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A Model of Innovation, Technology Transfer, and the World Distribution of Income

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This paper develops a simple general-equilibrium model of product cycle trade. There are two countries, innovating North and noninnovating South. Innovation consists of the development of new products. These can be produced at first only in North, but eventually the technology of production becomes available to South. This technological lag gives rise to trade, with North exporting new products and importing old products. Higher Northern per capita income depends on the quasi rents from the Northern monopoly of new products, so that North must continually innovate not only to maintain its relative position but even to maintain its real income in absolute terms.

I. Introduction

It is a commonplace that technological innovation in developed countries and the transfer of technology to less developed countries both play an important role in determining the pattern of world trade and changes in that pattern over time. There is an immense empirical and policy literature on innovation and technology transfer in world trade; a literature which draws heavily on simplified, stylized descriptions of these processes at work, notably Vernon's (1966) celebrated concept of the "product cycle." One might have expected that phenomena which are of recognized importance and at the same time display clear empirical regularities would have attracted the attention

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of theorists. But there have been surprisingly few attempts to introduce technological change into the theory of international trade.[1]

There appear to be several reasons why technological change has received so little emphasis in international trade theory. One is that existing models, while well suited to the analysis of once-for-all changes in technology, are less suited to the analysis of ongoing technical change. Also, the kind of technical change which can be analyzed in conventional models involves increased efficiency in production of a given range of goods, while the product cycle literature stresses the development of new products. Related to this is the problem of defining what is meant by a transfer of technology when technical change is assumed to take the form of disembodied increases in the efficiency of factors. Although there have been some useful efforts to solve these problems, notably the recent paper by Findlay (1978), the insights of the empirical workers are still hard to integrate into trade theory. It is not surprising, then, that the role of technology in trade has been relatively neglected.

The purpose of this paper is to take a first step toward making up for this neglect. It develops a fully worked-out model of international trade in which the pattern of trade is determined by a continuing process of innovation and technology transfer. I postulate a world of two countries: innovating North and noninnovating South. Innovation takes the form of the introduction of new products which can be produced immediately in North but only after a lag in South. The lag in adoption of new technology by South is what gives rise to trade.

The model has a number of interesting implications. There is no fixed pattern of trade; each good is exported by North when first introduced but eventually becomes an export of South instead. The model tends to approach a moving equilibrium in which North exports new products and imports old products. Wages will be higher in North, even if labor in the two countries is equally productive in comparable occupations, because of North's monopoly position in new goods. Finally, because northern wages reflect in part a rent on North's monopoly of new goods, a slowing of innovation or an acceleration of technology transfer narrows the wage differential and may even lead to an absolute decline in living standards of workers in North.

While the results of this paper are highly suggestive, the limitations of the analysis should be noted. I am concerned with the effects of innovation and technology transfer, not their causes; the rates at which they occur will be taken as exogenous. Also, the assumptions

[1] The effects of technological change in a Ricardian model are discussed by Dornbusch, Fischer, and Samuelson (1977). The effects in a Heckscher-Ohlin model are discussed in Jones (1970).

are chosen for simplicity and clarity, and no attempt is made at generality. I believe, however, that many of the qualitative results would hold in a more general model.

The remainder of the paper is in four parts. Section II develops the basic model. Section III examines the dynamics of the model and the effects of changes in the rates of innovation and technology transfer. In Section IV the model is extended to allow for international investment; the implications of the analysis are then discussed in Section V.

II. A Model of North-South Trade

There are two things we would like a theory of trade between developed and less developed countries to do. It ought to explain both the pattern of trade and why wages are higher in the developed country. The explanation that much of the literature on technology in world trade seems to be proposing is as follows: The advantage of developed countries does not lie in greater endowments of nonhuman inputs per worker or in superior overall efficiency as much as in a superior ability to exploit *new* technology. As a result, developed countries export newly developed products, and the rent on their monopoly in such products accounts for their higher wages.

In this section I develop a model designed to place this explanation of North-South trade into sharp relief by suppressing all other sources of trade. There is assumed to be only one factor of production—labor—in each country, ruling out differences in factor endowments; at the same time all goods are assumed to be produced with the same cost function, ruling out a Ricardian explanation of trade. Labor productivity in those goods which can be produced in both countries will be assumed to be the same in North and South, so that the special ability of North to produce certain goods will be the only source of inequality in wages.

There are assumed to be two kinds of goods—old goods and new goods. Old goods are goods which were developed some time ago. Their technology is common property, and they can be produced either in North or in South.[2] I choose units so that one unit of labor produces one unit of an old good.

New goods are recently developed products. They can only be produced in the developed country. This is simply assumed here. Vernon (1966) and others have discussed at length the reasons why

[2] What I call old goods correspond fairly well to what Hirsch (1974) calls Heckscher-Ohlin goods, i.e., goods which, unlike what he calls product cycle goods (my new goods), can be produced with the same technology anywhere in the world; and which, unlike his Ricardo goods, do not have special environmental requirements. My model, of course, omits Ricardo goods.

developed countries may have an advantage in producing new products; the reasons include a more skilled labor force, external economies, and a simple difference in "social atmosphere."

All goods, whether old or new, are assumed to enter demand symmetrically. The utility function, which is shared by all individuals, is assumed to be of the form[3]

$$U = \left\{\sum_{i=1}^{n} c(i)^{\theta}\right\}^{1/\theta} \quad 0 < \theta < 1, \tag{1}$$

where $c(i)$ is the consumption of the ith good, and n is the total number of products available. The number of products is the sum of the number of both new and old goods. For the moment we will take these as given, reserving the determination of these numbers to Section III.

There is also assumed to be a latent demand for as yet unproduced goods with the additional goods entering into the utility function the same way those previously produced did. That is, if Δn additional goods were made available to consumers, they would now maximize

$$U = \left\{\sum_{i=1}^{n+\Delta n} c(i)^{\theta}\right\}^{1/\theta} \tag{1a}$$

subject to their budget constraints.

Before proceeding, we ought to note an important point about the assumed utility function. The utility function (1) gives a positive value to the increased variety of available goods. For a given income and prices, an individual will become better off if he is offered a wider selection of goods. In Section III technological change will be assumed to take the form of development of new products. Given the assumed utility function, this is as much an increase in the economy's productive capacity as there would be if there were increased efficiency in production of existing products.

Turning now to the production side, we assume that it takes one unit of labor to produce one unit of any good. All goods will be

[3] This is a restrictive functional form which appears to be necessary if the model is to have a steady-state equilibrium in Sec. III, below. Something should also be said about the assumption that all goods enter demand symmetrically. This is clearly unrealistic: There is no reason why mopeds and toothbrushes should have identical demand functions. It also assumes away all differences in substitutability among goods, making all goods equally good substitutes for one another. The only justification for the assumption is its simplifying power which allows us to analyze economies producing many goods. The assumption also has an honorable lineage since it was adopted by Chamberlin (1962) for the analysis of monopolistic competition. Equation (1) is borrowed from the recent reformulation of Chamberlin's theory by Dixit and Stiglitz (1977).

assumed to be produced under conditions of perfect competition, so that profits will be driven to zero, and we must have

$$P_N = w_N$$
$$P_S = w_S \tag{2}$$

where w_N, w_S are the wage rates (in arbitrary units) and P_N, P_S are the prices of *any* good produced in North or South, respectively. Which goods are produced where is yet to be determined.

I have already assumed that new goods can only be produced in North; thus North will produce all new goods and South only old goods. The remaining question is whether North produces any old goods or not. This depends on relative wages. If $w_N/w_S = 1$, North will be competitive in old goods; if $w_N/w_S > 1$, it will specialize in new goods.

The relative wage can be determined by looking at the derived demand for Northern labor as illustrated in figure 1. Suppose initially $w_N/w_S > 1$, so that the developed country is specialized in new goods, and we lower the relative wage. Then the demand for new goods will rise and with it the demand for Northern labor as shown by the line segment DE. At $w_N/w_S = 1$ the demand curve for Northern labor will become infinitely elastic, because Northern and Southern labor are perfect substitutes in the production of old goods. In figure 1 the Northern labor force is OA, so in equilibrium w_N/w_S is greater than one and North produces only new goods. In the rest of the paper I

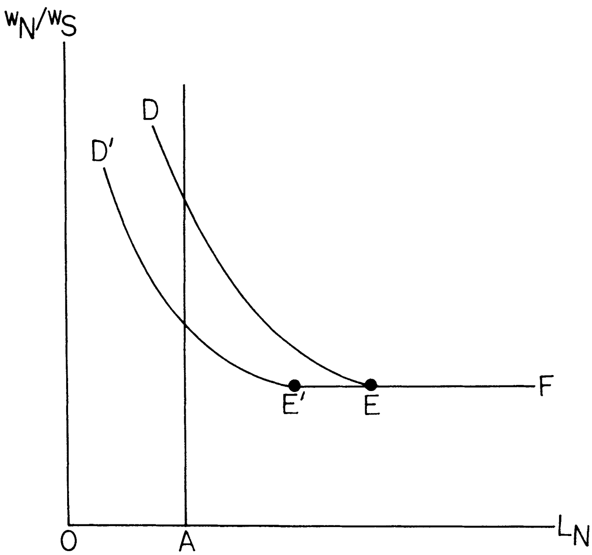

Fig. 1

will assume that this is true so that we can identify the number of goods produced in each country, n_N and n_S, with the number of new and old goods, respectively.

Now consider what happens if a "technology transfer" takes place, so that some new goods become old goods, in other words, their technology becomes available to South. The effect is to shift the derived demand for Northern labor left, to $D'E'F$. This narrows the wage differential; if there were no increase in $n = n_N + n_S$, workers in North may be absolutely worse off.

We can develop these results algebraically. Consider the relative demands for a good produced in North and one produced in South. The utility function (1) implies that the relative demand will depend only on prices:

$$\begin{aligned} c_N/c_S &= (P_N/P_S)^{-(1/1-\theta)} \\ &= (w_N/w_S)^{-(1/1-\theta)} \end{aligned} \tag{3}$$

where c_N is consumption of a Northern good and c_S consumption of a Southern good. Demand for labor in each country will equal demand for each good times the number of goods, so the relative demand for labor can be written

$$\begin{aligned} L_N/L_S &= n_N c_N/n_S c_S \\ &= (n_N/n_S)\,(w_N/w_S)^{-(1/1-\theta)}. \end{aligned} \tag{4}$$

This can then be turned around to give an expression for relative wages as a function of relative labor forces and the ratio of new to old goods:

$$w_N/w_S = (n_N/n_S)^{1-\theta}(L_N/L_S)^{-(1-\theta)}. \tag{5}$$

The important point to notice here is that the relative wage rate in the developed country depends on the relative importance of newly developed products which it can produce and the less developed country cannot. A burst of innovation which increases n_N will raise the relative Northern wage. This is in contrast to the result in conventional models in which technological progress in the export sector generally worsens the terms of trade.[4]

We have now seen how momentary equilibrium in the world economy involves exports of new products by North and exports of old products by South with relative wages depending on the numbers of new and old products in existence. Our next step must be to look at the factors determining n_N and n_S—innovation and technology transfer.

[4] On the relationship between technological change and the terms of trade in a Ricardian model, see Dornbusch, Fischer, and Samuelson (1977).

III. Innovation and Technology Transfer

The stocks of new and old products are determined over time by two processes of technological change—innovation and technology transfer. Innovation is the process by which new products are created; technology transfer is the process by which new products are transformed into old products. Both of these can be assumed to be taking place continually.

In keeping with the general strategy of placing the unconventional aspects of this model in as uncluttered a form as possible, I will assume that *all* technological change takes the form of adding new products or making it possible for Southern labor to produce more products. Thus technological change of the kind which is usually supposed to take place—an increase in productivity in the production of a given range of goods—will be assumed away. There will be a technical progress in this model, but it will be entirely in the form of the availability of new products rather than in the form of an increased volume of production of old products.

The process of innovation will mean increases in n, the number of goods produced. We know very little about the factors which affect the rate of innovation. One reasonable guess, though, is that the number of new products invented depends positively on the number already developed: The more you know, the more you can learn. I will assume that innovation is proportional to the number of products already in existence:

$$\dot{n} = i\,n\,. \tag{6}$$

The reason for making this assumption is the same as the reason for assuming exponential technological change in conventional growth models and has the same justification: It causes the model to approach a long-run steady growth path.

The process of technology transfer turns new goods, which are a Northern monopoly, into old goods, which are in the public domain. Again, we have no good theory of this process. One might suppose that goods would remain new for some fixed period, as if they were patented. On the other hand, the time required for South to adopt a new product might vary considerably from product to product. It may therefore be just as realistic, and certainly more convenient, to represent the process by which new products become old products as one of "radioactive" decay:

$$\dot{n}_S = t\,n_N. \tag{7}$$

Notice that this implies that the average "imitation lag"—the time taken before South learns how to manufacture a new product—is $1/t$.

The rate of change of the number of new products will be the difference between the rate of innovation and the rate of technology transfer:

$$\dot{n}_N = i\, n - t\, n_N. \tag{8}$$

The system of equations (6)—(8) is not stable; it will explode upward in continual technological progress. The composition of the stock of goods will, however, tend toward a stable mix. Let $\sigma = n_N/n$, the share of new goods. Then we have

$$\dot{\sigma} = \dot{n}_N/n - \sigma \dot{n}/n = i - (i + t)\sigma. \tag{9}$$

Thus the system will tend toward an equilibrium at $\sigma = i/(i + t)$.

Finally, we should note that the ratio of new to old goods, which we saw in the last section determined relative wages, is

$$n_N/n_S = \frac{\sigma}{1 - \sigma} = \frac{i}{t} \text{ in equilibrium.} \tag{10}$$

The world economy, then, tends toward a moving equilibrium or steady state. What does this steady state look like? Relative wages are constant, with a fixed differential in favor of the developed country which is an increasing function of the rate of innovation i and a decreasing function of the rate of technology transfer t. The structure of trade remains unchanged in one sense in that North always exports new products and imports old products. But the actual goods involved continually change. Each good is at first produced in and exported by North; then when the technology becomes available to South, the industry moves to the lower wage country. Case studies in such a world would reveal a Vernon-type product cycle.

Now let us move beyond the consideration of the steady state and examine the effects of changes in the rates of innovation and technology transfer. Such changes, by altering the number of goods produced and the location of production, have an efficiency effect which alters world productivity. They also, more interestingly, have effects on the distribution of world income between North and South.

Let us start with the efficiency effects. It is immediately apparent that innovation, by increasing the range of products, represents an increase in real world productivity. It is less obvious but true that technology transfer, allowing production of a wider range of goods in the less developed country, also represents a gain from a global point of view. To see this we can consider the dual of the production problem—the problem of producing the existing output of goods at minimum cost.[5] This is illustrated in figure 2, which compares differ-

[5] Notice that since tastes are assumed identical and homothetic, we can separate the problem of efficiency in production from that of income distribution. More generally, we would have to assume lump-sum redistribution by some kind of world government for world efficiency to have any meaning.

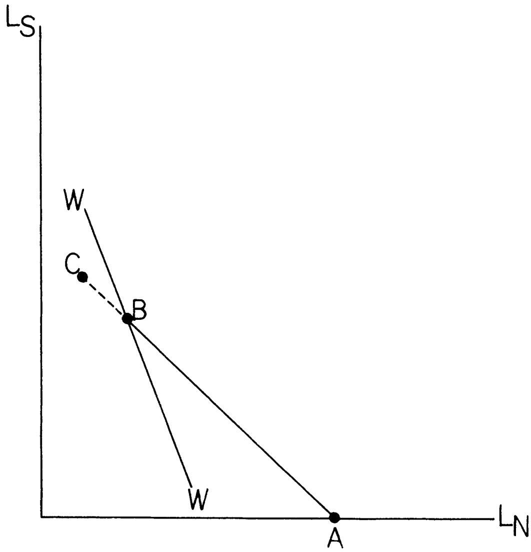

FIG. 2

ent combinations of Northern and Southern labor which could be used to produce a given basket of goods. As long as both North and South are producing old goods, Northern and Southern labor can be freely substituted for one another, as illustrated by the line segment AB. But we have been assuming that the world is at a corner solution; that relative wages, as shown by WW, are such that North and South specialize in new and old goods, respectively, as at B. A transfer of technology, turning some new goods into old goods, makes it possible to substitute Southern labor for Northern in the production of a given basket of goods as shown by the extension of AB to C. At initial prices this would reduce production cost, which indicates that production possibilities have been expanded.

Both innovation and technology transfer, then, increase world output. But they also alter the world distribution of income.[6] As a result of this, innovation disproportionately benefits the developed country, while technology transfer can actually make the developed country worse off.

These results can easily be seen by referring back to Section II. Innovation increases n_N, the number of new goods, while leaving n_S, the number of old goods, unchanged. The resulting increase in the variety of products available benefits both countries. But n_N/n_S increases, which means that the North-South wage differential rises,

[6] By world distribution of income I mean distribution between nations. This model has nothing to say about distribution within nations.

and the terms of trade move in North's favor. This effect on the terms of trade is a secondary benefit to North and partially offsets the gains to South.[7]

Technology transfer has equally striking distributional impacts. There is no increase in the variety of goods; the increase in n_S equals the reduction in n_N. The terms of trade move against North so that while South gains, Northern workers can be worse off.[8]

So far we have considered once-for-all changes in n_N and n_S, instead of changes in rates of innovation and transfer of technology, but the extension is straightforward: We simply compare n_N and n_S with what they would have been if rates of innovation and transfer had not changed. There are, however, some interesting comparative dynamic examples that emerge from this model.

Consider the effects of a slowing in innovation. In a conventional model of growth this might lead to a narrowing of the gap between the developed and less developed country, but the developed country would continue to grow. In this model real income in North might actually decline for a time as its monopoly position in new goods is eroded. We can demonstrate this with an extreme example: If innovation came to a complete halt, while transfer of technology continued, North would eventually lose its wage advantage, leaving Northern workers worse off.

An increase in the rate of technological borrowing by the less developed country would work similarly, shifting the terms of trade against North. If this happened fast enough, it could lead to a temporary reduction in Northern welfare.

The crucial point in each of these examples is that the incomes of Northern residents depend in part on the rents from their monopoly of newly developed products. This monopoly is continually eroded by technological borrowing and must be maintained by constant innovation of new products. Like Alice and the Red Queen, the developed region must keep running to stay in the same place.

[7] One might suppose that South could actually be made worse off by innovation in North, but given the assumptions of this paper that cannot happen. Letting a "hat" over a variable represent a proportional rate of change, the change in Southern welfare can be shown to be

$$\hat{U}_S = \theta^{-1} (1 - \theta)^2 \mu \cdot \hat{n}_N > 0$$

where μ is the share of new goods in expenditure. It is possible, however, that immiserizing effects of innovation could appear in a more general model.

[8] Using the same notation as in the previous note, we have

$$\hat{U}_N = \left(1 - \mu + \frac{\mu}{\theta}\right)(1 - \theta)\hat{n}_N + \theta^{-1} (1 - \theta)^2 (1 - \mu)\hat{n}_S$$

which is of ambiguous sign. However, if the technology transfer is large enough to lead to equalization of wages, the result will be to make North unambiguously worse off.

IV. International Investment

The model developed in Sections II and III is concerned only with trade in goods. A simple extension of the model, however, can give us some insights into the relationship between technological change and the international movement of factors of production.

Suppose, then, that there are old and new products entering into demand symmetrically as described by (1) and that North specializes in new goods. The stocks of old and new products will continue to be determined by the processes of innovation and technology transfer described by (6) and (7). We now assume, however, that there are two factors of production in each country: labor, which is assumed to be immobile between countries, and capital, which is assumed to be perfectly mobile internationally. All goods will be produced by capital and labor using the same constant returns to scale production function. I assume that there is a given world stock of capital and assume away net investment in the world as a whole.

To analyze short-run equilibrium in this extended model, we can begin by noticing that new goods as a group and old goods as a group can be regarded as composite commodities, since relative prices will not change within each group. The relative demand for the two composite commodities will depend on the price of the new relative to old goods. The relative supply of the two kinds of goods—which was fixed by the relative labor supplies in Section II—will now also be variable because of the possibility of reallocation of the world capital stock. Since capital will move until it earns the same return in both countries, a rise in the relative price of new goods will cause capital to move from South to North.

Figure 3 shows how the allocation of the world capital stock is determined. The vertical axis shows the rental price of capital measured in terms of old goods. $D_S D_S$ shows the marginal product of capital in South, which is also the demand for capital. $D_N D_N$ shows the marginal *value* product of capital in North measured in terms of old goods at some *given* relative price of new goods. At that relative price the equilibrium return on capital is r_0, with K_S the stock of capital in South, K_N the stock of capital in North, and $K_S + K_N$ the world stock of capital.

If the relative price of new goods were to rise, the marginal value product of capital in North would increase. In figure 3 this is illustrated by a shift of $D_N D_N$ to $D'_N D'_N$, with the return on capital rising to r_1, Northern capital rising to K'_N, and Southern capital falling to K'_S. We know that $K'_N + K'_S$ equals $K_N + K_S$, since the world capital stock has not changed. Output of new goods will rise, while output of old goods will fall.

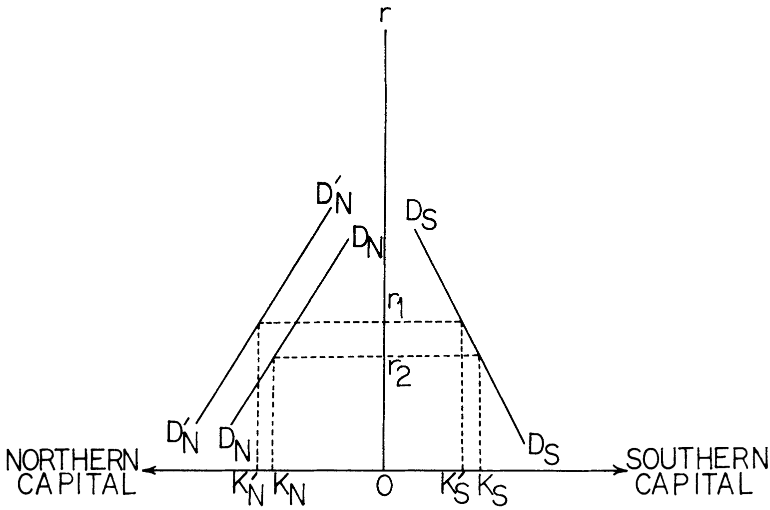

FIG. 3

We have, then, relationships between the relative price of new goods and relative demand, on one side, and relative supply on the other. These relationships determine the relative prices of new goods; this in turn determines factor prices. A rise in the relative price of new goods redistributes income toward Northern labor and away from Southern labor with an ambiguous effect on the capital share.

The final step in the analysis is to relate changes in relative prices to technological change. Technological change, whether by innovation or transfer, alters the definitions of the composite commodities "new goods" and "old goods," with the result that demand shifts. Innovation, by extending the range of new goods, increases the demand for Northern goods at any given relative price. Thus the relative price of Northern goods rises and capital moves from South to North. The income of Northern workers relative to Southern rises for two reasons: The relative prices of the goods they produce rise, and their real wage in terms of their output rises (while that of Southern workers falls) because of the reallocation of capital. In the same way technology transfer shifts demand toward goods produced in South so that capital moves south and the relative income of Southern workers rises.

What can we learn from these results? There are two major lessons. The first is that technological change will be associated with capital movement: The region experiencing the most rapid technological advance will also experience capital inflow. Notice, though, that the causation runs from technological change to capital movement, not the other way around. Essentially what happens is that technological progress raises the marginal product of capital wherever it occurs and provides an incentive for foreign investment.

The second point we should notice is that rents on North's monopoly of new goods are collected by the immobile factors of production. Migration of mobile factors, which we have called "capital" but could include skilled labor, will equalize incomes of these factors while increasing the inequality of incomes of immobile factors in North and South.[9]

V. Implications of the Analysis

This paper has developed a model of international trade which differs considerably from conventional Ricardian or Heckscher-Ohlin models and draws its inspiration instead from such authors as Vernon (1966) and Hirsch (1974). Distinctive aspects of the model are that it postulates a large number of goods; that it assumes a continuous process of technological change; and that technical progress takes the form of development of new products instead of increased productivity in the manufacture of old products. The assumptions of the model are, like those of conventional models, highly simplified and unrealistic, and the model is not proposed as a replacement of existing theories. Instead, it is a supplement, providing some insight into neglected aspects of the international economy.

The picture of the world which emerges is quite different from what we are accustomed to in trade theory. Although there may be stability in some macroeconomic aggregates, there is continual change at the micro level. New industries are constantly emerging in the developed region, then disappearing in the face of low-wage competition from the less developed region. The picture of trade seems in some ways more like that of businessmen or economic historians than that of trade theorists.

To the extent that the model captures some aspects of the real world, there are some implications for economic policy. One is that the decline of industries in developed countries will be a recurrent event; and one which, from the point of view of world productive efficiency, is a desirable event. Another implication is that technical innovation is even more important than it appears to be in conventional models since developed countries must continually innovate, not just to grow, but even to maintain their real incomes.

For less developed countries, there appear to be two major implica-

[9] When capital is mobile, it becomes possible that innovation in North will leave Southern *workers* absolutely worse off.

tions of the model. One is that transfer of technology, in addition to its direct benefits, brings the indirect benefit of improved terms of trade. What this means for policy is not clear, since we do not know much about the factors determining the rate at which technological borrowing takes place.

The other implication of the effects of technological borrowing is less encouraging. Success by less developed countries in accelerating their adoption of new techniques can leave workers in developed countries worse off; and it is easy to imagine that by encouraging protectionism such success could be self-defeating.

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