The quantity sold by the innovating firm at any time equals the market demand minus the output that is sold by competitors who successfully copy the new technology.

(2) $q\{P(t),t\} = q_0\{P(t)\} - X(t)$

where $q_0(P)$ = initial demand schedule

$X(t)$ = level of rival sales

The rate of entry of competitors is clearly determined by their expected return. Because competitors view the current price of the product as the future price, the change in the output by the competitor is

(3) $\dot{X}(t) = k\,\{P(t) - \bar{P}\}$

where $\bar{P}$ = a limit price for the new product (price at whcih no firm would copy and attempt to sell the innovating firm's new high technology product)

$\dot{X}$ = rate of entry (time derivative of X)

k = competitor's response coefficient ≥ 0

The difference between the limit price and the innovating firm's average total cost is a measure of the cost advantage enjoyed by the innovating firm. One restriction, however, is that the limit price must exceed or equal the innovating firm's average total cost since the innovating firm is assumed to have an initial cost advantage. With these simplifying assumptions, it is possible to determine the optimal pricing strategy with the mathematics of optimal control. In the language of control theory, the objective function to be maximized is:

(4) $$V = \int_0^t \{\bar{P} + \delta(t) - C\}\,[a - b\{\bar{P} + \delta(t)\} - X(t)]\,e^{-rt}dt$$
$$= L\{\delta(t),\, X(t), t\}$$

subject to $\dot{X}(t) = K\delta(t)$; $X(0) = 0$

where $\delta(t) = P(t) - \bar{P}$

$$C \leq \bar{P} \leq \frac{a + bC}{ab}$$

$$q(t) = a - b(\bar{P} - \delta(t)) - X(t)$$

a, b, C, $\bar{P}$ are positive constants

a = output intercept of original demand curve

b = slope of demand curve

Through an extensive mathematical manipulation,[2] the optimal price trajectory[3] is given by the following:

(5) $$P(t) = \bar{P} + \delta(t) = \bar{P} + \frac{X}{k} - \frac{\lambda_2 \Theta e^{\lambda_2 t}}{k}$$

where $$\lambda_2 = \frac{r - (r^2 + 2kr/b)^{\frac{1}{2}}}{2}$$

$$\Theta = \frac{k}{r}(C - \bar{P}) + b(C - 2\bar{P}) + a$$

Figure 1 shows the possible price trajectory for infinite time horizons.[4] The optimal price is a decaying exponential approached from above and

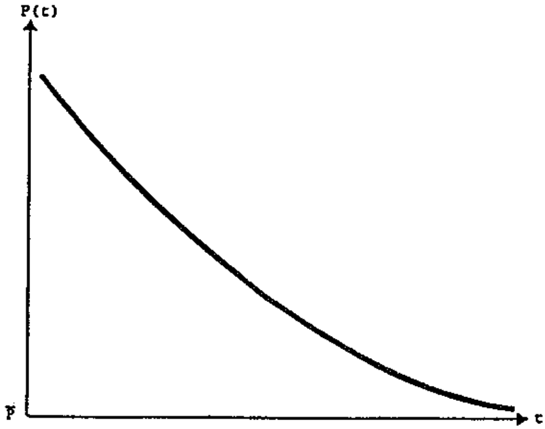
2 Making the substitution $Y(t) = Z(t)e^{rt}$, the necessary conditions become a simple two point boundary value problem involving ordinary linear differential equations with constant coefficients.

3 The continiuty and concavity of L and $\dot{X}$ with respect to δ and X assures at least one optimal path by using Pontryagin's maximum principle.

4 Mathematically speaking, it is possible that the optimal price trajectory is a decaying ex-

Figure 1

Optimal Price Trajectory for New Product



the optimal price trajectory is the path that the innovating firm should follow in pricing its new product so as to maximize its profit in the long run. By differentiating Equation (5), it is possible to verify the following comparative static results concerning the effect of various structural parameters on the optimal price at any instant in time.

$$\frac{dP}{d\bar{P}} < 0 \text{ and } \frac{dP}{dC} > 0$$

It is conceivable that the cost advantage of the innovating firm, measured by the difference between the innovating firm's average total cost and the limit price, shrinks as competitors slowly develop matching technology. This is true for the case where a cost advantage established by the innovating firm gradually erodes as competitors gain experience. Thus, it could also be assumed that potential entrants acquire new technology embodied in the new product without cost but with a lag. Slight modification of the assumption (5) implies that potential entrants' learning is a function of both the length of time an industry has been produc-

ponential approaching P from below where the value of Θ is negative. The value of Θ, in turn, is determined by the values of parameters. But this possibility is ignored because it has little economic meaning. In the real world, firms rarely set prices low initially and raise them gradually because of uncertainty about the future. Uncertainty could be a good excuse for eliminating the negative Θ case, but there is a problem to justify this model, since the model itself is deterministic rather than uncertain. Another reason for eliminating negative Θ could be explained by the assumption put in this model. Negative Θ means that firm's price trajectory approaches $\bar{P}$ from below, then it may lead to dumping, which is excluded in the assumptions.

ing a particular new product and the technological capability of firms. Thus, the presumption is that the competitor will enter the market at a disadvantage that can only be overcome after experience accumulates. Assuming that the limit price declines exponentially over time as:

(6) $\bar{P}(t) = (\bar{P}_0 - C)\, e^{-\sigma t} + C$

where $\bar{P}_0$ = initial level of the limit price

σ = rate of decline of limit price

Optimal price trajectory looks basically like a monotonically declining exponential in that it eventually approaches average total cost. As indicated by $\frac{dP}{d\sigma} > 0$, the initial level of the optimal price will be raised as the rate of decline of the limit price is increased. Also, higher levels of σ will increase the observed rate of decline in the optimal price trajectory.

B. Market Growth Model

The model just discussed is based on a strict assumption that the market does not grow at all. This is not only unrealistic but inconsistent with the dynamic feature of the economy, where demand for a new product stops growing only after saturation. In an infinite time horizon, a change in market size depends upon various factors like taste, income, population changes, and so on. Noting that an economy with a growing population and increasing per capita income is not consistent with a static product market, Gaskins postulates that product demand increases exponentially. It is unreasonable to expect the demand curve for a new product to continue to shift in this manner. One assumption that must be added to the static market model, therefore, is that the market grows at a diminishing rate.

Demand for a new product continuously increases as it becmes a commercial success; however, the market eventually becomes saturated. This assumption is empirically confirmed by Thorelli and Burnett (1981) based on PIMS data. As the age of the product increases, there is a steady and highly significant decrease in the average rate of market growth. Hence, the output intercept of the demand curve continues to shift, but the magnitude of shifts eventually approaches zero. Under the assumption of a diminishing rate of market growth, the output intercept of the demand curve continues to shift, but the magnitude of shifts eventually approaches zero. Under the assumption of a diminishing rate of market growth, the output intercept of the demand curve is

(7) $$a(t) = A(1-\frac{1}{1+t})$$

With the diminishing rate of market growth,[5] the innovating dominant firm's objective function becomes

(8) $$V = \int_0^t \{\bar{P} + \delta(t) - C\} [\frac{A}{1+t} - b\{\bar{P} + \delta(t)\} - X(t)] e^{-rt} dt$$

$$\text{subject to } \dot{X}(0) = 0, \quad \dot{X} = k\delta$$

Application of Pontryagin's maximum principle yields necessary conditions for maximum V to exist.[6] These conditions are converted into simultaneous differential equations such that solving these equations with end point constraints yields the optimal price trajectory that follows

(9) $$P(t) = \bar{P} + \frac{\dot{X}}{k} = \bar{P} + \frac{1}{k} \{\lambda_2 \Phi_2 j_2 + \frac{\Phi_2 f_2 k}{2b} (A + bC - 2bP)\} e^{\lambda_2 t}$$

$$-\frac{A(\Phi_1 f_1 + \Phi_2 f_2 k)}{2b(1+t)k} + \frac{\lambda_1 \Phi_1 f_1}{k} e^{\lambda_1 t} \int_0^t \{-\frac{A}{2b(1+r)}\} e^{-\lambda_1 s} ds$$

$$+ \frac{\lambda_2 \Phi_2 f_2}{k} e^{\lambda_2 t} \int_0^t \{-\frac{Ak}{2b(1+r)}\} e^{-\lambda_2 s} ds.$$

This optimal price trajectory is composed of three components: First is the constant limit price portion, the second is the monotonically declining exponential with respect to time, and the third is the declining hyperbola with time. These components are combined to generate a price trajectory that continually declines over time, asymptotically approaching the limit price as time passes.[7] This differs from Gaskins' result which stipulates that the optimal price trajectory does not approach the limit price or average total cost but rather diverges over time. The price of a new pro-

[5] It is conceivable that optimal price trajectory will decline faster when the entry coefficient is allowed to grow than the constant entry coefficient case.

[6] Pontryagin argues that the maximum principle holds for a function taking the form of an indefinite integral if the integral converges and the boundary condition on the adjoint variable is defined as a limit rather than a strict equality.

[7] Although the mathematical solution is not explicitly shown, one can imagine that the optimal price trajectory approaches the total average cost if both the dominant firm's cost advantage and market growth rate diminish.

duct embodying new technology remains elevated when the innovator has substantial monopoly power. However, it eventually approaches the limit price or average total cost level after technological diffusion, when the innovator becomes one of many perfectly competitive firms. Such behavior is caused by the interaction between innovating and emulating firms who wish to maximize profit over time.

IV. Implications of the Analysis

The model that emerges is quite different from what economists are accustomed to in international trade theory in a sense that this model allows continual changes to take place at a micro level in a dynamic economy. New products (industries) are constantly emerging in the developed countries, then disappearing in the face of low-wage competition from the less developed countries. To the extent that the model captures some aspects of the real world, it provides some insights into neglected aspects of the international economy and it has implications for economic policy.

A. Market Concentration and Technology Standardization

One implication of the limit pricing model concerns the relationship between market concentration and technology standardization. The continually declining nature of the optimal price trajectory of the innovating firm reflects the continuous shift from a private good to a public good as imitation and diffusion of the technology embodied in the product continues. As more firms enter into competition, $X(t)$ increases and the innovating dominant firm's market share gradually falls to zero.[8] The continual shift of market structure from a monopoly to a perfectly competitive market is the result of the continual entry of competitors.

Along with the diminsihing market share of the innovator, the price of the product also continuously declines. This reflects a reduction of the innovator's monopoly rent as competitors copy the new technology. The initial market power of an innovator originates from the monopolistic possession of the technology as a private good. As time passes, competitors are progressively to catch up on the technology, which in turn, erodes the innovator's competitive edge.

[8] The market share of the innovating firm at any point in time is

$$S(t) = \frac{q_0(p) - X(t)}{q_0(P)}$$

The relationship between market concentration and technology standardization has been supported by a number of empirical studies. For instance, Magee (1977a) demonstrated that industry concentration fell with the average age of the industry's product. Goodman and Ceyhun (1976) also found that technological innovations and industry concentration in new industries appeared to have statistically significant correlation.

B. Duration of the Product Life Cycle

In the case of a declining limit price (declining technological advantage by innovator), the rate at which limit price declines is correlated to the decline in the observed price trajectory. Such a feature is verified by the comparative static result ($\frac{dP}{d\sigma} > 0$). This might suggest that as a limit price declines more rapidly, current profit is regarded as more important relative to future profit. Hence, as the optimal price trajectory declines more rapidly, the innovator's market power diminishes more quickly and market structure tends to approach the perfectly competitive situation more rapidly. In the extreme case, where the rate of the innovator's cost advantage decline is infinite, then the initial optimal price will be very high, and the slope of the optimal price trajectory will be a nearly vertical line, indicating that the price of the new product will decline instantaneously.

The product that embodies less sophisticated technology matures faster and is easier for competitors to copy. In return, the time period that the innovator holds its competitive advantage is shortened, which results in a speeding-up of the product life cycle. The hula-hoop is often given as a good example of a product that embodied an unsophisticated technology and matured very quickly. The rapid decline in the price of the new product rendered a shorter duration of competitive advantage to its producer.

The duration of the product life cycle is also shortened when competitors improve their technological capabilities. Comparative static results $\frac{dP}{d\bar{P}} < 0$ and $\frac{dP}{dC} > 0$ jointly suggest that as a firm's relative cost advantage decreases, the optimal price trajectory will increase. When $\bar{P}$ decreases, the optimal response for the innovator is to raise its price trajectory since a reduction in $\bar{P}$ lowers the value of future profits. A decrease in average costs will similarly raise current profits relative to future profits. The innovator's cost advantage narrows as competitors' technological capabilities improve. This, in turn, creates a tendency for the innovator's new technology to be diffused quickly, meaning future profits are less important than current profits. As a result, the innovator raises the current price level, which implies a reduction in the future price. This indicates that the technological edge of the innovator erodes rapidly, resulting in a shorter duration of the product life cycle.

As shown in the comparative statics results, the duration of the innovating firm's cost advantage relative to the potential imitators varies positively with the technological sophistication embodied in the new product and with the technological gap between the innovator and imitators. Thus, the duration of innovator's cost advantage in the new product *vis-à-vis,* any potential imitator will be longer when the product life cycle proceeds slowly, *ceteris paribus.*

The above arguments, accordingly, can be used to formulate determinants of PLC duration in the following general forms:

$$L = f(\overset{-}{D}, \overset{+}{I}, \overset{-}{A}, \overset{+}{T}, \overset{+}{F})$$

where L = duration of product life cycle
D = dominant firm's rate of technological diffusion
I = dominant firm's rate of technological innovation
A = competitor's capacity to absorb and utilize new technology
T = technological complexity of new technology
F = dominant firm's factor cost advantage

Thus, the duration of the product life cycle is determined by various factors. The length of advantage enjoyed by the innovator is positively related to the sophistication of the technology embodied in the new product, the innovative activity, and the innovator's relative factor cost advantage. It is inversely related to the imitator's technological capacity to absorb or utilize new technology and the technological diffusion faced by the innovator.

C. Shift of Comparative Advantage

As Johnson (1977) alludes, technology will generate international trade at the micro-economic level of comparative advantage due to a combination of superior technology and abundant endowments. Technology, unlike the natural climatic conditions of the Ricardo model, can be both moved from one location to another and accumulated or decumulated. And, unlike the material capital of the factor proportions model, technology can be accumulated fairly rapidly on a massive scale, though it cannot be quickly decumulated or transformed from one specific form into another. Therefore, when one country has comparative advantage in one good, that advantage may arise from superior technology or factor endowments, or combination of the two.

The comparative advantage that is derived from technology can be called "dynamic advantage" because this kind of advantage changes over time. Dynamic advantage is distinct from "static advantage," which originates from relative factor endowments. Dynamic advantage, therefore, constitutes a source of comparative advantage in trade which is "additional or alternative" to static advantage as Johnson (1976) indicated.[9]

With the conceptual framework of the two distinct advantages, the country's comparative advantage should be determined neither by dynamic advantage alone nor by static advantage, but by the combination of both advantages. For instance, if one country has both advantages, they reinforce each other and produce even greater comparative advantage. When country A is not able to produce the new product because of the unavailability of technology, then country B has a dynamic advantage in the new product. Thus it exports the product to country A. When country A can produce the new product, but relative production cost is cheaper in country B due to superior technology, then country B also has a dynamic advantage in the new product.

However, a country may not maintain dynamic advantage permanently because the technology underlying the product can be imitated by foreign competitors or transferred abroad through one channel or another. When neither country has a dynamic advantage as a result of technological diffusion, relative production cost is solely determined by static advantage, which in turn is determined by relative factor endowments. But these two advantages may not occur together. If a country with a dynamic advantage has a static disadvantage, the static disadvantage counteracts the dynamic advantage and the comparative advantage is determined by the combination of the two. If, however, a country's dynamic advantage outweighs its static disadvantage, then that country will have a comparative advanage. Shifts of comparative advantage are determined by overall advantage.

Recently a surprising number of manufacturers, which make everything from semiconductors to auto parts, are shutting down foreign manufacturing facilities and moving back to the U.S.[10] North American

9 Similar points are also made by others such as R. Klein (1974), I. B. Kravis (1956) and B. A. Majumdar (1979)

10 These days some industries have experience remarkable technological innovation. Recently, color TV contained 750 electronic components, but now the number is down to 400, and by 1988 it should be close to 200. With fewer parts to assemble, labor is less im-

Philips Corporation is gradually shifting production of its Magnavox, Sylvania and Philco chassis from Mexico to a modern plant in Tennessee. RCA stopped producing surveillance cameras in Taiwan and moved back to Pennsylvania. Motorola is bringing semiconductor production back to the Arizona plant. Ford Motor Company formerly made automatic transmission for its Pinto abroad, but now equivalent parts for its replacement model, the Escort, come from a new Ohio plant. This counter trend cannot be explained by conventional framework of comparative advantage. This trend is responsible for changes in dynamic and static advantages and is explained by the fact that dynamic advantage more than offsets static disadvantage by producing in the U.S.

D. Policy Implication

Vicissitude of industries in a dynamic economy is recurrent because of technological innovation and diffusion among countries; it is a natural result of competitive activity between innovators and imitators. Technological innovation is more important than it usually appears in conventional models since it is a decisive factor determining which country is likely to possess a comparative advantage at a particular stage of the PLC. Developed countries should continually innovate, not just to grow, but also to maintain their comparative advantage through monopoly by compensating for factor cost disadvantage. For less developed countries, transfer of technology is the only way to shorten the duration of the product life cycle and to snatch a developed country's monopoly rent.

Another policy implication for a developed country like the U.S., which suffers from chronic deterioration in international competitiveness, is to encourage new industries to innovate rather than to protect old industries.

portant. Moreover, the gap between U.S. wage rates and those of the developing countries is beginning to narrow. In Taiwan, for example, wages have risen four times as fast as they have in the U.S. in the past 15 years. The firms moved back to the U.S., because dynamic advantage more than offsets static disadvantage by producing in the U.S. plant.

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