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The Role of Technology in the Theory of International Trade

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"Technology" refers to the way in which resources are converted into commodities. This is such a basic feature of an economic model, whether of a closed or open economy, that any discussion of the "role" of technology in the theory of trade must be arbitrarily incomplete. In what follows I have tried to cast the net widely and deal with several aspects of technology in the theory of international trade.

I. A TWO-COUNTRY, TWO-COMMODITY, TWO-FACTOR MODEL

Some years ago the literature on trade theory was largely concerned with the analysis of the impact of technological change on the equilibrium position in a two-commodity, two-country model of trade. Although the analysis involved in discussing the role of technical change in influencing trade patterns may be in its infancy, the analysis of the impact of *exogenous* changes in techniques is basically complete. It is useful to begin by sketching out the standard trade model in a form that permits a general treatment of the exogenous case. In doing so I shall rely heavily on the procedure I developed several years ago [8].

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Consider a competitive trade model in which each of two countries is incompletely specialized in the production of two goods, M (manufactured goods) and F (food). Two factors of production are fully employed, L (labor) and T (land), and no international factor mobility is allowed. For the questions to be discussed in this section, it is easy to consider the general case in which production functions are allowed to differ between countries.

Even in this simple two-country case many conditions are required to describe a world trade equilibrium. It is useful to consider these conditions in smaller groups. First, examine the conditions relating to the production sector in each economy. The prevailing technology in each country can be specified by a set of input-output coefficients and their dependence upon the factor-price (wage-rent) ratio (w/r) ruling in that country at the time (t). These are shown by set (1).[1]

$$a_{ij} = a_{ij}\left(\frac{w}{r}, t\right) \tag{1}$$

For any time t the unit isoquant in the jth sector can be traced out by considering the set of a_{ij} that would be chosen over the whole range of factor price ratios. Technical change is shown by a shifting of the unit isoquant (through a change in t). The basic (exogenous) parameters of technical change show the relative reductions in a_{ij} that would take place as of a given factor price ratio.[2]

There remain four other relationships on the production side in each country. The requirement that both factors be fully employed is shown by (2), and the competitive profit conditions, whereby the unit cost of producing each good is equated to its price, are given by the "dual" set (3).

$$\begin{aligned} a_{LM}M + a_{LF}F &= L \\ a_{TM}M + a_{TF}F &= T \end{aligned} \tag{2}$$

$$\begin{aligned} a_{LM}w + a_{TM}r &= p_M \\ a_{LF}w + a_{TF}r &= p_F \end{aligned} \tag{3}$$

[1] Subscripts for each country are omitted where no confusion is apt to arise. Thus there is a different set (1) for each country.

[2] One input-output ratio might increase. In this case the other must be reduced if technical *progress* is to be shown.

Before proceeding to complete the model, consider the impact on the production sector in each country of a change in technology. From set (1) it is clear that the methods of production change directly at the initial factor prices and indirectly through any tendency for the equilibrium set of factor prices to change. Thus the relative change in a_{ij} can be broken down into the two components shown by (1′). $\hat{b}_{ij}$ represents the relative *reduction* in an input requirement at constant factor prices, and $\underline{\hat{a}}_{ij}$ the relative change in the input-output coefficient along a given isoquant.[3] Furthermore, $\underline{\hat{a}}_{ij}$ depends upon the extent

$$(1') \qquad \hat{a}_{ij} = \underline{\hat{a}}_{ij} - \hat{b}_{ij}$$

of any change in the factor price ratio, and on the elasticity of substitution in sector j. As I have shown elsewhere,[4]

$$\underline{\hat{a}}_{Lj} = -\theta_{Tj}\sigma_j(\hat{w} - \hat{r})$$

$$\underline{\hat{a}}_{Tj} \quad \theta_{Lj}\sigma_j(\hat{w} - \hat{r})$$

where θ_{ij} denotes factor i's distributive share (e.g., wa_{LM}/p_M for labor's share in the M industry) and σ_j the elasticity of substitution in the jth industry.

Whereas the $\hat{b}_{ij}$ reflects the details of technological change, it is only certain aggregates of these parameters that are important in tracing through the impact of technical change on terms of trade, outputs, and real incomes. These aggregates are of two types: (1) the relative extent of the cost reduction in industry j. This is denoted by $\pi_j \equiv \theta_{Lj}\hat{b}_{Lj} + \theta_{Tj}\hat{b}_{Tj}$, the distributive-share weighted average of the direct reduction in all input-output coefficients in the jth industry: (2) relative extent of the cost reduction in a particular factor's use in all industries. This is a less familiar concept. Considering labor, the relative reductions in labor use per unit output in the two industries are $\hat{b}_{LM}$ and $\hat{b}_{LF}$. Weight each by the fraction of the labor force used in that industry, λ_{Lj}, and define π_L as $\lambda_{LM}\hat{b}_{LM} + \lambda_{LF}\hat{b}_{LF}$. Now consider the effect of a general tech-

[3] In general a "^" over a variable denotes a relative change in that variable. Thus $\hat{a}_{ij}$ is da_{ij}/a_{ij}.

[4] For a derivation see Jones, [8]. Consider the M industry. Cost minimization per unit of output is shown graphically by requiring a tangency between the unit isoquant and an isocost line. Algebraically this states that the distributive share weighted average of the changes in input-output coefficients, $\theta_{LM}\underline{\hat{a}}_{LM} + \theta_{TM}\underline{\hat{a}}_{TM}$, must be zero. This, together with the definition of σ_M as $-(\underline{\hat{a}}_{LM} - \underline{\hat{a}}_{TM})/(\hat{w} - \hat{r})$, is sufficient to solve separately for $\underline{\hat{a}}_{LM}$ and $\underline{\hat{a}}_{TM}$.

nological change on an economy with given factor endowments by differentiating (logarithmically) the sets (2) and (3) to obtain (2′) and (3′):

$$(2') \qquad \begin{aligned} \lambda_{LM}\hat{M} + \lambda_{LF}\hat{F} &= \pi_L + \delta_L(\hat{w} - \hat{r}) \\ \lambda_{TM}\hat{M} + \lambda_{TF}\hat{F} &= \pi_T - \delta_T(\hat{w} - \hat{r}) \end{aligned}$$

$$(3') \qquad \begin{aligned} \theta_{LM}\hat{w} + \theta_{TM}\hat{r} &= \hat{p}_M + \pi_M \\ \theta_{LF}\hat{w} + \theta_{TF}\hat{r} &= \hat{p}_F + \pi_F \end{aligned}$$

where

$$\begin{aligned} \delta_L &= \lambda_{LM}(\theta_{TM}\sigma_M) + \lambda_{LF}(\theta_{TF}\sigma_F) \\ \delta_T &= \lambda_{TM}(\theta_{LM}\sigma_M) + \lambda_{TF}(\theta_{LF}\sigma_F) \end{aligned}$$

If there were no change in technology, (2′) and (3′) would show how any change in commodity prices would disturb factor prices (through (3′)) and how such a change in factor prices would require a change in the composition of outputs in order to maintain full employment (through (2′)). These output changes, of course, could be represented by movements along a transformation curve. Technological progress is seen to complicate matters further in two ways. First, the reduction in factor requirements is seen to act like an increase in the quantity of factors available in (2′). Thus if factor prices were constant and only labor coefficients were reduced ($\pi_L > 0$, $\pi_T = 0$), the transformation schedule would be shifted outward and the output of the labor-intensive commodity would be increased while the output of the land-intensive commodity would be reduced. Although this sounds like the Rybczynski result [16], technical change of this kind also disturbs the relationship between commodity and factor prices through its cost-reducing impact in (3′). Therefore at the new production point the new (outer) transformation schedule need not have the same slope as at the initial point. That is, not only does any technical change act in part like an increase in factor endowments, it also acts in part like a change in commodity prices, or more accurately, like a set of industry subsidies.

With an exception I shall consider below, exogenous technical change disrupts only the production side of the model. However, it is necessary to consider the demand side in order to complete the picture of this two-country trading community. In each country demand functions must be specified. By Walras' law it would only be necessary to specify, say, that the demand for M in each country depends on that country's income and the terms of trade. Then derive a world demand function and require that, as a result of technical progress, commodity prices must adjust so as to clear markets. The relationships shown by (3′) would suffice to determine the impact on each country's factor prices.[5]

The exception I noted refers to the possibility that technical change results in an improvement in the quality of commodities instead of (or in addition to) a reduction in input coefficients. To handle this (in an exogenous fashion), introduce "t" as a variable in the demand functions. This would serve to capture the shift in taste patterns that would be triggered off by the quality changes.

Attention in the trade literature has sometimes centered on the impact of technical change on the real incomes of the countries participating in trade. In an extreme form the question raised concerns the possibility of immiserizing growth: Can technical progress in a country so affect the terms of trade that real income in that country is reduced? The answer, of course, is that this is a theoretical possibility. Any deterioration in a country's terms of trade (e.g., through progress in its export sector) reduces real income directly by an amount that is related both to the extent of the deterioration and the extent of the country's *imbalance* between consumption and production patterns. For example, suppose a country exports commodity M; let its real income be denoted by "y" measured in units of commodity F, and its consumption of M by M^*. If θ_M and θ_F denote the shares in national income (Y) of the *production* of each commodity, the following expression shows the change in real income.[6] Any deterioration in p_M/p_F would have

$$dy = (M - M^*)\, d\left(\frac{p_M}{p_F}\right) + Y[\theta_M \pi_M + \theta_F \pi_F]$$

[5] It should be mentioned that this nonmonetary system will not yield a solution for the change in each commodity price. One commodity, say F, could be taken as numeraire. I have retained $\hat{p}_F$ so as not to disturb the symmetry in the expressions.

[6] This expression is derived from the budget constraint (or balance-of-payments constraint), $p_M M^* + p_F F^* = p_M M + p_F F$ and the definition of a real income change (in units of F) as the price-weighted sum of changes in consumption, $(p_M/p_F)\,(dM^*) + dF^*$.

to be set against the directly beneficial effect on real incomes of the improvement in technology.

This is the basic model that has been used to analyze the impact of any kind of technical change on prices, consumption, production, and real incomes of countries in a trading community. It is deficient because it does not come to grips with the *inducement mechanism* whereby the $\hat{b}_{ij}$, and therefore the π's, are linked to changes in other economic variables. I shall comment upon this in more detail in Section III. However, it is worth setting out the model in some detail because whatever inducement mechanism is considered, it is this basic model that can then be used to trace through the consequences of technical change.

II. A MODIFICATION OF THE HECKSCHER-OHLIN THEORY

The preceding section has been devoted to the question of how a *change* in technology used anywhere in the world disturbs a pre-existing trading equilibrium. In this section I discuss a closely related but separable aspect of the role of technology in trade theory, namely, how the basic Heckscher-Ohlin model of trade that assumes identical production functions must be modified to take account of *differences* in production functions between countries.

In a sense the Heckscher-Ohlin model represents a step backward from the earlier Ricardian tradition. With Ricardo, international differences in production functions were not only allowed, but served as the basis for explaining positions of comparative advantage. Early work on the Heckscher-Ohlin model concentrated on differences in factor endowments as the source of comparative advantage and found it convenient to ignore differences in technologies between countries (and tended to minimize the influence of differences in taste patterns). This deficiency was repaired in the trade literature of the past decade.[7]

One immediate consequence for the Heckscher-Ohlin theory of allowing countries to differ in their prevailing states of technology can be inferred from equations (3′). The changes in factor and commodity prices exhibited there can be interpreted as reflecting the pretrade differences in these prices between two countries with slightly differing

[7] For a summary statement, see Amano [1].

technologies. Subtract the bottom equation in (3′) from the top and rearrange to obtain (4):

$$(4) \qquad (\hat{p}_M - \hat{p}_F) = |\theta|(\hat{w} - \hat{r}) - (\pi_M - \pi_F)$$

where $$|\theta| \equiv \theta_{LM} - \theta_{LF}$$

The sign of $|\theta|$ indicates which industry is labor intensive. Suppose in both countries M is labor intensive so that $|\theta|$ is positive. A strong form of the Heckscher-Ohlin theorem states that when two countries have identical technologies, the low-wage country has a comparative advantage in producing the labor-intensive commodity. Equation (4) suggests how easily this proposition can be modified to account for differences in technologies. The labor-intensive commodity could turn out to be relatively expensive in the low-wage country if the other country had a sufficiently strong *relative* technological superiority in producing M. In the spirit of the doctrine of comparative advantage it is only relative differences in productivity that count.

Further analysis is required if the role of technological differences between countries in determining positions of comparative advantage is to be contrasted with the bias imposed by differences in physical factor endowments. The production side of the model needs to be expanded by adding L and T respectively to the right-hand side of equations (2′) to allow for differences in factor endowments as well as technologies. Solve (4) for the difference in factor price ratios and insert into (2′). Then solve this set for the difference in the ratio of goods produced to obtain (5): [8]

$$(5) \quad (\hat{M} - \hat{F}) = \frac{1}{|\lambda|}\{(\hat{L} - \hat{T}) + (\pi_L - \pi_T)\} + \sigma_S\{(\hat{p}_M - \hat{p}_F) + (\pi_M - \pi_F)\}$$

where $$|\lambda| \equiv \lambda_{LM} - \lambda_{TM}$$

$$\sigma_S \equiv \frac{\delta_L + \delta_T}{|\lambda| \; |\theta|}$$

For a closed economy, this change in the ratio of outputs produced must be matched by a similar change in the ratio of quantities consumed.

[8] $|\lambda|$ is positive if, as assumed, M is labor intensive. σ_S is the elasticity of substitution on the supply side (along the transformation schedule).

To wash out the separate role played by differences in tastes or income levels, I assume that both countries have identical homothetic taste patterns. Equation (6) follows from the definition of the elasticity of

$$(6) \qquad (\hat{M} - \hat{F}) = -\sigma_D(\hat{p}_M - \hat{p}_F)$$

substitution on the demand side. Equating (5) and (6) permits a solution for the difference in the relative commodity price ratio, and this is shown as follows:

$$(7) \quad (\hat{p}_M - \hat{p}_F) = -\frac{1}{|\lambda|(\sigma_S + \sigma_D)}\{(\hat{L} - \hat{T}) + (\pi_L - \pi_T) + |\lambda|\sigma_S(\pi_M - \pi_F)\}$$

What the expression given by (7) allows is a comparison of the autarchy price ratios that would rule in two economies slightly different, both in their technologies and in factor endowments. It points out that two general features of the differences in technologies are crucial in influencing positions of comparative advantage. The first, $(\pi_L - \pi_T)$, might be termed the "differential factor effect" and it is seen that this influences commodity prices in exactly the same manner as do differences in factor endowments. The second, $(\pi_M - \pi_F)$, the "differential industry effect," points out that technological differences between countries bias commodity prices directly to the extent that a country's technological superiority over another country is not evenly spread over both industries.[9] Elsewhere I have defined technical change (or, in this case, differences between countries) to be "regular" if a greater aggregate reduction in labor coefficients than in land coefficients corresponds to a differential impact on costs favoring the labor-intensive industry.[10] In such a case $(\pi_L - \pi_T)\ (\pi_M - \pi_F) \geqq 0$,[11] and both features of the technological differences between countries influence the commodity price ratio in the same direction. The Heckscher-Ohlin theorem, of course, can be reversed by differences in technology. Expression (7) shows how pronounced these differences would have to be.

[9] π_M and π_F are Hicksian measures of technological difference. Later in this section I shall point out how the different Harrod measures may be crucial in explaining comparative advantage positions in a world in which capital is freely mobile.

[10] See Jones [8]. Technical change need not be "regular." Consider a reduction in the labor coefficient only in the land-intensive industry.

[11] This assumes again that M is labor intensive.

Perhaps the most celebrated result of the standard Heckscher-Ohlin model is the factor-price equalization theorem: with identical technologies, incomplete specialization in both countries guarantees that free trade brings about an equality in the real returns to similar factors in both countries.[12] This result disappears if technologies differ between countries.

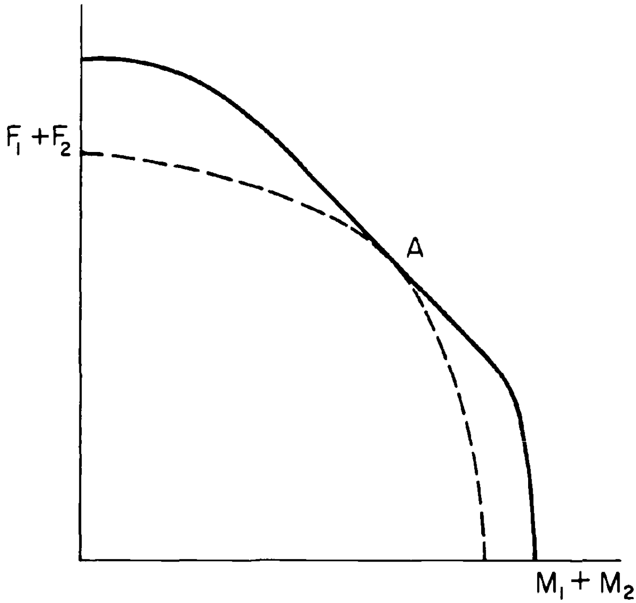
The fact that factor prices are not equalized in the Heckscher-Ohlin model is the factor-price equalization theorem: with identical techquences for the standard assumption of international factor immobility underlying the body of traditional trade theory. This assumption is tolerable if goods trade is a perfect substitute for factor movements. In what follows I assume that capital and labor replace land and labor as the two explicit factors of production in the model and, for simplicity, assume that only capital is potentially mobile.[13] At initial pretrade stocks of capital, rates of return to capital in the two countries would normally not be brought into line. In such a case there is incentive to develop the theory of trade to incorporate trade in capital goods and foreign investment. For example, recent theoretical work on foreign investment has been concerned with the problem of the interconnections between impediments placed on goods trade and taxes levied on income earned on capital placed abroad, in the context of a model in which technologies in two countries are assumed at the outset to differ [12, 10]. Quite aside from the question of devising optimal tariff and tax strategy is the more general question relating to the properties of trade models in which capital is internationally mobile subject, perhaps, to certain taxes on repatriated earnings. In concluding this section I shall briefly note a few of these.

Consider, first, the question of specialization in production in a two-commodity, two-factor, two-country, competitive, riskless world in which real capital is mobile (through the possibility of foreign investment). In a recent article I claimed it was unlikely, if technologies differed between countries, to find both countries incompletely specialized. As has recently been suggested by Kemp and Inada [13], this is an unwarranted remark. If the technological comparison between coun-

[12] I rule out the possibility of factor-intensity reversals.

[13] It would be possible to construct a three-factor model to include land, and require land to be immobile internationally.

FIGURE 1



tries is such that at any common commodity price ratio the return to capital is higher in one country than another, unimpeded capital flows will drive at least one country to specialize completely. Kemp and Inada were concerned with another case—that in which there existed some commodity price ratio at which rates of return to capital would be equalized with both countries incompletely specialized. As John Chipman has pointed out, it is possible to derive a world transformation schedule assuming capital is freely mobile [5]. Such a schedule has a "flat"—a portion of the schedule is linear. This transformation schedule is shown by the solid curve in Figure 1. The curved sections of this schedule correspond to price ratios at which at least one country is driven to specialize completely. Thus with capital mobile it is quite possible that a free trade solution occurs along the flat and both countries are incompletely specialized. It is interesting to compare this locus with the world transformation schedule that would obtain if capital were immobile internationally, as in the traditional Heckscher-Ohlin model. This schedule is the dashed one in Figure 1.

In drawing this second locus I have assumed that there exists one commodity price ratio at which rates of return to capital can be equated consistent with incomplete specialization in both countries and with the given stocks of labor and capital in the two countries. This corresponds to point *A*. For all other points rates of return differ between countries. Free trade in goods will then not suffice to substitute for movements of capital, either to bring about international equality in their returns or to reach the solid world efficiency frontier.[14]

Second, consider the determinants of comparative advantage if trade in capital goods serves to equalize rates of return to capital between countries. Let the two countries differ only slightly in their technologies. Subtract $\hat{r}$ from both sides of (3′) to obtain (3″) as the solution for the difference in the factor price ratio between countries

$$(3'') \qquad (\hat{w} - \hat{r}) = -\frac{1}{\theta_{LM}}(\hat{r} - \hat{p}_M) + \frac{\pi_M}{\theta_{LM}}$$

To consider equal rates of return to capital, set $(\hat{r} - \hat{p}_M)$ equal to zero in (3″) and substitute into (4) to obtain (4′):

$$(4') \qquad (\hat{p}_M - \hat{p}_F) = \theta_{LF}\left\{\frac{\pi_F}{\theta_{LF}} - \frac{\pi_M}{\theta_{LM}}\right\}$$

In a world of capital mobility, positions of comparative advantage are determined by the Harrod, as opposed to the Hicks, measures of technical difference.[15] Now suppose that in the capital abundant country more resources have been devoted to improving the technology and that this country has a uniform Hicksian advantage in all lines (i.e., $\pi_M = \pi_F$). In a world of capital mobility, this nonetheless biases comparative advantage in the direction of having the capital abundant country export the capital intensive commodity.[16] Note the sensitivity

[14] Of course, with labor assumed immobile and technologies different, there will generally not be any tendency to equate real wages in the two countries. Interesting further work remains in following up Chipman's results in those cases in which taxes (or perhaps considerations of risk) serve to impede capital flows. One preliminary result may be noted: the world transformation curve will lie inside the solid curve of Figure 1, but will also have a linear segment. However, unlike the untaxed case shown in Figure 1, the slope of the transformation curve does *not* correspond to the commodity price ratio despite the fact that no direct impediments exist to commodity movements.

[15] π_j/θ_{Lj} shows the improvement in output per man at a given capital-output ratio (or, for small changes, at a given rate of profit). See Jones [8, 9].

[16] If *M* is capital intensive the right-hand side of (4′) is negative.

of this result to the crude inducement mechanism whereby it is the more capital abundant country that has devoted more resources to technical improvement. If production functions in the labor abundant country should represent superior technology, of the same Hicksian measure for each industry, and if rates of profit should be equalized between countries, the labor abundant country would tend to have a comparative advantage in the capital intensive commodity.

Of course the entire concept of factor abundance is subject to question if capital is mobile between countries. Equation (4′) suggests how differential rates of technical differences between countries come to dominate the determination of comparative advantage. Differences in factor endowments, in the sense of national ownership of capital per man, then get linked to commodity price ratios through the intermediate step of affecting levels of technology through research and development.

To conclude this section consider the way in which the Heckscher-Ohlin model could be applied to Vernon's concept of the "product cycle" [18]. Vernon argues that advanced countries tend to have a comparative advantage in producing those commodities that are newly being developed. Whereas special knowledge of the large home market and the prior existence of distribution channels imparts a bias to producing *for* the home market, the question of interest here is why the location of production should also be at home.[17] Vernon suggests that high labor costs at home may nonetheless be outweighed by the advantage of having a location in which a variety of factors of production (or special skills) is readily accessible. The role of technology is important, for what is being suggested is that the input mix at the early stages of the development of the product is different from the input mix later, when production becomes standardized. That is, in the course of the product cycle there is a systematic bias in the change in the production function required to produce the commodity.

In simplified terms, this suggests a three factor model: capital, "ordinary" labor, and a third factor that comprises a host of special skills on the part of labor or of capital equipment. The uncertainty associated with early stages of production, whereby the actual production process that will be required at a later stage is still not known, is thus

[17] Significant transport costs could heavily influence this decision.

translated into a third factor of production. Advanced countries, such as the United States, have a relative abundance of this third factor and hence a comparative advantage in producing new commodities at early stages of production. Later stages are associated with a shift in factor intensities toward a relatively greater role played by capital and labor.

To the extent that foreign production of commodities is undertaken as a form of foreign investment by firms in advanced countries, the previous remarks about trade theory in a world of capital mobility are relevant. If the rates that must be paid for the use of capital are brought into line for certain industrial activities between advanced and less advanced areas, the role of returns to capital as an explanation of comparative advantage tends to be neutralized, making it easier to conceptualize Vernon's product cycle in terms of two factors—labor and this third bundle representing various skills and amenities. That is, a comparison of labor shares with third-factor shares would be crucial in depicting a ranking of industries by comparative advantage.

One special feature of a trading world in which foreign investment is important should be noted. Capital markets within less developed countries tend to be fragmented in the sense that some industrial activities—particularly if foreign owned—yield rates on capital in line with generally low rates in the advanced countries, whereas local entrepreneurs might have to pay higher returns for the use of capital. The standard idealization in the theory of trade, whereby factor prices are equated within, but not necessarily between, countries (especially if technologies differ), needs to be revised to take account of differences within and similarities between countries with reference to returns to factors that may be more mobile internationally than nationally.[18]

III. INDUCEMENT MECHANISMS

What determines technical change? This basic question is not specific to trade theory, but any theory of the inducement mechanism has consequences for the kind of trade model discussed in the preceding sections.

[18] This brings up the old concept of noncompeting groups and the stimulating challenge to traditional trade theory given by J. H. Williams [19].

A crude sort of inducement mechanism was given in Section II. It was suggested there that the rate of technical progress in any industry would increase as the economy's relative stock of owned capital (or wealth) increased. That is, wealthy countries put more resources into improving technology. Although this assumption had consequences for positions of comparative advantage in a model in which capital is mobile, it nonetheless gave no clue as to which industries would be especially favored by the input of resources to improve technology.

There is a simple inducement mechanism that discriminates between industries and is formally similar to the existence of external economies. The state of technology in any industry is linked to the level of that industry's output. In a recent article I have explored some of the ties between the Rybczynski theorem linking factor growth with the composition of outputs, the Stolper-Samuelson theorem linking commodity and factor prices, and the question of the shape of the transformation schedule, demonstrating how standard results in trade theory are altered when each a_{ij} is dependent not only upon factor prices but also upon the level of output in industry j.[19] The existence of economies of scale acts like a shift in the production function facing firms if these economies are external to the operation of the firm. If the resources devoted to R&D tend to increase with the scale of operations, further support is lent to treating each a_{ij} as a function of the output of j. Instead of pursuing the formal analysis here, I only note that the model described in Sections I and II can be used with proper modification of (1).

Although the effects of economies of scale on the model may be similar to those of having knowledge improved with greater use of resources for research as output expands, they are not identical in that economies of scale may be reversible whereas genuine technical progress is presumably permanent. That is, it may be useful in modifying (1) to introduce a "ratchet" effect whereby each a_{ij} depends upon the previously attained highest level of output. A more complicated adjustment would entail having the inducement to technical change be represented by the past integral of output. In this way, the unit isoquant would still be shifting inward, even if the level of output were to remain constant.

[19] See Jones [11]. A variation on this type of external economy is to have each a_{ij} linked to the quantity of capital employed in industry j.

An even better procedure might entail setting up a distinction between the use of resources to produce the commodity and the use of resources to produce new technical knowledge. That is, the $\hat{b}_{ij}$ could be considered to be outputs of a separate production process.

Any of the above alternatives falls short of capturing a realistic mechanism to explain rates of technical change. Expectations as to future sales must affect the quantity of resources devoted to improving the technology. To highlight this distinction consider, again, Vernon's model of the product cycle. It is at the early stages, where new products are being introduced, that relatively heavy use is made of resources in R&D. Reliance on current output levels as an explanation of the level of technology would fail to incorporate this phenomenon.

All these remarks deal primarily with the determinants of the *rates* of technical progress by industry and with the scale of resources devoted to shifting the production function. A small literature over the past few years has been devoted to the question of the determinants of *bias* in technical progress, *given* the inputs of resources used to improve technology [14, 17, 6, 2]. This literature derives its motivation from models of growth rather than models of trade and, in particular, attempts to demonstrate a tendency toward Harrod neutrality. Nonetheless, any inducement mechanism that serves to explain why labor coefficients are altered by different relative amounts than are capital coefficients has implications for the model set out in Sections I and II.

The basic concept in the literature on induced bias is that of a convex technological improvement frontier representing the maximum possible saving in the use of one factor for various prescribed levels of saving in the other factor (and given a fixed research budget). However, there are several interpretations of this frontier, depending upon which parameters are chosen to represent "saving" for a factor of production. For example, augmenting coefficients could be used, or improvements in marginal products at given capital/labor ratios, or reductions in input-output coefficients at constant factor prices (the $\hat{b}_{ij}$ of this paper) or at a constant rate of profit. Basic to the theory in its present state is the assumption that the frontier is exogenously positioned in time.[20] This

[20] This rules out the possibility of diminishing returns to research effort, which would cause the frontier to shrink over time, especially perhaps in the neighborhood of points previously chosen.

represents little advance over a completely exogenous treatment of technical change. In addition, the assumption that a frontier specified in terms of one set of parameters is fixed in position over time in general negates the possibility that a frontier specified in terms of another set of parameters is also stationary. Furthermore, the conditions for convergence to "neutrality" depend crucially upon which representation is chosen.

For these reasons I suspect that this literature is not now directly useful to trade theory. However, it does throw out the notion that a factor's distributive share may be a key inducement variable. That is, at the optimal point along the innovation possibility frontier, the absolute value of the slope of the frontier is equated to the ratio of distributive shares. In the language of the model in Section I, the object is to pick $\hat{b}_{ij}$ in such a way that π_i, equal to $\theta_{Lj}\hat{b}_{Lj} + \theta_{Kj}\hat{b}_{Ki}$, is a maximum.[21] Given any disturbance to a trading world (such as the imposition of tariffs or the adjustment required in the face of growth and capital accumulation), distributive shares as well as factor prices are affected, and thus indirectly the choice of new technologies. The novel element is that the question of whether the elasticity of substitution between factors is greater or less than unity becomes important because the behavior of the θ's depends upon this. Thus it might be possible that through trade there is a tendency for factor prices to get equilibrated but at the same time for factor shares to move further apart, thus stimulating more diverse developments in the technologies of the two countries.

The view that technology is improved because there is "learning by doing" is a statement both about the inducement mechanisms for rates of change and about bias.[22] According to this concept the higher the level of production (or, in some models, the integral of past production or investment) or the more "experience" about techniques gained by using them, the greater is the rate at which these techniques become more productive. This is similar to the external economy effect discussed earlier. But there is an important difference: the learning-by-doing hypothesis suggests that the unit isoquant gets pushed in primarily in

[21] Implicitly it may be assumed that Section I's model has a right-angled innovation possibility frontier.

[22] The basic paper is K. J. Arrow, [3]. See also the interesting paper by A. B. Atkinson, and J. E. Stiglitz [4].

the region where production is taking place. In the words of Atkinson and Stiglitz, technical progress is "localized." Although nothing is hypothesized about a "local" tendency to "bias" (i.e., whether learning by doing makes the production process more or less labor intensive), there is bias in a "global" sense—that rates of change are higher near the prevailing factor proportions.

The "localization" feature of learning by doing is of interest to trade theory because it raises the question of how transmittable technical change is from one country to another.

IV. TRANSMISSION OF TECHNOLOGY

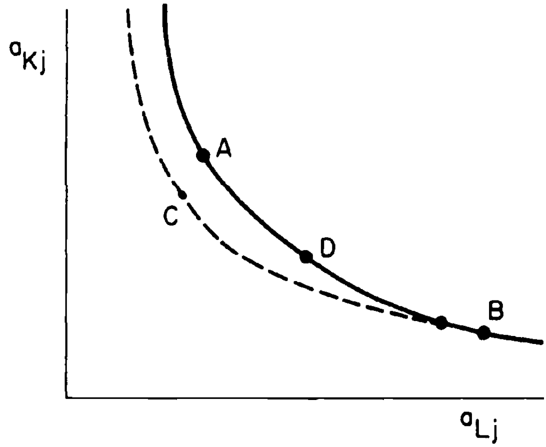
Is the technical progress of one country readily transmittable to other countries? The discussion in Section I presumed that it was not, but underlying the traditional Heckscher-Ohlin model is the notion that it is difficult to keep secret new techniques of production.

For some types of technical knowledge patents or licensing arrangements would allow new techniques to be sold internationally as are other commodities. The traditional view is that basic knowledge cannot be appropriated in this way, that technical knowledge takes on more the form of a public good. In this sense technical progress is freely transferable.

Even in this limiting case, however, technical progress in one country may not spill over to actually affect techniques used in other countries. Consider Figure 2 in which a common (solid) isoquant for two countries is shifted to the dashed isoquant again commonly available to two countries. If the high wage advanced country is producing at A, and if the low wage country is using techniques shown by B, the improvement in techniques shown by the dashed curve does not serve to lower costs in the low wage country.

Two features of this example are crucial in limiting the transference of technical improvements: (1) Factor prices differ between countries, so that different actual techniques are used along the same isoquant, and (2) technical progress in one country tends to be "localized" in the region of existing techniques. The learning-by-doing hypothesis fits the latter category and thus serves as one basis for explaining why it is that all countries need not benefit from improvements made in one of

FIGURE 2



them, even though no secrets are kept. But the argument against the effective transmittal of new knowledge is even stronger than this. The movement from *A* to *C* in Figure 2 may have been the result of a technical improvement that was discovered as a consequence of time spent using the technique at *A*. On the other hand, what may be represented is that labor needs the experience of working with capital before point *C* can be reached. In this latter instance even if the low wage country is at point *D* it may not be able to benefit until its factors can adapt to the techniques at *A*.

The picture that emerges from this is that production functions may in some sense be the same between countries, but factor prices are different, and in their research efforts countries are really "chipping away" at different points on a common production surface.

If technical progress is embodied, clearly the transmission of technical knowledge depends upon allowing trade in capital goods. The same feature also obtains with labor and the possibility of moving trained managers and special skills, perhaps through foreign investment. The view that much of the change or difference that is observed in input-output coefficients is a reflection of changes in factor skills rather than in technical knowledge leads to the position that a critical bottleneck to the international transmission of technology resides in international factor immobilities. Trade in factors is synonymous with exporting the technology.

In concluding this paper I would like to suggest how a mixture of these views could be fitted together into the framework of a model developed recently by Peter Kenen [15]. Kenen views capital as a resource which is used to improve the quality of uneducated labor and infertile land. That is, resources (capital) are used to raise the quality of the basic factors of production, which are then used to produce commodities that enter into trade (as well as capital). By analogy think of techniques newly developed in an advanced country. Before these can be utilized in a less developed country, resources must be devoted to the learning process. In this way, technical knowledge is not kept "secret," but transmission is nonetheless not without cost.

With foreign-produced technology not adaptable without the use of a country's own resources, the question arises as to the proper allocation of local capital and labor to improve "technology." Two uses are suggested, each perhaps subject to diminishing returns: (1) adapt the foreign technology as suggested above, or (2) devote resources, partly through learning by doing, to improve local techniques that are dictated by local factor prices. These uses for resources must compete with the alternatives of raising labor productivity through capital accumulation or working directly, through education, to improve factor skills. It is not difficult to envisage a model in which the productivity of all four uses for resources gets equated at the margin.

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COMMENT

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The papers of Harry Johnson and Ronald Jones concur in the theme that trade theory has been somewhat left behind by the real world, especially in relation to the phenomenon of technological progress.[1] While Jones essentially tries to develop the traditional Heckscher-Ohlin-Samuelson model of trade theory (which is basically a simplified general equilibrium model of the Hicksian variety) in directions implied by the consideration of technical change, the Johnson paper attempts to develop themes which are on a more "imaginative" scale but which seem to have no theoretical foundations as of the present moment.

In the case of technological progress, trade theory's lag behind non-trade theory is only nominal, as John Chipman's introductory survey to his theoretical exercise incisively indicates. We still have very little theoretical work on the causes of technical change, either in terms of its origins or its spread. In this respect, I find Ronald Jones' review of the existing literature on technical change in trade theory excellent. He has elegantly restated an important body of literature starting with the work of Findlay-Grubert and Johnson. This line of investigation explores the effects of Hicks-neutral and Hicks-biased technical change, *exogenously* introduced, on the output-elasticity of supply at constant commodity prices, embodied in the Heckscher-Ohlin-Samuelson model. Jones has also extended the analysis to the case explored by Minhas, Bhagwati, and Bardhan where Hicks-neutral efficiency differences are introduced between countries, so that we have what I described in my *Economic Journal* survey (1964) as a Ricardo-Heckscher-Ohlin theory.

[1] For Johnson comment, see page 22 above.

Of considerably greater interest is his review of the recent literature which introduces the international mobility of one of the factors in a world of such technological differences.

I also find interesting Jones' review of different suggestions concerning the origin and dissemination of technical change, on which there is practically no theoretical work in trade yet. As soon as we bring in these types of possibilities, I can think of several interesting questions, particularly in welfare analysis. Think, for example, of technical change being determined by any specified form of technical-progress function (e.g., a Kennedy function). If we can then introduce into such a system the possibility of dissemination of technical change abroad, distinguishing between different rates of dissemination on different types of technical change (either by the nature of the bias or by the activity in which the change occurs), then there could well be a case of externalities requiring governmental intervention, because the market could well lead to allocation of resources to technical change which are socially less productive via the spread effects abroad.

Furthermore, among the interesting, dynamic models that could be built around the notion of dissemination of technical change would be one in which an Atkinson-Stiglitz type of "localized," learning-by-doing technical change were introduced and combined with international mobility of one of the factors (say, labor) with a constraint on the magnitude of factor mobility permitted per unit period. Such analyses would permit the examination of welfare questions in a dynamic context. Thus, once we have begun to introduce technical change as an *endogenously* produced and disseminated factor, there are numerous possibilities of pushing economic analysis ahead to yield interesting insights and results in both positive and welfare theory.