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Issues of technology creation and the international transfer of technology are increasingly important in domestic political debate in the leading technology-creating countries and in international political debate between these industrial countries and the developing countries. The discussions are hampered not only by the difficulties of defining such concepts as technology, but also by a scarcity of existing economic analysis, both theoretical and empirical.

In the domestic political setting, at least two issues can be identified, especially in the United States. First, labor has voiced concern that technology transfer reduces comparative advantage in technology-intensive industries. The loss of domestic production leads directly to structural changes that increase domestic unemployment. Labor thus bears the burden of such adjustment. Second, a general concern has arisen that the pace of technological change has slowed. In the United States, a smaller fraction of the gross national product is devoted to research and development, relative to this fraction in the 1960's, although most of the decline is due to reduced government funding of research. A slowing in the pace of technological change may result from the relative decline in research and development, with adverse consequences for the rate of economic growth.

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In the international political setting, the developing countries often argue that the terms of technology transfer are unfavorable to them. In the extreme they demand that technology be provided freely to aid their development efforts. At the same time, they wish to increase the rate at which technology is transferred and to foster the development of technology more appropriate to their economic conditions.

Existing economic analyses of technology transfer nearly all assume that the level or pace of creation of new technology is exogenously given.[1/] Rodriguez (1975) and McCulloch and Yellen (1976) examine the case in which the home country initially has exclusive use of the technology to produce a new product. The effects of various conditions of technology transfer on welfare in the home country are explored, given the exogenous existence of the new product. Koizumi and Kopecky (1977) and Findlay (1978) examine the effects of technology transfer in a steady-state, dynamic setting, in which the recipient country benefits from spillover effects of the transfer. Both assume the rate of technological change is exogenously given.

The assumption of exogenously given technological change is useful to reduce the complexity of economic analyses, but such an assumption is often inappropriate. Among those who have argued against the tendency of economists to view technological change as exogenous, Schmookler (1966) is perhaps the most vocal. According to the analysis of Schmookler, technological progress is fundamentally an economic process, responsive to supply conditions, such as the expected costs of progress, and to demand considerations, expected returns.

Thus, the conditions of technology transfer, which alter the perception of economic returns, is likely to alter the pace of technological progress. Existing analyses of technology transfer fail to capture this fundamental linkage. Concern over the domestic rate of technological progress, on the other hand, often fails to place such progress in an international setting, as befits the position of a nation in an increasingly interdependent world.

This study is an attempt to address some issues that arise if the linkages between the endogenous rate of technological progress and the conditions of technology transfer are modeled explicitly. The approach of the study is similar to that used in a brief article by Connolly (1973) and incorporates the model of an intermediate public good developed by Manning and McMillan (1979).

The study uses a Ricardian trade model of two goods and two countries. Technological improvements can be created in the home country within a third economic sector performing research and development (R&D). R&D yields process improvements useful in both industries, so that new technology is an intermediate public good. The amount of new technology created depends on the return to R&D achieved through royalty payments, which may be tied to the value of the improvements. The royalty scheme determines the appropriability of the benefits of the new technology. The economy in antarky is discussed in section I, and in free trade with no technology transfer in section II.

The focus of the paper is on the effects of the international transfer of endogenously created new technology on welfare in the home country (transferor) and the foreign country (recipient). Sections III and IV explore the case of free technology transfer. Section V develops the case of globally optimal royalties. Sections VI, VII, and VIII explore various nationally optimal deviations from the regime of globally optimal royalties.

The approach of the study is one of comparative statics within a Ricardian one-factor world. The use of comparative statics is not wholly appropriate because technological progress in an ongoing dynamic process. Nonetheless, a dynamic analysis of a steady state world often differs little from comparative static analysis, although issues not explored in this study, such as uncertainty, diffusion rates, and the costs of adaptation and adjustment, could be explored within a dynamic setting.

The use of a Ricardian model is based upon a desire to reduce complexity and to abstract from issues of factor bias in a multi-factor world.[2/] The home economy is assumed to have resources, called labor, that can be devoted to producing goods or to R&D. Again to avoid complexity, the foreign country is assumed to do no R&D, and free trade in goods is assumed. The limitations of such assumptions and possible avenues for further research are discussed in the final section of the study. This section also includes a summary of the major conclusions of the study.

Important differences between the conclusions of this study and those in which technological progress is exogenous can be summarized. First, the globally optimal royalty paid by the recipient country exceeds zero, because production of the public good, new technology, is costly. If technology is exogenous, the globally optimal royalty is zero. Second, the nationally optimal royalty according to the recipient country need not be zero, because royalty payments induce increased creation of new technology. Third, the position and shape of the offer curves depend on the conditions of technology transfer, not only because international royalty payments transfer purchasing power between countries, but also because they alter the production of new technology.

This study also explores two areas that cannot be analyzed within models that assume technology is exogenous. First, the conditions of technology transfer and of international trade in goods are shown to affect the creation of new technology. This is relevant to domestic concerns about the rate of technological progress. Second, nationally optimal resource reallocation to affect the creation of new technology can be determined.

I. Research and Development in a Ricardian Economy

Research and development is an economic activity to discover better ways of producing and to invent new or improved products. A static Ricardian model of the economy is useful in analyzing important aspects of endogenous technological change that results in improvements of production processes, given the goods produced, although such a static model is not well-suited to an analysis of endogenous new product introduction.

An important feature of the output of R&D, new technical knowledge, is that it is often usable in several industries. Use in one industry does not preclude use nor diminish the value of the new knowledge in another industry. An example of technological change that is consistent with the model developed here is an improvement in the method of organizing or managing production. Such improved methods are often general enough to be useful in several industries simultaneously. Other examples, which arguably would require far more complex models to be analyzed fully, include improvements in the design or functioning of basic parts, such as ball bearing or microelectronics, that are used in the capital-goods machinery of several industries. In this case product improvements in one industry are process improvements in several others.

Although not all process-oriented technological change has this character, some of it can be considered a public good in the sense that the new knowledge can be used simultaneously in several industries.[3/] This observation is the basis for development of a model of technological change through costly R&D, within the familiar setting of a Ricardian general equilibrium model of an economy. A two-good model in which a third sector provides an intermediate public good is developed by Manning and McMillan (1979). This section briefly summarizes their analysis of such an economy. Here the third sector is specifically called the R&D sector, and its output is improved process technology. The results of the study, of course, could equally be applied to any similar intermediate public good.

Following Manning and McMillan, let an economy produce goods 1 and 2 using labor inputs (L), where the productivity of labor is dependent on the level of technology t. Further, utilize the standard Ricardian proposition that, given the technology, the marginal and average product (A) of labor is constant in each industry,

$$Y_i = A_i(t)L_i, \ A_i' > 0, \ A_i'' < 0. \tag{1}$$

Technology can be improved through R&D within a third sector,

$$t = f_t(L_t), \ f' > 0, \ f'' = 0. \tag{2}$$

Since units of technology are arbitrary, it is here assumed that the new technology created is simply proportional to the labor (L_t) engaged in R&D. Diminishing returns to R&D are captured indirectly in the diminishing effectiveness of new technology is raising labor productivity (negative second-derivatives of the A_i). Full employment of a fixed total labor force is assumed,

$$L_1 + L_2 + L_t = L. \tag{3}$$

Efficient supply of technology occurs where the employment of one more worker in the R&D sector just saves a total of one worker in both industries, holding outputs constant.

$$\frac{A_1' L_1}{A_1} + \frac{A_2' L_2}{A_2} = \frac{1}{f_t'} \tag{4}$$

Define the elasticity of the marginal product of labor with respect to new technology as η_i,

$$\eta_i = A_i' t / A_i \quad i = 1,\ 2. \tag{5}$$

In the analysis below, each η_i is assumed for simplicity to be constant, for all t greater than zero.

To achieve the efficient supply of technology through a market mechanism, each industry should pay a total royalty (R_i), stated in units of output, based upon the marginal value of new technology,

$$R_i = tA_i' L_i = \eta_i Y_i. \tag{6}$$

This is a Lindahl pricing scheme.

The transformation curve of the economy, for a fixed level of t, can be stated as,

$$\frac{Y_1}{A_1} + \frac{Y_2}{A_2} = L - L_t. \tag{7}$$

This clearly is a Ricardian (straight-line) segment. The true transformation curve for the economy is the outer envelope of such Ricardian segments, obtained by solving simultaneously the general equation (7) and its derivative with respect to t. The derivative equation is the same as the condition for efficient supply, equation (4).

In general, the actual point achieved on the production possibility curve determines the optimal level t* of new technology. As Manning and McMillan prove,

$$\frac{dt^*}{dY_2} \gtrless 0 \quad \text{as} \quad \eta_1 \lessgtr \eta_2. \tag{8}$$

The rationale is clear: Holding L_t constant, shifting one worker from industry 1 to industry 2 changes the value of total royalty payments. If η_1 is less than η_2, total royalty payments rise, and L_t and t* increase.

Total differentiation of the equation for the production possibility curve yields the slope of the curve,

$$\frac{dY_1}{dY_2} = \frac{A_1}{A_2}. \tag{9}$$

The slope of the curve is the same as the slope of the Ricardian segment. Total differentation of equation (9) yields the rate of change of the slope of the curve,

$$\frac{d^2Y_1}{(dY_2)^2} = -\frac{A_2A_1' - A_1A_2'}{(A_2)^2}\,\frac{dt^*}{dY_2} \tag{10}$$

If η_1 equals η_2, the expression is zero, and the production possibility curve is a straight-line Ricardian curve. If η_1 does not equal η_2, Manning and McMillan show that the two components of the expression are of opposite signs, so that

$$\frac{d^2Y_1}{(dY_2)^2} > 0 \text{ if } \eta_1 \neq \eta_2. \tag{11}$$

In this case the production possibility curve is nonconvex, as shown in Figure 1 (curve $E_1C_0C_1E_2$).

An interesting feature of the model is that optimal royalty pricing of technology, zero profits in goods production, due to competition, and perfect labor mobility, does not result in optimal commodity pricing, if η_1 does not equal η_2.[4/] The wage bill in each industry is equal to the value of output less royalty payments, so the wage rate is

$$w_i = p_iA_i(1 - \eta_i). \tag{12}$$

Setting the wage rates equal between sectors,

$$\frac{P_2}{P_1} = \frac{A_1}{A_2}\cdot\frac{1 - \eta_1}{1 - \eta_2} \tag{13}$$

Commodity prices differ from the slope of the transformation curve, so pricing is not efficient, if both goods are produced and consumed, and if η_1 does not equal η_2. For instance, if η_2 is greater than η_1, royalty payments from industry 2 are a relatively large fraction of industry output, so that the price ratio P_2/P_1 is too large, relative to the slope of the production possibility curve, given by the ratio of labor productivities. This is shown in Figure 1 as equilibrijm at C_o on community indifference curve IC_o, whereas the optimum would be reached at C_1 on IC_1. One method to achieve the optimum would be a tax-cum-subsidy on consumption.[5/] Also note that the inefficiency is such that the actual level of new technology created (with inefficient pricing, as at C_o) is always less than the fully optimal level of new technology at C_1.

II. The Opening of Trade in Goods

The previous section described a closed Ricardian economy that could create costly new technology as a public good. Manning and McMillan also explore the effects of opening this economy to trade with a second country, assuming no international transfer of the public good. This section briefly restates their conclusions, and the following sections then develop the behavior of the two-country world when various forms of technology transfer are permitted.

If the transformation curve is nonconvex, the country always specializes completely if given the opportunity to trade. Further, the offer curve is discontinuous in such a case, lacking the straight-line segment found in standard Ricardian treatment.

The international price ratio at which the country is indifferent between specialization in good 1 or good 2 is given by the slope of the straight line connecting the two endpoints of the transformation curve, shown as $(p_2/p_1)_I$ in Figure 2. Letting t_1* and t_2* represent the optimal amount of new technology for each complete specialization, the razor's edge price-ratio is equal to

$$\left(\frac{P_2}{P_1}\right)_I = \frac{A_1 (t_1^*) L_1^*}{A_2 (t_2^*) L_2^*} . \qquad (14)$$

This can also be shown to be equal to

$$\left(\frac{P_2}{P_1}\right)_I = \frac{A_1 (t_1^*) (1-\eta_1)}{A_2 (t_2^*) (1-\eta_2)} , \qquad (15)$$

based on the equality of wage rates between the two sectors.

Complete specialization and consumption at C_2 yields two points on the offer curve OC, shown in Figure 3 as points B_1 and B_2. The offer curve has two regular segments "beyond" these points, but the straight line $B_1\ OB_2$ is not part of the offer curve.

Manning and McMillan note that complete specialization yields a simple rul for the allocation of labor to the production of technology, assuming zero profits in the R&D sector,

$$L_t^* = \eta_i\ L, \qquad (16)$$

where i refers to the good in production.

The opening of trade easily could lead to a fall in the level of R&D effort for the economy. For instance, if the country specializes in good 1 and η_2 exceeds η_1, the optimal level of t falls as the country specializes. Although productivity in industry 1 is less responsive to the new technology, the relative productivity of this industry (based partly on old technology) is sufficiently high to yield a comparative advantage in this good.

The discontinuity of the offer curve means that an international equilibrium could fail to exist. Nonetheless, the remainder of the paper assumes that a unique international equilibrum does exist.

With no international transfer of technology, the model now can be analyzed as a standard trade model (assuming an equilibrium exists). For instance, given the existence of a second (foreign country, the first (home) country could impose an optimal tariff. Note that the imposition of such a tariff has no impact on the distribution of labor between the production of goods and technology in the home country.

III. Free Technology Transfer and the Foreign Country

The previous two sections developed a model of endogenous technological change for one country. The public good nature of technology is generally international, however, so that the foreign country is able to utilize the technology created by the home country. An important issue is the pricing of the technology transferred. In part this is an issue of appropriability: can the home country prevent the transfer unless the foreign country is willing to pay some royalty? In this section appropriability is taken to be impossible, perhaps because the legal system of the home country, which can be used to assure appropriability if the technology is used domestically, cannot be applied to economic activity in the foreign country. Thus, foreign producers can use the new technology without paying a royalty. Free technology transfer occurs.

The foreign economy is similar to the home economy, except that no R&D is performed in the foreign economy. Rather, any new technology must be transferred internationally (imported). Production relations and full employment then define a production possibility curve,

$$\tilde{Y}_i = \tilde{A}_i(t)\tilde{L}_i \quad i = 1, 2 \tag{17}$$

$$\tilde{L}_1 + \tilde{L}_2 = \tilde{L}, \tag{18}$$

where a tilda over the variable indicates the foreign country.

The position of the foreign transformation curve depends on the level of technology creation in the home country. Given the existence of trading relations, the position of the foreign curve then depends on whether the home country specializes in good 1 or good 2, yielding outputs of new technology t_1* or t_2*, respectively. Assume that η_2 is greater than η_1, so that t_1* is less than t_2*.

If the home country specializes in good 1, the foreign transformation curve is $\tilde{PP}_1$, in Figure 4. If the home country specializes in good 2, the foreign transformation curve is $\tilde{PP}_2$.

If the home country specializes in good 1, the foreign country must export good 2, and this part of its offer curve can be derived using $\tilde{PP}_1$. Assuming no trade at point N_1, this part of the foreign offer curve is shown in Figure 5 as ON.

If the home country specializes in good 2, a similar section of the foreign offer curve can be derived for foreign exports of good 1. The two segments need not form a single linear segment about the origin. The slope of each segment is given by $-\tilde{A}_1/\tilde{A}_2$. This slope generally will vary will the level of new technology imported,

$$\frac{d\left(-\frac{\tilde{A}_1}{\tilde{A}_2}\right)}{dt} = -\frac{\tilde{A}_2\tilde{A}_1' - \tilde{A}_1'\tilde{A}_2'}{(\tilde{A}_2)^2} \tag{19}$$

This value depends on the relation of $\tilde{\eta}_1$ and $\tilde{\eta}_2$, the elasticities of foreign labor productivity with respect to transferred technology,

$$\frac{d(-\frac{\tilde{A}_1}{\tilde{A}_2})}{dt} \gtrless 0 \text{ as } \tilde{\eta}_1 \lessgtr \tilde{\eta}_2 \tag{20}$$

The slope of the lower linear segment (and the slope of $\tilde{PP}_2$ relative to $\tilde{PP}_1$) is steeper if $\tilde{\eta}_1$ is greater than $\tilde{\eta}_2$. This is shown in Figure 5 as $\tilde{OC}_1$. If $\tilde{\eta}_1$ equals $\tilde{\eta}_2$, a single linear segment exists around the origin ($\tilde{OC}_2$), and, if $\tilde{\eta}_1$ is less than $\tilde{\eta}_2$, the lower linear section is less steep ($\tilde{OC}_3$). If the foreign offer curve has a shape like $\tilde{OC}_1$, multiple international equilibria are possible, with the pattern of trade reversing between the two equilibria. If the foreign offer curve has the shape of $\tilde{OC}_3$, the likelihood of the nonexistence of an international equilibrium increases.

Nonetheless, a unique equilibrium is assumed to exist in the analysis of this study. The home country is assumed to export good 1, and both countries are assumed to be completely specialized. The international equilibrium with free trade and free transfer is shown as point Z in Figure 6, and the international price ratio is the negative of the slope of line OZ.

The home country may well object to the free use of its technology by the foreign country. The home country could, for instance, threaten to completely eliminate the international transfer of technology Indeed, this may be the only possible threat, if the new technology is lumpy in the sense that it forms a single package which cannot be subdivided once created.[6/] In this case the transfer is all or nothing. This approach is used throughout the remainder of the study.

Given our assumptions, the effect of completely eliminating technology transfer would be (1) to shrink the foreign transformation curve in toward the origin (its endpoints would be $\tilde{A}_1(0)\tilde{L}$ and $\tilde{A}_2(0)\tilde{L}$), (2) to rotate the linear portions of the foreign offer curve (if η_1 does not equal η_2), and (3) generally to shift the curved portions of the foreign offer curve in toward the origin. The latter effect is assured if demand is homothetic. The effect of such a cut off is shown in Figure 6, assuming η_1 is less than η_2, so that the linear portion of $\tilde{O}C'$ is steeper than $\tilde{O}C$. International equilibrium moves from Z to Z' and the relative price p_2/p_1 rises. This is a general result, as long as both countries initially are completely specialized and foreign demand patterns are homothetic (or at least not too perverse).[7/]

The increase in the relative price of good 2 indicates that the terms of trade of the home country deteriorate if technology transfer is completely prohibited. With no change in domestic production, the home country must be worse off. Free technology transfer is superior to no technology transfer for the home country. Free technology transfer is also superior for the foreign country, unless the foreign country is subject to immiserizing growth.

IV. Optimal R&D Policy of the Home Country Under Free Transfer

Analysis of the previous section demonstrated that the home country would suffer a decline in social welfare if it cut off technology transfer to the foreign country. A second question then arises: Is the amount of R&D acheived under optimal domestic pricing socially optimal in the presence of free technology transfer? Connolly (1973) has considered this question in a Ricardian framework. Connolly concludes that an expansion of R&D would improve the social welfare of the home country.[8/] The gain is based on an improved terms of trade. For instance, starting from equilibrium, move one worker in the home country from producing good 1 to producing technology. The output of good 1 is approximately unchanged. The additional new technology created increases output of good 2 in the foreign country, so the curved portion of the foreign offer curve shifts out. The terms of trade of the home country improve. The welfare of the home country increases. Note that this effect is qualitatively different from, and additional to, the gains from the imposition of an optimal tariff by the home country. The difference lies in the shift in the foreign offer curve, which would not occur if an optimum tariff were imposed.

The optimum home country policy can be derived rigorously by introducing a government policy to affect the distribution of resources (labor) in the home country. For instance, the government could force producers of good 1 to increase their royalty payments by a rate s,

$$R_1 = t\, A_1'\, L_1\, (1 + s) = \eta_1\, A_1\, L_1\, (1 + s)\,. \tag{21}$$

The amount of labor producing technology is then,

$$L_t = \eta_1\, L\, (1 + s\,)\,. \tag{22}$$

The optimum rate s, which is a subsidy to R&D, is found by maximizing a social welfare function U,

$$U = U\,(D_1,\, D_2) \tag{23}$$

where D_1 and D_2 are domestic consumption of goods 1 and 2. We can define changes in real income in terms of units of good 1,

$$\frac{dR}{ds} = \frac{dU/ds}{\partial U/\partial D_1} = \frac{\partial D_1}{\partial s} + P\,\frac{\partial D_2}{\partial s} \tag{24}$$

where p equals (p_2/p_1). Trade must be balanced,

$$Y_1 - D_1 = pD_2. \tag{25}$$

Using the total derivative of equation (24), we can rewrite the expression for the change in real income,

$$\frac{dR}{ds} = \frac{\partial Y_1}{\partial s} - D_2\frac{dp}{ds} \tag{26}$$

and, from equation (1),

$$\frac{\partial Y_1}{\partial s} = (L_1\ A_1'\ f_t' - A_1)\ \frac{\partial L_t}{\partial s} \tag{27}$$

Equation (27) has a value of zero for s equal zero, so that real income rises with the imposition of a small subsidy if the country's terms of trade improve.

The change in the terms of trade can be found in two steps. First, the initial disequilibrium in international markets resulting from a small increase in the subsidy rate is derived, at a constant relative price. Then the necessary change in international prices to restore equilibrium is determined.

Initially, an international equilibrium exists in which the quantity of good 2 exported by the foreign country equals the quantity imported by the home country,

$$\tilde{Y}_2 - \tilde{D}_2 = D_2 \tag{28}$$

where

$$\tilde{D}_2 = \tilde{D}_2\ (p,\ \tilde{Y}_2) \tag{29}$$

and

$$D_2 = D_2\ (p,\ Y_1). \tag{30}$$

At the initial equilibrium relative price, a change in the subsidy rate s is likely to cause a disequilibrium,

$$\frac{\partial(\tilde{Y}_2 - \tilde{D}_2 - D_2)}{\partial s} = (1-\tilde{m}_2)\ \tilde{L}\ \tilde{A}_2'\ f_t'\ \frac{\partial L_t}{\partial s} - (m_2/p)\ (L_1\ A_1'\ f_t' - A_1)\ \frac{\partial L_t}{\partial s} \tag{31}$$

where $\tilde{m}_2$ is the foreign marginal propensity to consume good 2 (as $\tilde{Y}_2$ increases) and (m_2/p) is the home marginal propensity to consume good 2 (as Y_1 increases).

According the equation (31), as s is increased, an excess supply of good 2 is created. Assuming a stable international market, the relative price p must fall to restore equilibrium. This is an algebraic proof of Connolly's conclusion that the home country can increase welfare by increasing R&D effort, as $(d\dot{R}/ds)$ is positive for s equal to zero.

The change in the international price can be found by determing the required offsetting change in excess supply of good 2,

$$\frac{\partial(\tilde{Y}_2 - \tilde{D}_2 - D_2)}{\partial p} = (D_2/p)(E_{MD} + \tilde{E}_{MD} - 1) \tag{32}$$

where E_{MD} is the price elasticity of import demand. Equilibrium in the international market is maintained if,

$$\frac{dp}{ds} = -\frac{\partial(\tilde{Y}_2 - \tilde{D}_2 - D_2)/\partial s}{\partial(\tilde{Y}_2 - \tilde{D}_2 - D_2)/\partial p} \tag{33}$$

Combining equations, an expression for the change in home real income is obtained. Setting this equal to zero, and substituting for L_1 an expression derived from equation (22), the optimal subsidy rate is obtained,

$$s^* = [(\Delta - m_2)(L(1 - \eta_1)A_1'f_t' - A_1) + p(1 - \tilde{m}_2)\tilde{L}\tilde{A}_2'f_t']/$$

$$[(\Delta - m_2)L\eta_1 A_1'f_t'], \tag{34}$$

where

$$\Delta = E_{MD} + \tilde{E}_{MD} - 1. \tag{35}$$

The expression $(\Delta - M_2)$ is positive unless the home country is subject to immiserizing growth, a possibility that is assumed not to apply in this case.9/ If immiserizing growth were applicable, the optimal subsidy would be quite large, because the home country would actually gain welfare by reducing output of good 1.

The optimal subsidy rate depends on several of the exogenous parameters. Given the initial equilibrium and assuming immiserizing growth is not relevant, the optimal subsidy is larger as the size of the initial disequilibrium is larger, for a small increase in s. The larger the initial disequilibrium, the larger the resulting improvement in the home terms of trade. Thus, the optimal subsidy is larger as the foreign country is larger $(\partial s^*/\partial \tilde{L} > 0)$, as the home marginal propensity to consume good 2 is larger $(\partial s^*/\partial m_2 > 0)$, and the foreign marginal propensity to consume good 2 is smaller $(\partial s^*/\partial \tilde{m}_2 < 0)$. In the latter case, less of the increase in foreign output is "offered back" to the home country. Given the size of the initial disequilibrium, the optimal subsidy is larger as the terms of trade improve more; that is, as the sum of import elasticities is smaller $(\partial s^*/\partial(E_{MD} + \tilde{E}_{MD}) < 0)$.

The effect of the optimum subsidy on the international equilibrium is shown in Figure 7. Both offer curves shift (to OC' and $\tilde{OC}$') with the imposition of the optimum subsidy. Both shifts contribute to the improvement in the home country terms of trade, as the equilibrium moves to Z'.

Welfare in the foreign country, $\tilde{U}$, also is affected by the subsidy, where

$$\tilde{U} = \tilde{U}(\tilde{D}_1, \tilde{D}_2).$$

Using the balance of payments constraint,

$$\tilde{D}_1 = p(\tilde{\tilde{Y}}_2 - \tilde{D}_2), \tag{37}$$

the change in foreign real income, stated in units of good 1, is,

$$\frac{d\tilde{R}}{ds} = \frac{\partial \tilde{Y}_2}{\partial s} + (\tilde{Y}_2 - \tilde{D}_2)\frac{dp}{ds}. \tag{38}$$

Using the derivative of equation (17) and equation (33), this is equal to,

$$\frac{d\tilde{R}}{ds} = [(\Delta - \tilde{m}_2)p\tilde{\tilde{L}}A_2{}'f'_t + m_2(L_1A_1'f_t' - A_1)]\frac{\partial L_t'}{\partial s} / \Delta. \tag{39}$$

For s equal initially to zero, this is generally positive, but the expression becomes negative for some initial positive s. A small subsidy thus leads to rise in foreign welfare, unless the foreign country is subject to immiserizing growth. A small optimal subsidy is thus a Pareto-optimal improvement. A large subsidy could result in a decline in foreign welfare, however, because the home offer curve is also shifting against the foreign country, as home production of good 1 declines. In such a case, the optimal home subsidy, if large, results in a new form of immiserizing growth (of the foreign country), based in part on the shift of the home offer curve inward as resources are reallocated to the R & D sector.

V. International Equilibrium Under Globally Optimal Royalty Rates

Technology transfer need not be free. Even abstracting from the costs of the transfer, royalty payments by the foreign country may be required before the transfer is permitted. The actual royalty rate is likely to be negotiated, especially if the technology is "lumpy," so that it cannot be purchased bit by bit. Rather, an entire package of technology must be transferred.

This section describes the equilibrium in a world in which globally optimal royalty rates are paid. The characteristics of the relevant offer curves are explored by determining the elasticities of import demand. The next sections explore various nationally optimal deviations from such a global optimum.

The assumptions that the home country completely specializes in good 1 and the foreign country in good 2 are maintained. The globally efficient quantity of new technology is found by maximizing the value of global output (at a constant relative price), and the condition for optimal supply is,

$$\frac{A_1'L_1}{A_1} + p\frac{\tilde{A}_2'}{A_1}\tilde{L} = \frac{1}{f'_t}. \tag{40}$$

This globally optimum allocation of resources can be obtained if optimum real royalty payments are made,

$$R_1 = tA_1'L_1 = \eta_1 A_1 L_1 \tag{41}$$

$$\tilde{R}_2 = t\tilde{A}_2'\tilde{L} = \tilde{\eta}_2\tilde{A}_2\tilde{L}. \tag{42}$$

Zero profit in producing good 1 and technology in the home country imply,

$$w = A_1(1 - \eta_1) \tag{43}$$

$$wL_t = A_1\eta_1 L_1 + p\tilde{A}_2\tilde{\eta}_2\tilde{L} \tag{44}$$

or

$$L_t = \eta_1 L + p\frac{\tilde{A}_2}{A_1}\tilde{\eta}_2\tilde{L}. \tag{45}$$

Note that the optimal amount of R & D labor (and therefore of new technology created) is greater than that under free transfer without a subsidy, but may be less than or greater than that under free transfer with the optimum subsidy.

An international equilibrium exists when the balance of intended payments is zero for each country. The balance can be viewed as comprising four transactions For instance, the home balance of payments includes the value of technology transferred (a surplus on the services account) balanced by the value of imports of good 2 comprising the foreign royalty payments, and additional imports of good 2 (M_2'), the value of which must be balanced against the value of exports of good 1. The latter balance, which may be termed the <u>balance of trade net of royalties</u>, occurs along an offer curve.[10/] The foreign country offer curve, similarly, consist of those points for which the value of exports net of royalties equals the value of imports ($\tilde{M}_1$).

Both offer curves are more complex in the presence of globally optimal royalties, because a change in the international price ratio changes the real value of foreign royalty payments. The output of new technology changes, changing the quantities produced of both goods.

The effect of globally optimal royalties on the elasticity of home import demand can be determined, where net imports are

$$M_2 = D_2 - \tilde{A}_2 \tilde{\eta}_2 \tilde{L}. \tag{46}$$

The elasticity of import demand along the offer curve equals

$$E_{MD} = \frac{p}{M_2}\frac{dD_2}{dp}\Bigg|_{Y_1} - \frac{L_t}{M_2}\frac{\partial D_2}{\partial Y_1}\frac{\partial Y_1}{\partial L_t}E_{LT} + \frac{L_t \tilde{\eta}_2 \tilde{L} \tilde{A}_2' f_t' E_{LT}}{M_2}, \tag{47}$$

where E_{LT} is the elasticity of labor in the R & D sector with respect to the relative price, calculated from equation (45),

$$E_{LT} = \frac{p\frac{\tilde{A}_2}{A_1}\tilde{\eta}_2\tilde{L}}{L_t[1 - p\frac{\tilde{A}_2'}{A_1}\tilde{L}f_t'(\tilde{\eta}_2 - \eta_1)]}. \tag{48}$$

The elasticity must be positive, based on optimal allocation equation (40). The elasticity of import demand can be written as,

$$E_{MD} = E_{MD}^* - \frac{L_t}{M_2}[(m_2/p)(L_1A_1'f_t' - A_1) - \tilde{\eta}_2\tilde{L}\tilde{A}_2'f_t']E_{LT} \tag{49}$$

where E_{MD}^* is the typical Ricardian elasticity of import demand, holding the production point constant. The remainder of the right-hand-side expression is positive. The addition of the feedback of a change in the relative price on domestic resource allocation serves to make the offer curve more elastic. An increase in p reduces the net quantity imported through three effects: typical demand effects, a partial income effect as the R & D sector expands and the output of good 1 falls, and an increase in foreign royalties as the R & D sector expands.

As the terms of trade of the home country improve exogenously (perhaps through shifts in the foreign offer curve), the output of new technology falls. The worth of current production of good 1 relative to the worth of new technology rises (because of the declining real value of foreign royalty payments). Workers are pulled into current production of goods as the terms of trade improve.

The demand for imports in the foreign country is,

$$\tilde{M}_1 = \tilde{D}_1 = \tilde{D}_1(\frac{1}{p}, \tilde{Y}_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}). \tag{50}$$

The effect of royalty payments on the foreign elasticity of net import demand can

$$\tilde{E}_{MD} = - \frac{1/p}{\tilde{M}_1} \frac{d\tilde{D}_1}{d(1/p)} \Bigg| (\tilde{Y}_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}_2) + \frac{\partial \tilde{D}_1}{\partial \tilde{Y}_2} \frac{\partial \tilde{Y}_2}{\partial L_t} L_t E_{LT} - \frac{\partial \tilde{D}_1}{\partial \tilde{Y}_2} \tilde{\eta}_2 \tilde{L}\tilde{A}_2' f_t' L_t E_{LT}. \tag{51}$$

or

$$\tilde{E}_{MD} = \tilde{E}^*_{MD} + p\tilde{m}_1 \frac{L_t}{\tilde{M}_1} E_{LT}(1 - \tilde{\eta}_2)\tilde{L}\tilde{A}_2' f_t'. \tag{52}$$

Again the effect of changing the relative price on the level of new technology created serves to make the offer curve more elastic than the standard Ricardian offer curve, whose elasticity would be E^*_{MD}. In this case, an increase in (1/p) serves to decrease the quantity imported through the standard demand effects, and through an additional adverse income effect as the quantity of new technology produced declines. Because pricing of the technology transfer occurs at its marginal worth, royalty payments fall by only a fraction $\tilde{\eta}_2$ of the fall in output of good 2.

VI. The Optimal Foreign Royalty According to the Home Country

The globally optimal royalty described in the previous section need not be nationally optimal for either country. The nationally optimal international royalty can be derived as a deviation from the globally optimal rate, in this section from the viewpoint of the home country, and in the next from the viewpoint of the foreign country. The conclusions are that the home country desires the highest royalty possible, and that the foreign country desires a low, but not necessarily zero, royalty. These conflicting desiderata set the stage for the negotiation of a mutually acceptable royalty rate for the transfer of the lump of new technology.

To achieve a nationally optimal foreign royalty, the home country increases the royalty by a factor q over the globally optimal royalty,

$$\tilde{R}_2 = \tilde{\eta}_2\tilde{A}_2\tilde{L}(1 + q). \tag{53}$$

One issue facing the home country government is whether to distribute the excess royalties generally throughout the economy or to permit payment of all royalties to the R & D sector. This decision does not matter to the size of the optimal royalty. In either case the optimal royalty is the largest possible, presumably the rate that leaves the foreign country with only slightly more income (stated in units of good 2) than the foreign country could achieve by foregoing the technology transfer. This minimum income is $\tilde{A}_2(0)\tilde{L}$.[11] All of the increase in foreign output due to the technology transfer would then accrue to the home country directly.

If the home government chooses to distribute the extra royalty payments throughout the economy, th extra royalty payments do not affect the allocation of home labor (given the price ratio). Thus the excess royalty payments are a pure transfer. Home country welfare must rise as the transfer (excess royalties) increase, as long as the home country is not subject to immiserizing growth.

If the home country permits the R & D sector to capture the excess royalties, the allocation of home labor is affected. As the tax rate q rises, given the terms of trade, more labor is employed in R & D, less in producing good 1, and the output of this good falls. Although analysis of this case is more complex, the result is the same: the optimal royalty is the highest possible, assuming the home country is not subject to immiserizing growth.

To demonstrate this, several equations must be restated,

$$L_t = \eta_1 L + p\frac{\tilde{A}_2}{A_1}\tilde{\eta}_2\tilde{L}(1 + q) \tag{54}$$

$$D_2 = D_2(p,\ Y_1 + p\tilde{A}_2\tilde{\eta}_2\tilde{L}(1 + q)) \tag{55}$$

$$\tilde{D}_2 = \tilde{D}_2(p,\ \tilde{Y}_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}(1 + q)). \tag{56}$$

The optimal royalty is found by maximizing social welfare subject to a balance of trade net of royalties,

$$Y_1 - D_1 = p(D_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}(1 + q)). \tag{57}$$

The change in home real income is,

$$\frac{dR}{dq} = \frac{\partial Y_1}{\partial q} + p\tilde{A}_2\tilde{\eta}_2\tilde{L} + p\tilde{\eta}_2\tilde{L}(1 + q)\tilde{A}_2' f_t' \frac{\partial L_t}{\partial q} - (D_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}(1 + q))\frac{dp}{dq} \tag{58}$$

where, from equation (54),

$$\frac{\partial L_t}{\partial q} = p\frac{\tilde{A}_2}{A_1}\tilde{\eta}_2\tilde{L}/[1 - p\frac{\tilde{A}_2}{A_1}\tilde{\eta}_2\tilde{L}(1 + q)f_t'(\frac{\tilde{A}_2'}{\tilde{A}_2} - \frac{A_1'}{A_1})] \tag{59}$$

The latter expression must be positive, because the appropriate supply of new technology occurs when

$$\frac{1}{f_t'} = \frac{A_1' L_1}{A_1} + p\frac{\tilde{A}_2'}{A_1}\tilde{L}(1 + q). \tag{60}$$

The effect of a change in the royalty tax rate on the price ratio can be found by determining the initial disequilibrium, given the price ratio. The excess supply of good 2 on world markets is given by

$$\tilde{X}_2 - M_2 = \tilde{Y}_2 - \tilde{D}_2 - D_2. \tag{61}$$

The partial effect of a change in q is

$$\frac{\partial(\tilde{X}_2 - M_2)}{\partial q} = \tilde{L}\tilde{A}_2' f_t' \frac{\partial L_t}{\partial q}(1 - \tilde{m}_2) + \tilde{A}_2\tilde{\eta}_2\tilde{L}(\tilde{m}_2 - m_2) + \tilde{\eta}_2\tilde{L}$$

$$(1 + q)\tilde{A}_2' f_t' \frac{\partial L_t}{\partial q}(\tilde{m}_2 - m_2) - (m_2/p)(L_1 A_1' f_t' - A_1)\frac{\partial L_t}{\partial q}. \tag{62}$$

An excess supply must develop if $\tilde{m}_2$ is greater than or equal to m_2. The price ratio must change to offset any excess supply,

$$\frac{dp}{dq} = - \frac{\partial(\tilde{X}_2 - M_2)/\partial q}{[D_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}(1 + q)]\Delta/p} \tag{63}$$

Substituting this expression into equation (58), and rearranging,

$$\frac{dR}{dq} = [(\Delta - m_2)[(L_1A_1'f_t' - A_1 + p\tilde{\eta}_2\tilde{L}(1 + q)\tilde{A}_2'f_t')\frac{\partial L_t}{\partial q}$$

$$+ p\tilde{A}_2\tilde{\eta}_2\tilde{L}] + (1 - \tilde{m}_2 + \tilde{m}_2\tilde{\eta}_2)p\tilde{L}(1 + q)\tilde{A}_2'f_t'\frac{\partial L_t}{\partial q} \tag{64}$$

$$+ p\tilde{A}_2\tilde{\eta}_2\tilde{L}]/\Delta$$

Using equation (59),

$$(L_1A_1'f_t' - A_1 + p\tilde{\eta}_2\tilde{L}(1 + q)\tilde{A}_2'f_t')\frac{\partial L_t}{\partial q} + p\tilde{A}_2\tilde{\eta}_2\tilde{L}$$

$$= (L_1A_1'f_t' + p\tilde{A}_2'\tilde{L}(1 + q)f_t'\eta_1)\frac{\partial L_t}{\partial q} \tag{65}$$

which is positive. Therefore, (dR/dq) is always positive, if the home country is not subject to immiserizing growth. The optimal royalty is the highest one possible.

VII. The Optimal Foreign Royalty According to the Foreign Country

The previous section demonstrated that the home country generally would prefer the highest royalty rate possible. The optimal royalty rate, again derived as a deviation from the global optimum, can also be determined from the point of view of the foreign country. The nationally optimal royalty rate according to the foreign country is found to be less than the globally optimal rate, but it need not be zero. Nonetheless, the stage is clearly set for bargaining between the two countries to fix the actual royalty rate for the transfer of the technology package.

Let the rate of foreign subsidy of royalty payments be $\tilde{q}$, so that $\tilde{q}$ less than zero is a foreign tax on royalty payments. Equations (53) - (56) apply if q is replaced by $\tilde{q}$. Only net foreign royalties are assumed to accrue to the R & D sector.

The optimal royalty tax is found by maximizing foreign social welfare $\tilde{U}$, subject to the balance of net trade constraint,

$$\tilde{D}_1 = p(\tilde{Y}_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}(1 + \tilde{q}) - \tilde{D}_2). \tag{66}$$

Using the total differentials of these equations, the change in real income $\tilde{R}$ due to a change in the royalty subsidy is,

$$\frac{d\tilde{R}}{d\tilde{q}} = p\tilde{L}\tilde{A}_2'f_t'(1 - \tilde{\eta}_2 - \tilde{\eta}_2\tilde{q}) \frac{\partial L_t}{\partial \tilde{q}} - p\tilde{A}_2\tilde{\eta}_2\tilde{L} + (\tilde{Y}_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}(1 + \tilde{q}) - \tilde{D}_2)\frac{dp}{d\tilde{q}}. \tag{67}$$

The first term can be viewed as the net gain in terms of domestic production if home R & D is subsidized, the second term is the direct cost of such a subsidy, and the third term is the effect of a change in the terms of trade, which is generally a deterioration if home R & D is subsidized.[12/]

Equations (59) - (63) apply if $\tilde{q}$ replaces q. Using these, and simplifying, the change in real income is,

$$\frac{d\tilde{R}}{d\tilde{q}} = [(\Delta + \tilde{m}_2 - m_2)(p\tilde{L}\tilde{A}_2'f_t'(1 - \eta_1 - \eta_1\tilde{q}) - A_1) - (1 - m_2)p\tilde{L}\tilde{A}_2'f_t' + m_2(L_1A_1'f_t' - A_1)] \frac{\partial L_t}{\partial q}/\Delta. \tag{68}$$

By substituting for L_1, the expression is negative for $\tilde{q}$ equal to zero. Thus, the optimal foreign policy is to tax foreign royalty payments.

The optimal $\tilde{q}$ can be found using equation (68) and substituting for L_1,

$$\tilde{q}^* = [(\tilde{p}\tilde{L}A_2'f_t'(1 - \eta_1) - A_1)(\Delta + \tilde{m}_2) - \tilde{p}\tilde{L}A_2'f_t' + m_2(1 - \eta_1)LA_1'f_t']/$$

$$[\tilde{p}\tilde{L}A_2'f_t'\ \eta_1(\Delta + \tilde{m}_2)] \qquad (69)$$

The lower limit on $\tilde{q}^*$ is -1, in which case the foreign country would pay no royalty (and free technology transfer would occur). This lower limit may, but need not be reached. The foreign country may find it optimal to pay some amount for the technology transferred, because such a payment increases the amount of new technology created and transferred.

The effects of various exogenous parameters on the size of the optimal tax can be determined. Unfortunately, the interpretation of these effects is not obvious, given the equation for $\tilde{q}^*$. The optimal tax is lower (less negative) as the home country is larger ($\partial\tilde{q}^*/\partial L>0$), or as the home marginal propensity to consume good 2 is larger ($\partial\tilde{q}^*/\partial m_2 > 0$). Both of these reflect smaller terms of trade gains as the tax rate increases, ceteris paribus.

VIII. The Optimal Home Subsidy, Given a Globally Optimal Foreign Royalty

The previous two sections demonstrated that the home country would prefer a higher royalty, and the foreign country a lower royalty, than the globally optimal foreign royalty. Given the lumpy nature of the new technology, the actual royalty is likely to be the result of negotiations between the two countries.

Once the actual royalty is set, the home country may still be able to improve its welfare by altering domestic resource allocation. One case is explored here, the case in which the negotiations result in the imposition of a globally optimal foreign royalty. Such an outcome has some plausibility, in that the globally optimal royalty is efficient (the foreign country pays for worth at the margin), and in that such a royalty offers a compromise focal point in the negotiations.

Connolly (1973) hypothesizes that the home country generally should move additional resources into the R & D sector, because additional R & D leads to an improvement in the home terms of trade. However, he argues this point from the unrealistic position that the home country receives <u>all</u> of the increase in foreign production due to the technology transfer.[13/] This represents achievement of the home country's optimal royalty, and is unlikely to occur, given the bargaining nature of the actual outcome.

In the case in which the globally optimal royalty is charged, the optimal home country resource reallocation is indeterminate. Reallocation tends toward the R & D sector because the home terms of trade improve, but away from the R & D sector, because this represents a monopolistic restriction to maximize the net benefits of foreign royalties. An additional unit of new technology produced increases royalty payments by the marginal worth of the additional new technology, but reduces the total payments made on the inframarginal new technology.

To demonstrate these points, assume that the home government is willing to subsidize the foreign royalty paid at a rate v. The subsidy is domestic in that the foreign country still pays the globally optimal royalty. A negative v represents a domestic tax on foreign royalties. The resource reallocation effects of such a subsidy are clear from the equation for equilibrium employment in the R & D sector,

$$L_t = \eta_1 L + p\frac{\tilde{A}_2}{A_1}\tilde{\eta}_2\tilde{L}(1 + v). \tag{70}$$

The optimum v can be found by maximizing home social welfare U subject the balance of net trade constraint,

$$Y_1 - D_1 = p(D_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}). \tag{71}$$

The effect on real income of a change in v is,

$$\frac{dR}{dv} = (L_1 A_1' f_t' - A_1 + p\tilde{\eta}_2\tilde{L}\tilde{A}_2' f_t')\frac{\partial L_t}{\partial v} - (D_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L})\frac{dp}{dv}. \tag{72}$$

The first term is negative (for a small increase in v), and the second term is generally positive. The increase in the value of net foreign royalties, as R & D is domestically subsidized, falls short of the loss of production of good 1, and the resulting improvement in the terms of trade may or may not lead to a net increase in social welfare.

The change in the relative price can be determined by finding the initial disequilibrium, given

$$D_2 = D_2(p,\ Y_1 + p\tilde{A}_2\tilde{\eta}_2\tilde{L}). \tag{73}$$

$$\tilde{D}_2 = \tilde{D}_2(p,\ \tilde{Y}_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L}). \tag{74}$$

The excess supply caused by a change in v at the initial equilibrium relative price is,

$$\frac{\partial(\tilde{X}_2 - M_2)}{\partial v} = [(1 - \tilde{m}_2)\tilde{L}\tilde{A}_2' f_t' + (\tilde{m}_2 - m_2)\tilde{\eta}_2\tilde{L}\tilde{A}_2' f_t'$$

$$-(m_2/p)(L_1 A_1' f_t' - A_1)]\frac{\partial L_t}{\partial v}. \tag{75}$$

This is positive for v equal to zero initially, and otherwise if $\tilde{m}_2$ is not too much larger than m_2.

The relative price must change to offset the initial disequilibrium,

$$\frac{dp}{dv} = -\frac{\partial(\tilde{X}_2 - M_2)/\partial v}{(D_2 - \tilde{A}_2\tilde{\eta}_2\tilde{L})\Delta/p} \tag{76}$$

The change in real income is then,

$$\frac{dR}{dv} = p\tilde{A}_2\tilde{L}f_t'[(\tilde{\eta}_2 - 1 - v)(\Delta - m_2) + 1 - \tilde{m}_2 + \tilde{m}_2\eta_2]\frac{\partial L_t}{\partial v}/\Delta \tag{77}$$

The optimum v is found by setting this expression equal to zero,

$$v^* = -(1 - \tilde{\eta}_2) + \frac{1 - \tilde{m}_2 + \tilde{m}_2\tilde{\eta}_2}{\Delta - m_2}. \tag{78}$$

The second term is positive, if the home country is not subject to immiserizing growth, and relates to the improvement in the terms of trade as the subsidy increases. The first term represents the net loss in income (at constant prices) because the value of the foreign royalty increases by only η_2 times the value of the loss in home production of good 1, as the R + D sector expands. Thus a subsidy is more likely as this fraction increases ($\partial v^*/\partial \tilde{\eta}_2 > 0$). Also note that a subsidy is more likely as $\tilde{m}_2$ is smaller ($\partial v^*/\partial \tilde{m}_2 < 0$) and as m_2 is larger ($\partial v^*/\partial m_2 > 0$). Both of these are related to the size of the initial disequilibrium, ceteris paribus. Finally, a subsidy is less likely as the sum of the two import demand elasticities increases ($\partial v^*/\partial(E_{MD} + \tilde{E}_{MD}) < 0$), because the terms of trade improve less, given the initial disequilibrium.

Thus the optimal domestic policy is indeterminate. Of course, if the entire increase in foreign production accrues to the home country, only the terms of trade effect is relevant, and the optimal policy is to subsidize R & D, as Connolly argues.[14/]

IX. Conclusion

This study presented a theoretical analysis of endogenous technological change and the international transfer of technology within a Ricardian model of trade. It was motivated by the importance of these issues in current domestic and international political discussions. The approach taken here differs from most previous analyses in recognizing explicitly the interrelationship of the two phenomena. In summarizing the results of the study, conclusions regarding the effects on welfare of varying the conditions of technology transfer are first described, especially as these differ from other analyses assuming technological improvement to be exogenous. The impacts of the international environment on the level of domestic R & D and on the creation of new technology are discussed. Finally, limitations of the approach of the study are cited, and suggestions for further research are presented.

Certain results of this study are similar to results obtained if technology is exogenous. First, the home country benefits from free technology transfer if it affects only the foreign export industry. Indeed this is the only possible result in this study, given the Ricardian model. Second, the optimal foreign royalty from the point of view of the home country is the highest possible royalty. In this case no "spillovers" lead to direct foreign benefits.

Other results differ sharply from the results obtained if technology is exogenous. First, the globally optimal foreign royalty is positive. Although new technology is a public good in consumption, it is costly to produce. Users optimally could share this cost according to the marginal benefits that accrue to each. If technology is exogenous, the globally optimal foreign royalty is zero. Such a conclusion is misleading in that it lends support on efficiency grounds to the demand of the developing countries for free technology transfer.

Second, the nationally optimal foreign royalty from the viewpoint of the foreign country may exceed zero. The foreign country may be willing to pay some royalty (less than the globally optimal royalty) because such a payment increases the creation and transfer of new technology. Thus, the demand of the developing countries for free transfer need not be their best demand.

Two other differences are analytical in nature. Under free transfer, the position of the foreign transformation curve depends on the pattern of trade. In such a situation, no international equilibrium may exist, or multiple equilibria with an indeterminate pattern of trade may exist. Under globally optimum royalty rates, both offer curves (net of royalties) are more elastic than the standard Ricardian offer curves. Altering the international price ratio alters the creation of new technology, and this affects the shapes of the offer curves.

Certain issues explored in this study cannot be analyzed within a framework in which technology is exogenous. In this study the effects of domestic resource reallocation between production of goods and R & D were analyzed. Under free transfer the home country should subsidize R & D. The production of foreign goods rises as new technology is created and transferred, and the home terms of trade improve. This may represent a Pareto-improvement for the world, but the foreign country could suffer a kind of immiserizing growth if the optimal home subsidy is large enough.

Under globally optimum royalties the direction of domestic resource reallocation is indeterminate. A subsidy to R & D is favored because of terms of trade gains, but a tax is favored because this represents a monopolistic restriction of technology creation and transfer.

Certain of the technology transfer regimes can be ranked by national welfare. For the home country, transfer at the highest possible royalty is the best. Transfer at the globally optimum royalty is superior to free transfer, and no transfer is the worst. For the foreign country, no transfer is also the worst. Free transfer is better, and payment of some royalty, less than the globally optimal royalty, may, but need not, be better yet. Transfer with the highest possible royalty, if defined as payment of the total increase in foreign production of good 2, is better than no transfer, because the higher home income in the former case results in better foreign terms of trade.

These rankings indicate the nature of the bargaining over the actual royalty to be paid for the transfer of the package of technology. For both countries, an outcome in which the threat of "no sale" or "no purchase" is realized would be the worst possible outcome. Both would prefer ex post that the other had achieved its desired royalty.

Other aspects of the results of this study suggest that the level of domestic R & D, and thus the level of technology creation, is responsive to the international economy. For instance, in moving from complete autarky to free trade in goods, the level of domestic R & D could, but need not, fall. In moving from free transfer to a regime of globally optimal royalties, the level of R & D must rise, given the goods price ratio. However, this level of R & D may still be below the autarky level. Perhaps most importantly, as the terms of trade improve and the home country moves out on its offer curve, the level of R & D declines. The basis for this decline can be viewed in two (equivalent) ways: (1) As the home terms of trade improve, the real value of foreign royalty payments declines, or (2) As the terms of trade improve, the relative value of employing labor in production of goods, rather than in R & D, increases. Thus, changes in the international economy, both changes in the conditions of technology transfer and changes in goods markets equilibria, are likely to affect the level of domestic R & D.

The limitations of a study such as this derive basically from inherent limitations of the Ricardian model. First, complete specialization is the general outcome, so that free technology transfer must benefit the home country. In contrast, McCulloch and Yellen (1976) find that free technology transfer generally reduces home welfare, because it strengthens the foreign import-competing industry. In such a case the home terms of trade deteriorate. Second, issues of factor-intensity cannot arise. Third, issues of product-specific technological change are of little interest, due to complete specialization. Fourth, the assumption of full employment at least abstracts from transitional adjustment costs. Fifth, the static setting is not fully compatible with the dynamic nature of technological progress.

Further research in the area would involve development of more complex models. A straight forward extension of the analysis would be to a world in which there are several monopolistically competitive industries, with many differentiated products produced in each. Krugman (1979a) develops such a model for the case of fixed technology, with assumptions assuring that the exact same product is never produced in both countries.

Another possible extension is toward a model more in the tradition of the Heckscher-Ohlin theory. Incomplete specialization is likely in such a model, and issues of factor-bias and industry-specific new technology could be addressed. One approach would be an extension of the standard two-factor model. Connolly (1973) briefly notes the complexities of the factor-intensity of R & D and the factor-bias of technological change inherent in such an approach. Another approach could be to add a third factor useful only in performing R & D, similar to that used by Teubal (1975).

Finally, one could develop a full dynamic model. In such a model, issues of uncertainty, diffusion rates (including the timing of technology transfer), and adjustment costs might be explored. Krugman (1979b) has developed a dynamic model of new product introduction in which the creation of new products is exogenous.

Footnotes

1/ These works are surveyed in Pugel (forthcoming).

2/ Pioneering articles on the factor-bias of technological change are Kennedy (1964) and Samuelson (1965).

3/ Most other process-oriented improvements would at least be a public good for firms within an industry.

4/ This result is not explicitly noted by Manning and McMillan.

5/ Another method, suggested by Manning and McMillan, would be complete government subsidization of R & D at its optimal level, with no royalty payments.

6/ The package can be larger or smaller according to the amount of resources devoted to R & D, but, once created, the package cannot be divided.

7/ Other possibilities may be noted. With the shift in the foreign offer curve, a new international equilibrium could fail to exist, or the pattern of trade could reverse. Or, if the foreign country is initially incompletely specialized, the rotation effect could result in a decline in the relative price of good 2.

8/ Johnson (1967) earlier reached a similar conclusion.

9/ See Caves and Jones (1977), p. 428.

10/ Thus, royalty payments are similar to international transfer payments, a similarity highlighted by Connolly (1973).

11/ Actually the highest possible royalty would exceed payment of the total increase in foreign production. Such a payment would leave the foreign country better off than with no transfer, because the higher home income due to the royalty would result in better foreign terms of trade. The home country potentially could extract more than the total increase in foreign production. Nonetheless, the highest possible royalty is assumed to be the total increase in foreign production throughout this study.

12/ If home R & D is subsidized, output of good 1 falls, and output of good 2 rises. The foreign terms of trade deteriorate as long as m_2 is not too much larger than $\tilde{m}_2$.

13/ Connolly actually is somewhat unclear on this point. Connolly argues in the introduction that a global optimum is the reference standard, but in the formal analysis Connolly uses the nationally optimum foreign royalty.

14/ Other cases in which a subsidy is unambiguously optimal can be specified, assuming the terms of trade effect is favorable. For instance, a subsidy is optimal if a lump-sum royalty is paid or if the royalty is some constant times the quantity t of technology transferred (which is equivalent to a constant times L_t).

References

Caves, R. E., and R. W. Jones, World Trade and Payments, second edition. Boston: Little, Brown, and Company, 1977.

Connolly, M. B., "Induced Technical Change and the Transfer Mechanism," in M. B. Connolly and A. K. Swoboda, eds., International Trade and Money. London: George Allen and Unwin Ltd., 1973.

Findlay, R., "Relative Backwardness, Direct Foreign Investment, and the Transfer of Technology: A Simple Dynamic Model," Quarterly Journal of Economics, Vol. 62, No. 1, February 1978, pp. 1-16.

Johnson, H. G., "Economic Expansion and International Trade," in H. G. Johnson, International Trade and Economic Growth. Cambridge, MA: Harvard University Press, 1967.

Kennedy, C., "Induced Bias in Innovation and the Theory of Distribution," Economic Journal, Vol. 74, No. 295, September 1964, pp. 541-547.

Koizumy, T., and K. J. Kopecky, "Economic Growth, Capital Movements, and the International Transfer of Technical Knowledge," Journal of International Economics, Vol. 7, No. 1, February 1977, pp. 45-65.

Krugman, P., "Intraindustry Specialization and the Gains from Trade," processed, August 1979(a).

Krugman, P., "A Model of Innovation, Technology Transfer, and the World Distribution of Income," Journal of Political Economy, Vol. 87, No. 2, April 1979(b), pp. 253-266.

Manning, R., and J. McMillan, "Public Intermediate Goods, Production Possibilities, and International Trade," Canadian Journal of Economics, Vol. 12, No. 2, May 1979, pp. 243-257.

McCulloch, R., and J. L. Yellen, "Technology Transfer and the National Advantage," H.I.E.R. Discussion Paper, No. 526, Harvard University, December 1976.

Pugel, T. A., "Technology Transfer and the Neo-Classical Theory of International Trade," in R. G. Hawkins and A. J. Prasad, eds., Technology Transfer and Economic Development. Greenwich, CT: JAI Press, forthcoming.

Rodriguez, C. A., "Trade in Technical Knowledge and the National Advantage," Journal of Political Economy, Vol. 83, No. 1, February 1975, pp. 121-135.

Samuelson, P. A., "A Theory of Induced Innovation along Kennedy-Weisaker Lines," Review of Economics and Statistics, Vol. 42, No. 4, November 1965, pp. 343-356.

Schmookler, J., Invention and Economic Growth. Cambridge, MA: Harvard University Press, 1966.

Teubal, M., "Toward a Neotechnology Theory of Comparative Costs, "Quarterly Journal of Economics, Vol. 89, No. 3, August 1975, pp. 414-431.

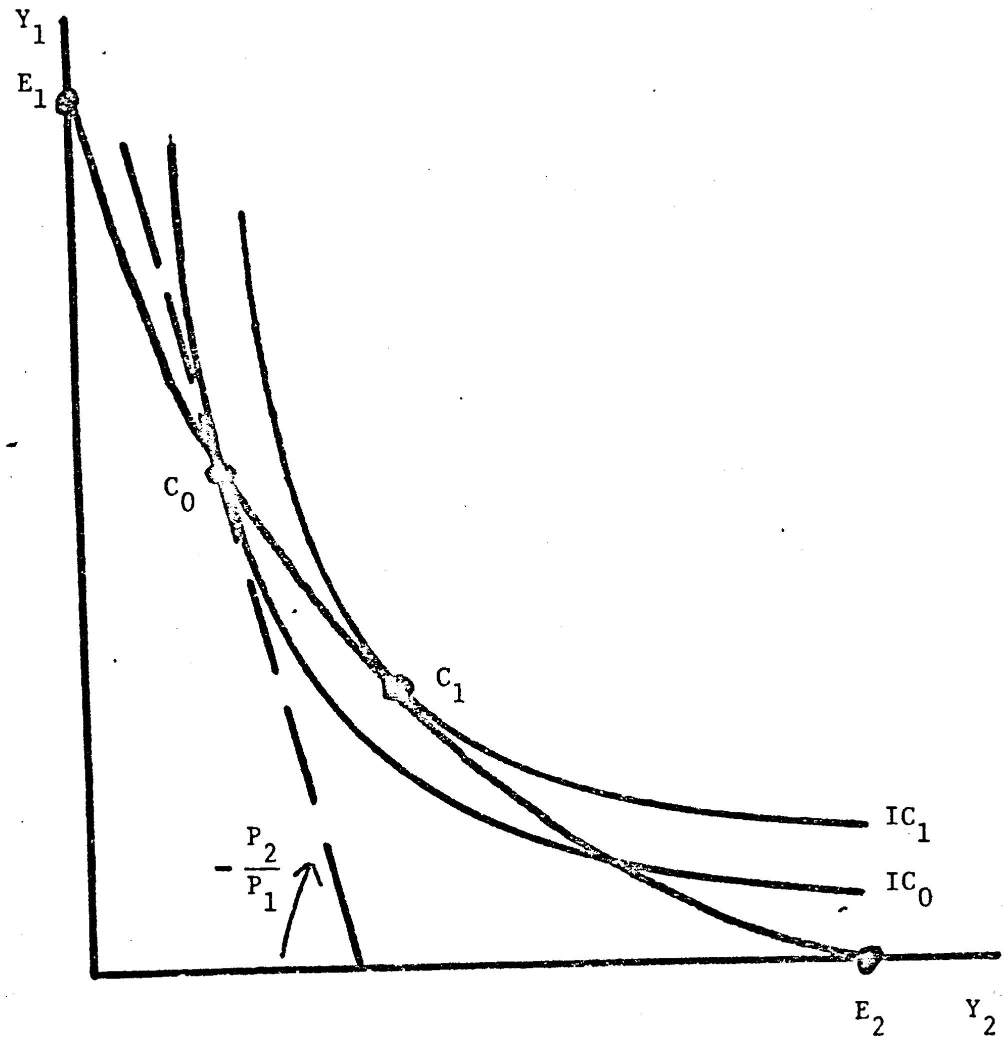

Figure 1: The consumption point C_0 with inefficient commodity pricing, and the optimal point C_1.

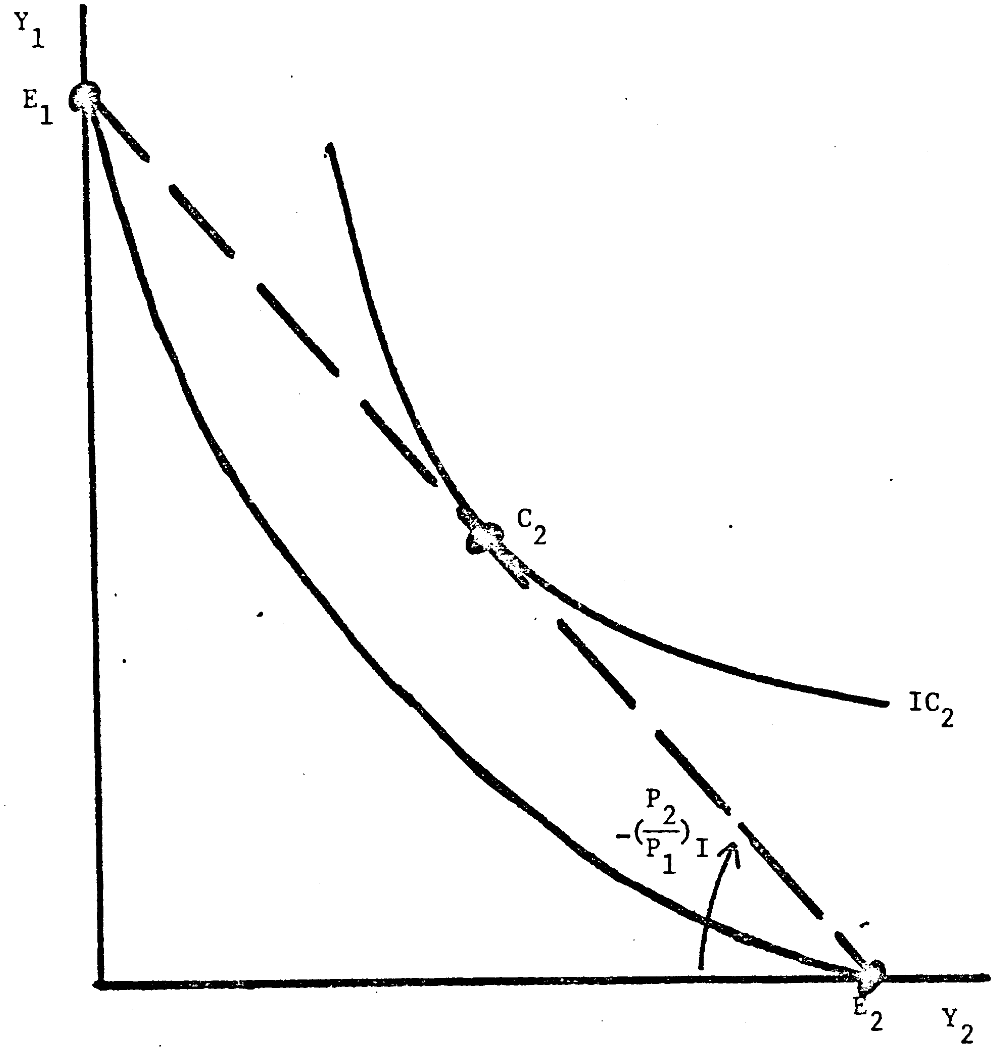

Figure 2: At world price $(P_2/P_1)_I$, complete specialization in either good, and consumption at C_2.

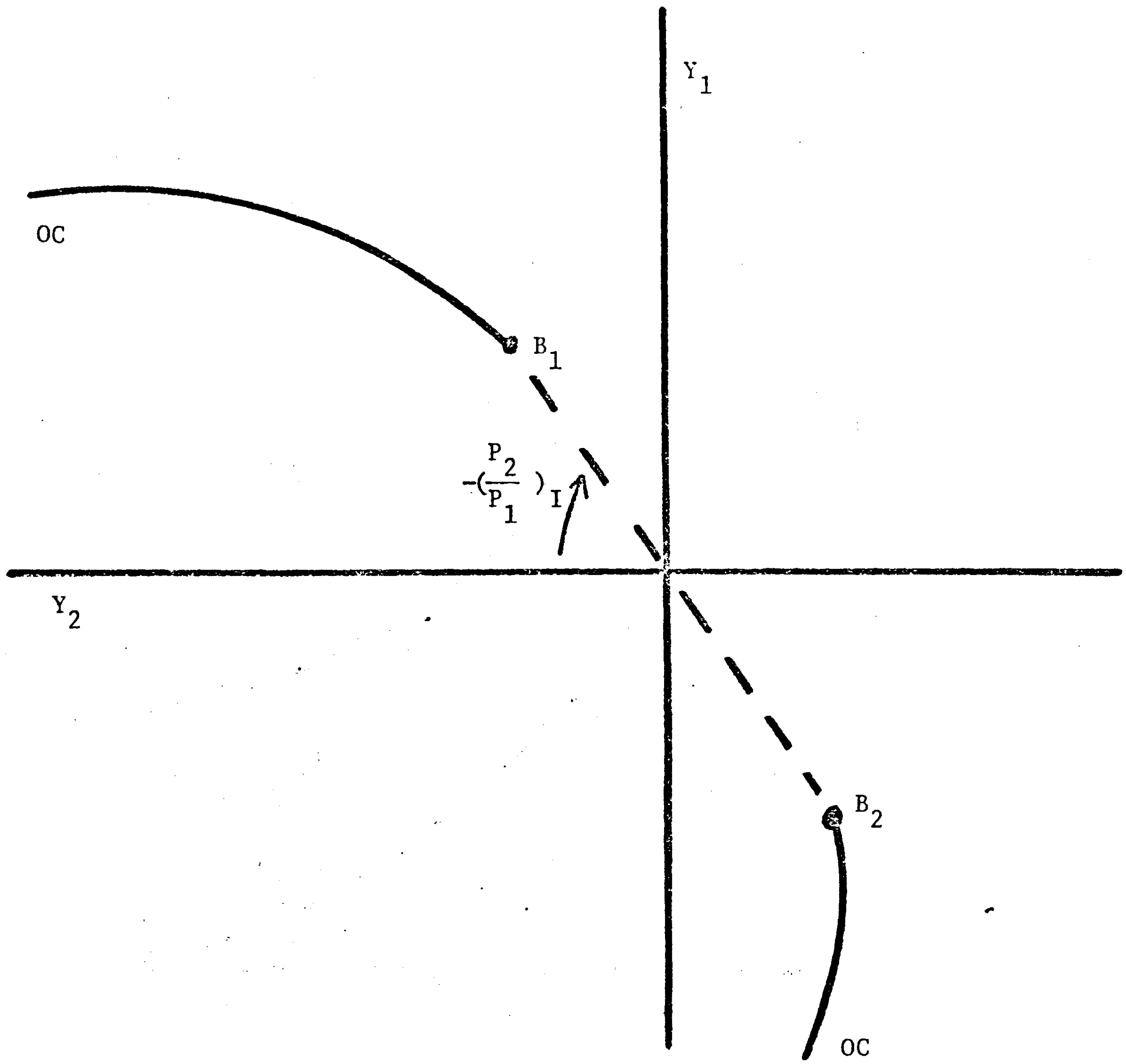

Figure 3: The two segments of the offer curve.

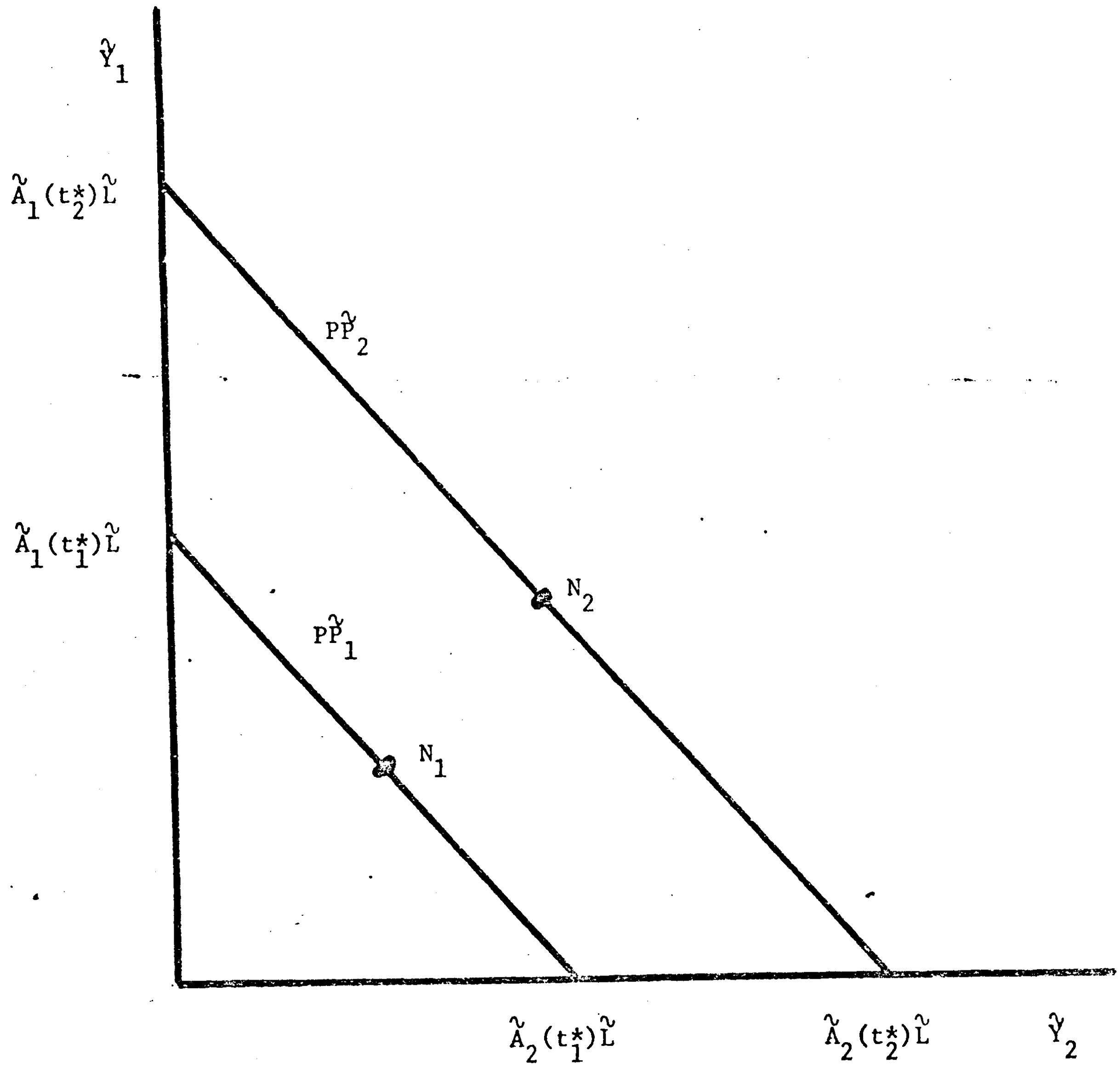

Figure 4: The foreign production possibility curves.

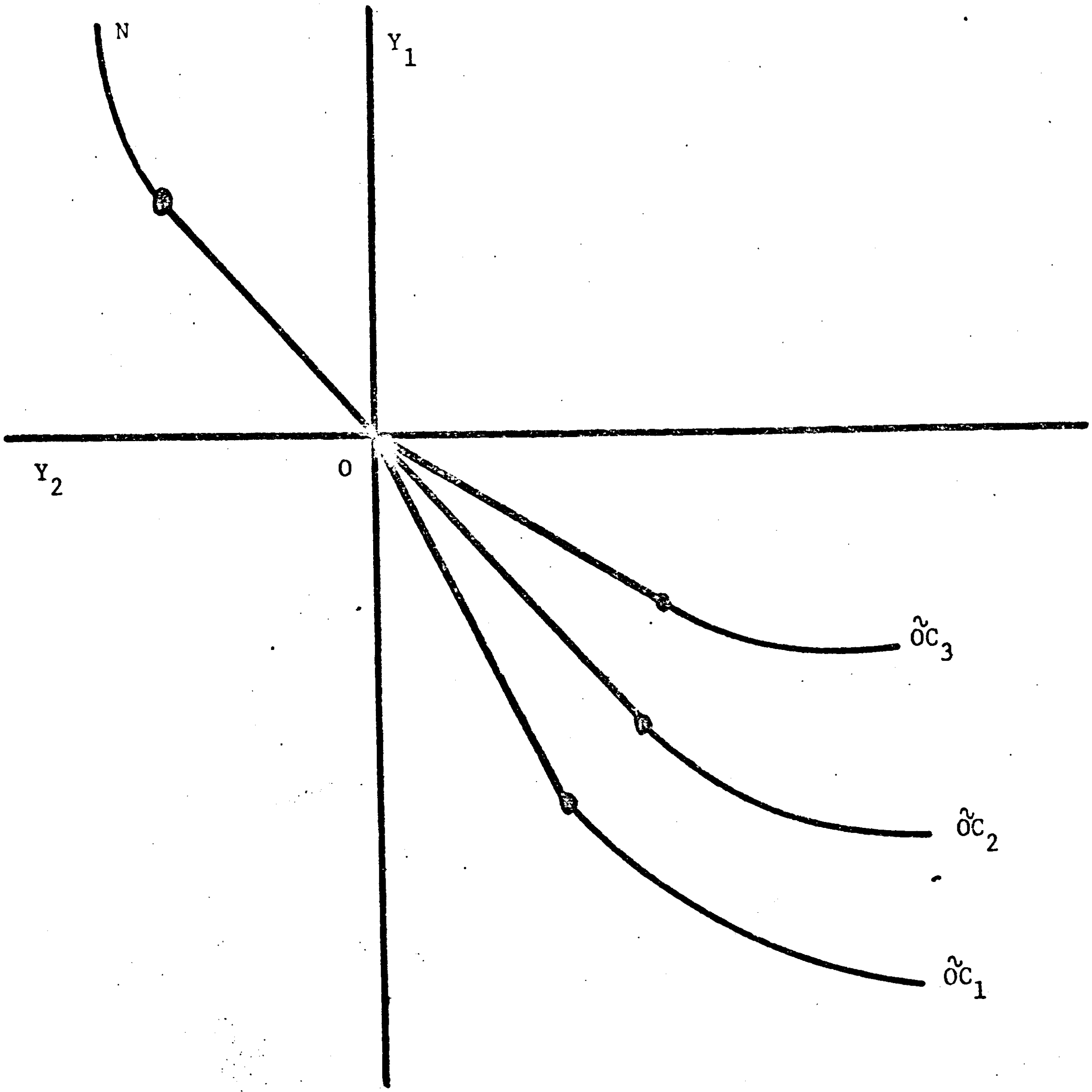

Figure 5: Possible shapes of the foreign offer curve.

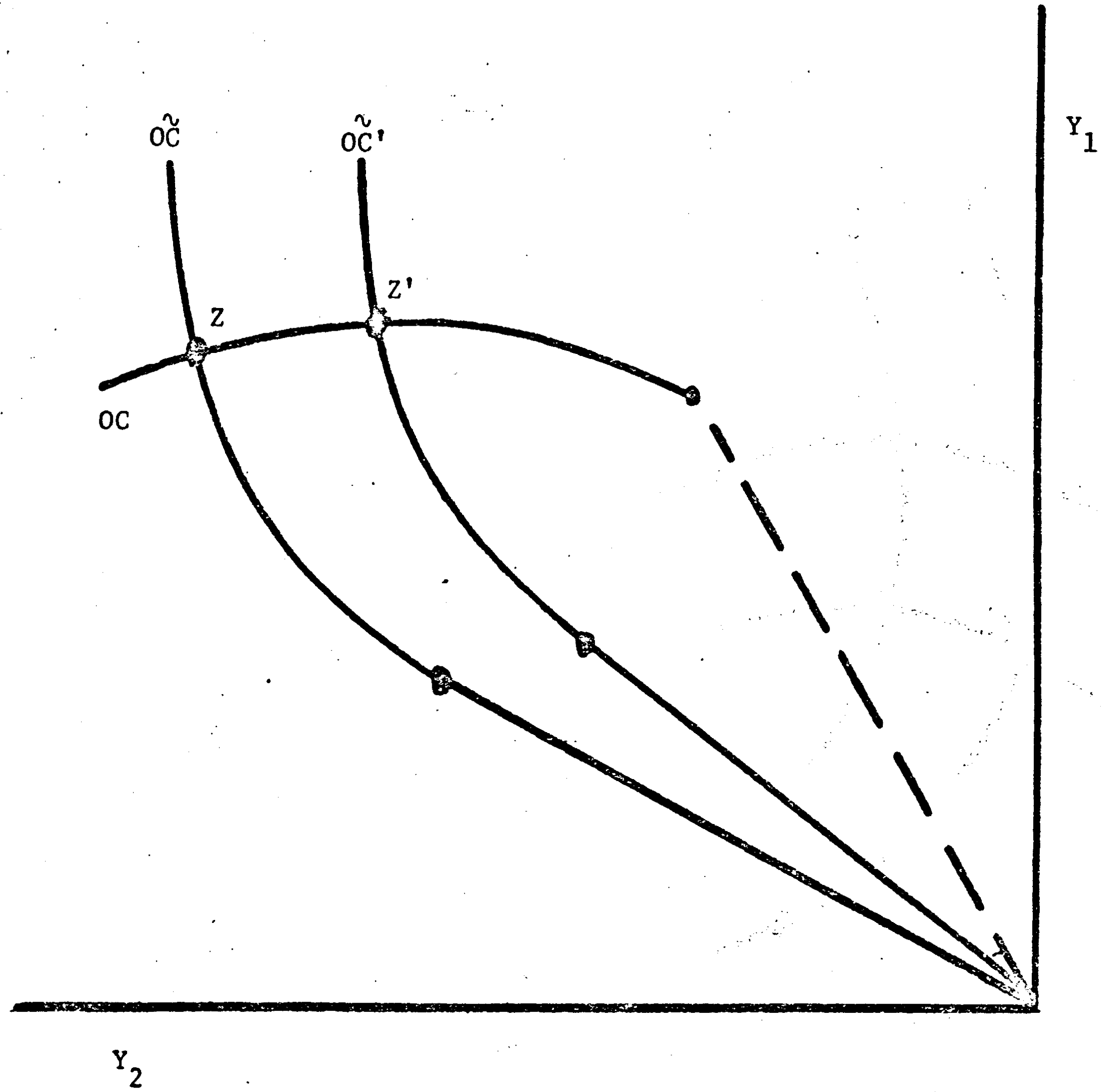

Figure 6: The effect of prohibiting technology transfer.

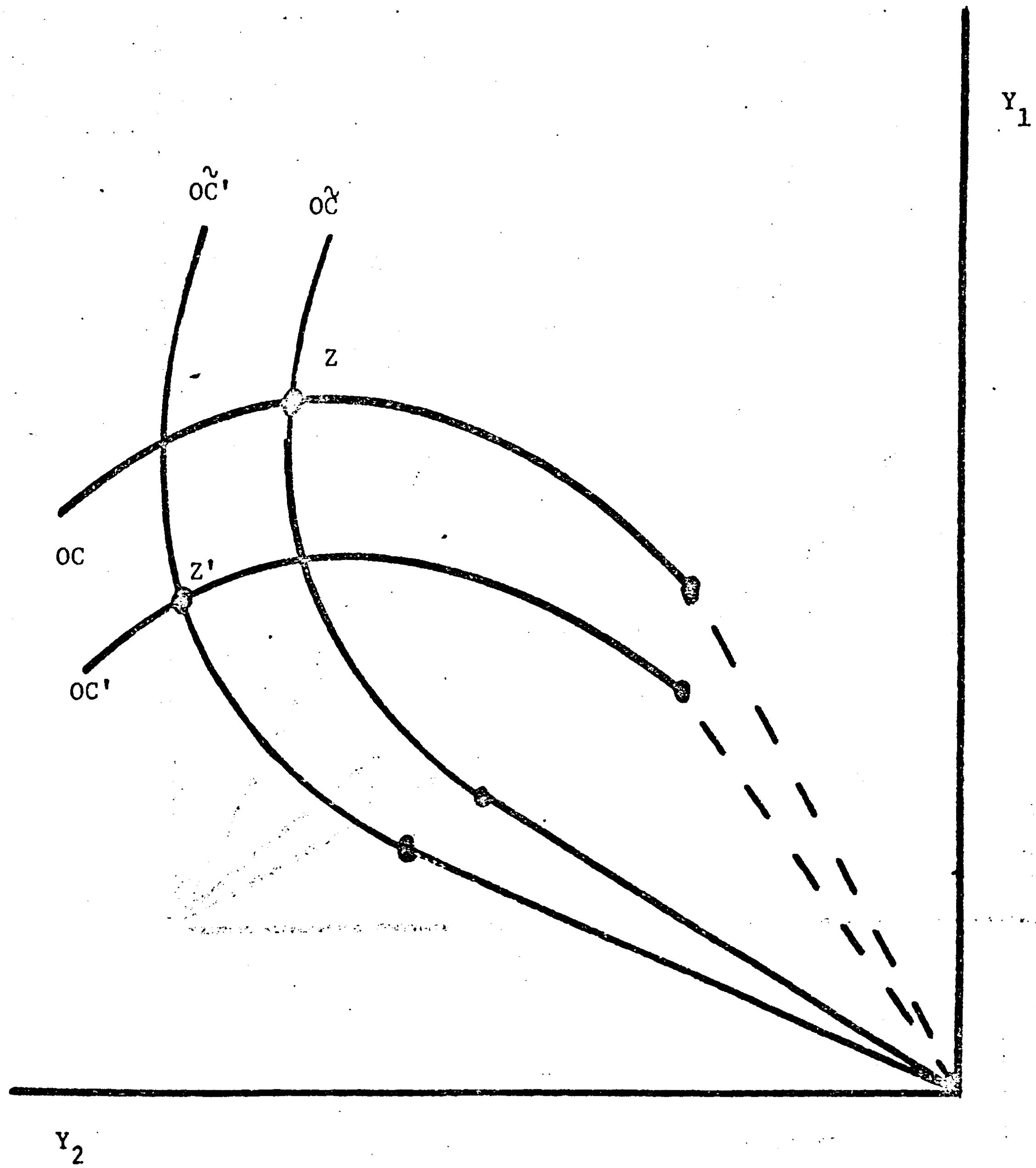

Figure 7: The effect of an optimum subsidy to
home R&D under free technology transfer.