TECHNOLOGY TRANSFER, FOREIGN DIRECT INVESTMENT AND INTERNATIONAL TRADE*

Leonard K. Cheng,† Larry D. Qiu, and Guofu Tan
Department of Economics
Hong Kong University of Science and Technology
Clear Water Bay, Kowloon
Hong Kong

August 1999

Abstract

By developing a Ricardian trade model that features technology transfer via foreign direct investment (FDI), we show that technology transfer via multinational enterprises (MNEs) increases world output and trade in goods and services. When there are many goods a continuous reduction in the cost of technology transfer will cause increasingly more technologically advanced goods to go through the product cycle, i.e., goods initially produced in the advanced North are later produced in the backward South as a result of increased technology transfer via MNEs.

* The authors would like to thank Henry Wan, Jr., Kar-yiu Wong, discussants at the Far Eastern Meeting of the Econometric Society 1999 in Singapore, 1-3 July 1999, and colleagues at the Hong Kong University of Science and Technology for their helpful comments and suggestions.

† Email address: leonard@ust.hk.

1. Introduction

In this paper we develop a Ricardian trade model that features technology transfer via foreign direct investment (FDI). FDI is traditionally regarded as an organic amalgamation of capital, technology, and management. With the increasing integration of the global capital market and the development of domestic capital markets in many host countries of multinational enterprises (MNEs), capital movement from the home countries of MNEs to the host countries seems to have become the least important ingredient of FDI.[1] In contrast, technology and managerial talent have increasingly become the key ingredients of FDI (see e.g. Root (1994, 591)).[2] In light of these facts, we regard FDI as synonymous to technology (and managerial skill) transfer.

There is a substantial literature on international trade and MNEs, and a recent survey of the literature is given by Markusen (1995). Among others, Helpman (1984) and Markusen (1984) incorporate MNEs into general equilibrium trade models based on "headquarter services" that can be used to support both local plants and subsidiaries set up abroad. On the one hand, production of headquarter services, which include management, distribution, marketing, and product-specific R&D, enjoy economies of scale. Thus MNEs have an incentive to concentrate their production in a single location. On the other hand, international differences in factor endowments and technologies provide an incentive to locate the production of final goods in countries with lower costs. These researchers show that MNEs and FDI arise if the relative factor endowments are sufficiently different across countries so that international trade alone does not lead to factor price equalization.[3] Ethier (1986) also incorporates FDI into a general equilibrium factor endowment trade mode. By emphasizing the internalization decision of MNEs, he obtains results that are contrary to those of Markusen (1984) and Helpman (1984): MNEs and FDI can arise when relative factor endowments are very similar. Moreover, FDI may either substitute or complement trade.

More recently, Brainard (1993) and Horstmann and Markusen (1992) develop models that feature two-way FDI. They find that MNEs are more likely to arise when firm-level fixed costs (like R&D) are large, tariffs or transportation costs are high, plant-level scale economies are not large, countries are large, and countries are similar in relative factor endowments (this last result is obtained in Brainard (1993) only). Most recently, Baldwin and Ottaviano (1998) propose a model of multi-product MNEs that simultaneously engage in intra-industry trade and intra-industry FDI.

Influenced by the large descriptive literature on MNEs and the empirical studies of the industry characteristics and geographical location of MNEs, as in Caves (1982), all existing theoretical studies in the literature of international trade and MNEs focus on the case where MNEs arise from imperfectly competitive markets as a result of increasing returns to scale or product differentiation. In contrast, our model is based on perfect competition in the product markets with neither transportation costs nor trade barriers.[4] Technology transfer via FDI (due to technologyical differences between countries and the need to spend resources to effect technology transfer) can occur even in the absence of imperfect competition in the product markets. In the presence of increasing cost of technology transfer at the level of the entire economy, firms in one country having superior technology may co-exist with firms in another country with inferior technology. Unlike the above-mentioned studies, we employ the Ricardian trade model that allows international differences in technologies rather than the Heckscher-Ohlin trade model that features international difference in factor endowments.

Our theoretical framework allows us to examine issues that are different from those studied by other researchers. Instead of explaining two-way trade and FDI among developed countries, our model is intended to complement the existing literature by explaining FDI made by firms from technologically more advanced economies in technologically less advanced economies.

In Section 2, after recapitulating a simple two-region (North and South) two-good Ricardian trade model, we augment it by allowing for international technology/management transfer that requires the use of resources. We examine in Section 3 different possibilities of technology transfer under the assumption that the South is small, and do so in Section 4 under the assumption that the South is large. In Section 5 we extend the two-good model to the case of infinitely many goods. The final section summarizes our findings and indicates directions for future research.

2. A Two-Region, Two-Good Ricardian Model with Technology Transfer and FDI

As in the standard Ricardian model, there are two regions (*N* for "North" and *S* for "South"), two goods (*f* for "food" and *m* for "manufactures"), and there is only one factor of production ("labor") in each region. The supply of labor in *S* and *N* is fixed at L and L^*, respectively. Labor is internationally immobile but goods are freely traded in the absence of any transportation costs. It is well known that FDI may arise in response to trade barriers and transportation costs, but in our model we assume away these two motives for FDI.

S's production technology for food and manufactures is described by two unit labor requirements, a_f and a_m, respectively. Similarly, *N*'s unit labor requirements are given by a_f^* and a_m^*. Without loss of generality, we suppose that *S* has a comparative advantage in food, i.e.,

$$\frac{a_f}{a_m} < \frac{a_f^*}{a_m^*}. \quad (1)$$

Thus, *S* exports food and *N* exports manufactures in the absence of technology transfer. Three possible configurations of technological differences are consistent with the direction of comparative advantage as described by inequality (1), namely,

(a) $a_f < a_f^*$, and $a_m > a_m^*$, (2a)

(b) $a_f > a_f^*$, and $a_m > a_m^*$, (2b)

(c) $a_f < a_f^*$, and $a_m < a_m^*$. (2c)

The inequalities in (2a)-(2c) describe the two regions' absolute advantages or disadvantages in production technology. In the case of (2a), *S* has both comparative and absolute advantage in the production of food while *N* has both comparative and absolute advantage in the production of manufactures. In the case of (2b), *S* has a comparative advantage in food but an absolute disadvantage in both goods; in the case of (2c), *N* has a comparative advantage in manufactures but absolute disadvantage in both goods. In these last two cases, one region is unambiguously more advanced than the other in production technology, and international direct investment by MNEs will emerge if the cost of technology transfer is small relative to the technology gaps. Given our interest in analyzing technology transfer from an advanced region to a backward region, we shall ignore (2a). Since cases (2b) and (2c) are symmetric, we shall focus on the case of (2b) alone, i.e., the case in which *N* has an absolute advantage in both goods. That is, *N* is technologically advanced whereas *S* is technologically backward.

It has long been recognized that FDI by MNEs is by far the most important channel of technology transfer from advanced economies to developing economies (e.g., Quinn (1969), Stewart and Nihei (1987, 8-12)). Many researchers of MNEs have emphasized the importance of training managers, workers and engineers of the technology recipients (e.g., Quinn (1969), Hieneman et.al. (1985), Stewart and Nihei (1987, 10-12, 74-75), Sakakibara and Westney (1992) and Root (1994, 590)). Teece (1976, 36-37 and 44) and Mansfield et.al. (1982, 69-71) identified four groups of transfer costs, and those costs all involve technical and operational personnel training.[5] They found the average transfer costs to be 19 percentage of total project costs and were far from trivial.

As trainers as well as managers, expatriate employees of MNEs play a crucial role in the process of technology transfer, even though their number is small in relative terms.[6] They are relatively more expensive and limited in supply, and are often supplemented by the nationals of the host economies who are educated in the advanced economies (e.g., Hieneman et.al. (1985), Stewart and Nihei (1987, 74) and Duning (1993, 373)).

Based on the empirical facts about technology transfer by MNEs and consistent with the transaction costs theory of technology transfer (see Markusen (1995)), we assume that MNEs are the only vehicle of technology transfer between S and N and that technology transfer requires the use of resources. The amount of resources required depends on the abilities of the MNEs, which in turn depend on the availability of expatriate managers and technicians who possess the knowledge needed in managing a foreign subsidiary and in adopting advanced production technology in the backward region. We assume that there is a continuum of MNEs with decreasing efficiency in technology transfer and each MNE can manage an increasing volume of foreign production only at increasing cost. Under these two assumptions, the resource requirements of the marginal MNE goes up as the total amount of MNE production increases.[7] That is to say, the "supply curve of technology transfer" is upward sloping. In our following analysis, we shall assume this upward supply curve to be linear. As we shall see, while the marginal MNE just breaks even from technology transfer, the intra-MNEs earn quasi-rents.

Workers in S and N are assumed to be equally productive given the same production technology. For every unit of food produced by a marginal MNE, it uses a_f^* unit of S labor for production and a certain amount of S labor in the process of technology transfer.[8] The latter amount is industry-specific but also depends on the total amount of technology transfer carried out by the MNEs. Specifically, the amount of S labor required for technology transfer per unit of food produced by an MNE is given by $rk_f a_f^*$, is where k_f is fixed and captures the characteristics of technology transfer specific to food, whereas r depends on the total amount of technology transfer by all MNEs in both industries.

As a result, the unit production cost measured in terms of S labor, our numeraire, incurred by the marginal MNE in food production is $a_f^* (1 + rk_f)$. The unit cost of production of food using the backward technology is a_f. Thus, FDI takes place in S's food industry if in equilibrium

$$a_f^* (1 + rk_f) \leqq a_f \tag{3}$$

and local firms using the backward technology a_f will survive only if the weak inequality in (3) is reversed.

Similarly, FDI takes place in S's manufacture industry if

$$a_m^* (1 + rk_m) \leqq a_m \tag{4}$$

and local firms using the backward technology a_m will survive only if the weak inequality in (4) is reversed.

To operationalize the assumption that r depends on the amount of technology transfer, let $T = a^*_f k_f q_{Mf} + a^*_m k_m q_{Mm}$ be the volume of technology transfer, where q_{Mf} and q_{Mm} are the MNE output of food and manufactures, respectively, in the South. For simplicity, suppose the relationship between T and r is given by

$$r = t_0 + cT \tag{5}$$

where both t_0 and c are positive coefficients. For analytical purposes, we may think of (5) as the "inverse supply curve" of T. From (5) we can obtain the "direct supply curve" of T,

$$T = (r - t_0)/c \tag{5'}$$

An upward sloping supply curve of T captures the probable phenomenon that when MNEs expand their operations in foreign countries they may have to tap marginal resources that are increasingly less efficient at technology transfer. An improvement in knowledge about foreign countries would shift T's supply curve outward or downward.

Whether technology transfer occurs in only one or both of the industries depends on absolute technological differences as captured by a_f, a_f^*, a_m, and a_m^*, the resource cost of technology transfer as captured by k_f, k_m, and the variable r that can analytically be thought of as the unit cost of T for the marginal MNE.

On the demand side, let us assume that the preferences of all consumers in the world are described by a Cobb-Douglas utility function $U = C_f C_m$, where C_f and C_m are the consumption of food and manufactures, respectively. Given this utility function, each consumer will divide his total expenditure equally between food and manufactures. If y is a region's GNP measured in food and p is the relative price of manufactures, then its welfare is given by $y^2/(4p)$ or any positive monotonic transformation of the expression.

In the next two sections we shall first study the case where S produces either food or manufactures, and then study the case where S produces both goods. In the first case technology transfer occurs in only one industry, while in the second case technology transfer occurs in one or both of the industries.

3. The South Produces Only One Good

3.1 The South Is Small

If S is small relative to N, then the equilibrium relative price p is determined by N's unit production costs of food and manufactures, i.e., $p = a_m^*/ a_f^*$. Which good the small S will specialize in depends on its comparative advantage after technology transfer.

3.1.1 The South Specializes in Food

Given the initial pattern of comparative advantage as described by (1), S will continue to specialize in food if technology transfer occurs in food but not in manufactures. A sufficient condition for this pattern of technology transfer is

$$(A_f - 1) > k_f t_0 \text{ but } (A_m - 1) < k_m t_0 \qquad (6)$$

where $A_f = \dfrac{a_f}{a_f^*}$ and $A_m = \dfrac{a_m}{a_m^*}$ are measures of the technological gaps between S and N, and t_0 is the value of r of the MNE that is most efficient at technology transfer. Condition (6) says that at the minimum r, technology transfer to food is profitable but that to manufactures is not.

Referring to the discussion preceding (3), we see that in producing a unit of food, all MNEs in S use a_f^* of local labor in direct production. The unit cost of technology transfer varies from t_0 to r. Thus, the marginal unit cost of technology transfer, $rk_fa_f^*$, exceeds the average unit cost $(r+t_0)k_fa_f^*/2$, where both costs are measured in terms of *S* labor.[9]

Let q_{Mf} be the quantity of food produced by all the MNEs in *S*. Then

$$T = a_f^* k_f q_{Mf}, \tag{7}$$

and the total amount of *S* labor employed by the MNEs, including labor employed directly to produce food and that employed for the purpose of technology transfer is given by

$$L_M = a_f^* \left(1 + \frac{r + t_0}{2} k_f\right) q_{Mf} . \tag{8}$$

Substituting (7) into (8) yields

$$L_M = \left(\frac{1}{k_f} + \frac{r + t_0}{2}\right) T, \tag{9}$$

Equation (9) shows that L_M is an increasing and convex function of *T* or *r*, where convexity follows from a positive relationship between *r* and *T* in (5).

The equilibrium value of *r* and *T* depends on the relationship between L_M and *S*'s total supply of labor *L*, as described in Figure 1. If the "supply of *T* is small" relative to the supply of labor in *S* (such as L_2), the constraint $L_M \leqq L$ is not binding. In this case the equilibrium configuration is given by $(\bar{r}, \bar{T}, L_M(\bar{T}))$, where $\bar{T}$ is determined by (5') and (9). If in contrast the supply of *T* is large relative to the supply of labor in *S* (such as L_1), the constraint $L_M \leqq L$ is binding. The corresponding equilibrium configuration is given by (r_1, T_1, L_1).

Using (5') in (9), we can distinguish two alternative cases. If $[A_f^2 - (1 + t_0 k_f)^2]/(2ck_f^2) \leqq L$, then the constraint $L_M \leqq L$ is not binding. We refer to it as a case in which "the supply of *T* is small". If $[A_f^2 - (1 + t_0 k_f)^2]/(2ck_f{}^2) > L$, then the constraint is binding. We refer to it as a case in which "the supply of *T* is large".

<u>The Supply of *T* is Small</u>

If the supply of *T* is small relative to *L*, then $r=(A_f-1)/k_f$ and $a_f = a_f^*(1 + rk_f)$, i.e., local firms co-exist with MNEs in *S*'s food industry. *S*'s GNP is given by L/a_f, but its GDP is given by the sum of its GNP and the quasi-rents of the MNEs, also measured in food. In other words, the small *S* region gains nothing from technology transfer and all the gains accrue to the MNEs.

The MNEs' quasi-rents are equal to the difference between their total output of food and the costs of L_M in terms of food,

$$\frac{L_M}{a_f^*\left(1+\frac{r+t_0}{2}k_f\right)} - \frac{L_M}{a_f^*(1+rk_f)} = \frac{L_M}{a_f^*(1+rk_f)}\frac{\left(\frac{r-t_0}{2}\right)}{\left(\frac{1}{k_f}+\frac{r+t_0}{2}k_f\right)} \qquad (10)$$

In view of (9), the MNEs' quasi-rents can also be expressed as $\frac{\pi_M}{a_f^*(1+rk_f)}$, where $\pi_M = \frac{(r-t_0)T}{2} = \frac{(r-t_0)^2}{2c} = \frac{cT^2}{2}$ is the "producer surplus" above the supply curve of T but below r. Not surprisingly, we can obtain the quasi-rents of all of the MNEs directly from the producer surplus associated with T's supply curve. This relationship will be used repeatedly in the subsequent analyses. In particular, a decrease in A_f, an increase in k_f, an increase in c, and an increase in t_0 will reduce π_M by reducing T. Moreover, it can be shown that $\frac{T^2}{1+rk_f}$ is an increasing function of T after the positive relationship between r and T is taken into account, and the equilibrium T is a decreasing function of t_0 and c. Thus, the MNEs' quasi-rents measured in food go up (down) as the supply curve of T shifts outward (inwards).

The Supply of T is Large

If the supply of T is large relative to L, then $a_f > a_f^*(1+rk_f)$, no local firms will survive, and $L_M = L$. Unlike the case in which the supply of T is small, S's GNP measured in food increases as t_0 and c decrease. Clearly, S's welfare is higher with than without technology transfer if the supply of T is sufficiently large.

If we assume that all of the MNEs' quasi-rents are spent in N, then S's export of food is equal to half of S's GNP plus the entire quasi-rents, i.e., $E_{Sf} = \left(\frac{L}{2}+\pi_M\right)/\left[a_f^*(1+rk_f)\right]$. Moreover, the exports associated with quasi-rents represent trade in services.

An outward shift of the supply curve of T results in a lower r and a larger T, leading to an increase in S's GNP as well as the MNEs' quasi-rents and consequently an increase in E_{Sf}. N's welfare goes up because its GNP is higher and the terms of trade remain unchanged.

The above results are summarized as

Proposition 1: Technology transfer via MNEs increases world output. If the South is small, then it gains from technology transfer in the food industry only if the supply of T is sufficiently large. The North always gains from technology transfer. An increase in the supply of T leads to a larger volume of trade in goods and services.

3.1.2. The South Specializes in Manufactures

An interesting consequence of technology transfer is that it may lead to a reversal in the direction of comparative advantage. For the South to specialize in manufactures, which is opposite to that described by (1), two conditions must hold

$$(A_m - 1)/k_m > (A_f - 1)/k_f, \text{ and} \quad (11)$$

$$1 + rk_m < A_f \quad (12)$$

Condition (11) is necessary because otherwise technology transfer occurs in food, thus reinforcing the initial pattern of comparative advantage, which is the case studied in Section 3.1.1. Given condition (11), condition (12) is both necessary and sufficient for the initial pattern of comparative advantage to be reversed. It implies that the supply of T is sufficiently abundant for r to be sufficiently small (a sufficient condition is $1+ t_0k_m << A_f$ and c is sufficiently close to zero). Under these conditions no local firms survive in the manufactures industry.

As in the previous case, N gains from the quasi-rents. But how about S?

Proposition 2: If the South is small and if its direction of comparative advantage is reversed due to technology transfer, then its welfare is higher with than without technology transfer. The North gains from technology transfer due to the presence of quasi-rents. An increase in the supply of T leads to a larger volume of trade.

Proof: S's GNP without technology transfer is equal to L/a_f, whereas its GNP with technology transfer is equal to $\left[L/(1+rk_m)a_m^*\right](a_m^*/a_f^*)$, where a_m^*/a_f^* is the relative price of manufactures. In light of (12), S's GNP and welfare are higher with technology transfer. S's export of manufactures is equal to

$E_{Sm} = \left(\frac{L}{2} + \pi_M\right) / \left[a_m^*(1+rk_m)\right]$, which increases as the supply of *T* increases. *S* must be better off when it chooses to specialize in manufactures because it always has the option of specializing in food.

3.2. Neither Region Is Large

When neither region is large, each will specialize in the production of one good and the equilibrium relative price depends on the regions' supply and demand. As in the previous sections, *S* will export one-half of its GNP in exchange for imports and the entire quasi-rents to repatriate the quasi-rents to *N*. In the following we shall focus on the equilibrium terms of trade and welfare; the behavior of trade volume is similar to that stated in Propositions 1 and 2.

3.2.1. The South Specializes in Food while the North Specializes in Manufactures

If the supply of *T* is small relative to *L*, then local firms co-exist with MNEs in *S*'s food industry. *S*'s GNP is given by L/a_f, and *N*'s GNP is equal to $\left(L^* p / a_m^* + \pi_M / a_f\right)$. Using the balanced trade condition, we derive the equilibrium relative price of manufactures, $p = \frac{a_m^*\left(L + \pi_M\right)}{a_f L^*}$. In the absence of technology transfer, $p = a_m^* L / \left(a_f L^*\right)$ because $\pi_M = 0$. Upon comparison, we see that *N*'s welfare improves with technology transfer due to an increase in its GNP and an improvement in its terms of trade. But *S*'s welfare declines due to a deterioration of its terms of trade.[10]

If the supply of *T* is large relative to *L*, then only MNEs produce food in *S*, whose GNP is equal to $L / \left[a_f^*(1+rk_f)\right]$. The equilibrium relative price of manufactures is equal to $p = \frac{a_m^*\left(L + \pi_M\right)}{a_f^*\left(1+rk_f\right)L^*}$. As revealed in this expression, *N*'s terms of trade improve due to two reasons: (i) the unit cost of producing food in *S* goes down and (ii) an increase in demand for manufactures arising from the MNE profits.

S's welfare with technology transfer may be higher or lower than that without technology transfer because it gains from an increase in productivity but loses due to deterioration in its terms of trade. If the supply of *T* is sufficiently abundant, then *r* and

π_M become very small. In that case S's welfare will be higher with technology transfer.

To sum up, we obtain

Proposition 3: If the supply of T is small, the South's welfare declines in the presence of technology transfer due to a deterioration in its terms of trade. If T is large, the South's welfare may improve if its gain in productivity is sufficiently large. The North's welfare improves unambiguously regardless of the supply of T.

3.2.2. South Specializes in Manufactures while North Specializes in Food

As in Section 3.1.2, to have a reversal in the pattern of comparative advantage, condition (12) must hold. The equilibrium relative price of manufactures is given by $p = \frac{L^* a_m^* (1 + rk_m)}{a_f^* (L + \pi_M)}$, which is rather different from that without technology transfer, namely, $p = a_m^* L / \left(a_f L^*\right)$. Under this pattern of specialization, S's GNP is given by $Lp / \left[a_m^* (1 + rk_m)\right]$. By comparing S's indirect utility with technology transfer and that without technology transfer, it can be shown that the former exceeds the latter if and only if

$$LA_f > (L + \pi_M)(1 + rk_m) \qquad (13)$$

If π_M did not appear in (13), then the condition is met because of (12). However, the presence of π_M may make the inequality go in the opposite direction. From the expression of p, one sees that π_M worsens S's terms of trade. Nevertheless, if a_f^* is sufficiently smaller than a_f (so that A_f is large) and that the supply of T is sufficiently large and elastic (so that r and π_M are small), S's welfare will be higher with than without technology transfer. That is to say, when S is not a small region, Proposition 2 holds only under somewhat more stringent conditions.

4. The South Produces Both Goods

If S is large relative to N, it produces both goods and its unit costs after technology transfer determine the relative price p. The volume of trade is equal to one-half of N's GNP less the entire quasi-rents of MNEs, but the pattern of trade depends on N's comparative advantage after technology transfer.[11] Depending on the size of technological gaps (A_f and A_m) and the parameters of technology transfer (k_f, k_m and r), technology transfer may occur in the food industry only, or in the manufactures industry only, or in both industries. More specifically, if

$$(A_f -1)/ k_f > t_0 > (A_m -1)/k_m,$$

then there is technology transfer in the food industry alone. If these strict inequalities are reversed, then there is technology transfer in the manufactures industry alone. For technology transfer to occur in both industries, it requires that

$$t_0 < (A-1)/k \equiv \min\{(A_f -1)/ k_f, (A_m -1)/k_m\} \text{ and}$$

c is sufficiently small so that $r \leqq (A-1)/k$.

In our analysis of these three cases below, we focus on S and N's welfare but omit the effect on p and the volume of trade.

4.1. Technology Transfer to the Food Industry Only

N will specialize in manufactures. The relative price of manufactures is equal to a_m/a_f, same as that without technology transfer if the supply of T is small, but is equal to $a_m /\left[a_f^*(1+rk_f)\right]$ if the supply of T is large. In the first case, S's welfare is unaffected by technology transfer but N's welfare improves unambiguously due to quasi-rents. In the second case, S's welfare improves because its gain in productivity dominates the deterioration in its terms of trade, while N's welfare increases further from an improvement in its terms of trade. That is to say, Proposition 1 is generalizable to the case of a large Southern region.

4.2. Technology Transfer to the Manufacture Industry Only

4.2.1. Technology Transfer Does Not Affect the Direction of Comparative Advantage

Unlike Section 3.1.2, the effect of technology transfer to manufactures depends on the supply of T. If the supply of T is small, the relative price of manufactures is unaffected by technology transfer. S's welfare remains the same but N's welfare increases. If the supply of T is large, then no local firms exist in S's manufacturing industry and the relative price of manufactures becomes $a_m^*\left(1+rk_m\right)/a_f$. S's welfare improves because its productivity increases and its terms of trade improve. The effect of technology transfer on N's welfare, however, is ambiguous because N gains from quasi-rents but loses from a deterioration in its terms of trade, something that cannot happen if N is large.

4.2.2. Technology Transfer Reverses the Direction of Comparative Advantage

This case arises if the supply of T is large and condition (12) is satisfied. S's welfare improves despite a deterioration in its terms of trade, but N's welfare may go up or down because the welfare derived from its GDP from producing food under technology transfer may be larger or smaller than from producing manufactures without technology transfer. Nevertheless, N's welfare is unambiguously higher with technology transfer if $A_f > A_m$ (i.e., a_f^* is sufficiently small relative to a_f).

4.3. Technology Transfer to Both Industries

In this unique case, the relative price of manufactures is $p = \frac{a_m^*(1+rk_m)}{a_f^*(1+rk_f)}$, where at most one of (3) and (4) may hold as equality.[12] The "demand curve for T" – the maximum r that permits different levels of technology transfer to occur - is depicted in Figure 2 under the condition that $[(A_f-1)/k_f] > [(A_m-1)/k_m]$. If the inequality is reversed, then the relative position of $(A_f-1)/k_f$ and $(A_m-1)/k_m$ is also reversed.

For technology transfer to occur in both industries, the supply of T must be sufficiently large to intersect the demand curve at points such as A and B. At A MNEs dominate the food industry whereas in the manufacture industry they co-exist with local firms. At B there are no local firms in either industry in S, implying that both (3) and (4) hold with strict inequality.

It can be shown that the pattern of comparative advantage depends on the relative magnitudes of k_f and k_m. If $k_f < k_m$, then N specializes in manufactures; if $k_f > k_m$, then N specializes in food. It is intuitive that N has a comparative advantage in a production technology that is more difficult to transfer to S.

It can be shown that S's welfare is higher with than without technology transfer, regardless of whether the point of intersection is A or B. For a large S, its welfare depends on its own production frontier, regardless of the pattern of trade. And the frontier is pushed out unambiguously due to technology transfer.

If $k_f < k_m$, N specializes in manufactures but if $k_f > k_m$, it specializes in food. However, the effect of technology transfer on N's welfare is in general ambiguous.

Proposition 4: Suppose the South is large, the North is small, and technology transfer occurs in both industries. The South's welfare improves with technology transfer regardless of the direction of comparative advantage. The North's comparative advantage in manufactures remains intact if and only if $k_m > k_f$, but the direction of comparative advantage is reversed if $k_m < k_f$. The North's welfare depends on the direction of comparative advantage as well as the differences between the terms of trade with and without technology transfer.

5. Technology Transfer in the Continuum Ricardian Model

In this section we extend the above analysis to the continuum Ricardian model developed by Dornbusch, Fisher, and Samuelson (1977) (hereafter DFS) in order to explore the question of technology transfer via FDI when there are many industries. Following DFS, let $a(z)$ be the amount of S labor, and $a^*(z)$ the amount of N labor that is needed to produce one unit of good z, where z lies within the unit interval, i.e., $0 \leqq z \leqq 1$. Let $A(z)$ be the ratio of $a(z)$ and $a^*(z)$.[13] With appropriate indexing of the goods, $A(z)$ can be made a monotonic function of z, and without loss of generality let us suppose that S's comparative advantage in good z decreases as z increases, i.e., $A(z)$ is an increasing function of z. Given this indexing convention z may be loosely interpreted as the level of technological sophistication. In addition, by choosing an appropriate unit of measurement for each good, we can also make $a^*(z)$ increasing in z.

As in the two-good model, N is assumed to be superior to S in the production technology of all goods, i.e., $a^*(z) < a(z)$ for all z. The Northern firms' technological edge over the Southern firms is measured by $a(z) / a^*(z)$, which is just $A(z)$, a monotonically increasing function. Thus, $A(z)$ measures the relative benefits from technology transfer. As before, the cost of technology transfer, measured in S labor by the marginal MNE, is given by $ra^*(z)k(z)$. We assume that the resource cost of technology transfer is higher the more sophisticated is the product, i.e., $k(z)$ is an increasing function of z.

The counterpart of (3) and (4) is

$$a^*(z)\left[1 + rk(z)\right] \leqq a(z). \qquad (14)$$

As in the two-good model analyzed above, we assume that preferences of all consumers are identical and are represented by the continuum version of the Cobb-Douglas utility function, i.e., each consumer will devote the same fraction of his income to the consumption of each good *z*.

In the continuum model without technology transfer, it has been established by DFS that under free trade and in the absence of transportation cost there exists $\tilde{z}$ strictly between 0 and 1 such that *S* produces all goods *z* demanded within the range $[0, \tilde{z}]$, and *N* produces all goods *z* demanded within the range $(\tilde{z}, 1]$. That is, the "borderline" good $\tilde{z}$ breaks the "chain of comparative advantage" *A(z)*. The equilibrium wage of Northern labor relative to Southern labor $\tilde{w}$, at which $\tilde{w}\, a^*(\tilde{z}) = a(\tilde{z})$, is determined by the balanced trade condition. This is to say, the continuum model corresponds to the two-good Ricardian model in Section 3.2 where neither region is relatively large.

In the presence of technology transfer, the "chain of comparative advantage" is changed. Observe that good *z* is produced by

$$\begin{cases} \text{S firms} \\ \text{MNEs} \\ \text{N firms} \end{cases} \quad \text{if and only if} \quad \begin{cases} A(z) \leqq \min\{1 + rk(z), w\} \\ 1 + rk(z) \leqq \min\{A(z), w\} \\ w \leqq \min\{A(z), 1 + rk(z)\} \end{cases} \tag{15}$$

As can be seen from (14), industry *z*'s maximum willingness to pay for *T* is given by $R(z) \equiv (A(z) - 1)/k(z)$. Since both *A(z)* and *k(z)* are increasing functions of *z*, the behavior of *R(z)* is unclear without further restrictions. We assume that *R(z)* is an increasing function of *z*, or equivalently *A(z)* increases faster than *k(z)*. With the help of Figure 3, it becomes clear that for any given *w*, there exists z_0 and z_1 such that *S* firms produce goods in the range $[0, z_0]$, MNEs produce goods in $[z_0, z_1]$, and *N* firms produce goods in $[z_1, 1]$, where z_0 and z_1 satisfy

$$1 + rk(z_0) = A(z_0)$$

$$1 + rk(z_1) = w. \tag{16}$$

There two equations, together with the trade balance condition and the equality of demand and supply of *T*, determine simultaneously the equilibrium $(z_0, z_1, \hat{w}, r)$.

To analyze these equilibrium conditions in more details, we first study the "aggregate demand function" for *T*. The demand for *T* by industry *z* is given by

$$T_D(z; r) = \begin{cases} a^*(z)k(z)D(z; r), & \text{if } 1 + rk(z) \leqq \min\{A(z), w\} \\ 0, & \text{otherwise} \end{cases} \tag{17}$$

where *D(z;r)* is the total demand for good *z* at the price $a^*(z)[1+rk(z)]$. Since the world's total income is $y_w = L + wL^* + \pi_M$,

$$D(z;r) = \frac{y_w}{a^*(z)[1+rk(z)]}. \tag{18}$$

Note that from (16), $1+rk(z) \leqq \min\{A(z), w\}$ is equivalent to $z_0 \leqq z < z_1$. Summing $T_D(z; r)$ over $[z_0, z_1]$ yields the total demand for T:

$$T_D(r) = \int_{z_0}^{z_1} T_D(z;r)dz. \tag{19}$$

Combining (17)-(19), we obtain

$$T_D(r) = (L + wL^* + \pi_M)\int_{z_0}^{z_1} \frac{k(z)}{1+rk(z)}dz \tag{20}$$

where $\pi_M = (r - t_0)^2/2c$. From (16), for any fixed w, z_0 is an increasing function of r but z_1 is a decreasing function of r. Thus, the integral in (20) is decreasing in r. This represents the price effect on demand. Since π_M increases with r, there is also an "income effect" on the demand for T. So long as the direct effect dominates the indirect effect, T_D is a decreasing function of r. Even if T_D is not a decreasing function of r, the equilibrium r is still unique and stable so long as T_D is steeper than the supply curve T in the usual price-quantity space. In any event, for any given w the equilibrium r is determined by

$$T_D = T, \tag{21}$$

where T is given by (5').

The determination of equilibrium T is illustrated in Figure 4. Given w, the maximum willingness to pay for T is $R(z_1)$ whereas the minimum willingness to pay for T *is* $R(0)$. The equilibrium r is $r^* = R(z_0)$ and the equilibrium T is T^*. An increase in w, by increasing z_1, will increase both r^* and T^*.

For any given r, the equilibrium w is determined by the balanced trade condition:

$$(1 - z_1)(L + wL^* + \pi_M) = wL^* \tag{22}$$

The left-hand side represents demand for goods produced in N while the right-hand side represents the supply of goods by N (i.e., N's GDP). There are two differences between this equilibrium condition and that without technology transfer: (i) with technology transfer w is given by $[1 + rk(z_1)]$ rather than by $A(\tilde{z})$, and (ii) there are quasi-rents associated with technology transfer.

Thus, the equilibrium conditions are given by (16), (21) and (22). The situation is illustrated in Figure 3.[14] The technologically least sophisticated goods within $[0, z_0]$ are produced by local firms and those more sophisticated goods within $[z_0, z_1]$ are produced by MNEs in *S*. The most sophisticated goods within $[z_1, 1]$ are produced in *N* by Northern firms. The equilibrium *w* is given by $[1+rk(z_1)]$ rather than $A(z_1)$ because if $w>[1+rk(z_1)]$ then it would be cheaper to produce the goods immediately to the right of z_1 in *H* by MNEs, contradicting the definition of z_1.

Recall that *R(z)* is increasing in *z*. Depending on the relationship between the equilibrium *r* and *R(z)*, we have three possibilities: (i) $r \geqq R(1)$; (ii) $r \leqq R(0)$, and (iii) $r \in (R(0), R(1))$. In the first case, *r* is too high to result in any technology transfer, so it degenerates into the original continuum model analyzed by DFS (1977). In the second case, *r* is so low that no local Southern firms survive in any industry. We shall ignore these two cases and instead focus on the third, general case in which Southern firms exist in industries $(0, z_0)$ while MNEs operate in industries (z_0, z_1), where $1+rk(z_0)=A(z_0)$, and $w=1+rk(z_1)$.

In this general case, *N* produces a narrower range of goods with technology transfer, i.e., $z_1 > \tilde{z}$. These goods would be produced by the technologically advanced North in the absence of technology transfer, but are produced by the backward South as a result of technology transfer. In a sense, technology transfer has generated a “product cycle” for goods within $[\tilde{z}, z_1]$. It can be seen from Figure 3 that a decrease in *r* over time increases the range of goods produced by MNEs. In other words, if the supply curve of *T* falls over time, then the product cycle applies to increasingly more sophisticated products over time.

Even though our model is static, it generates product cycles by way of technology transfer via MNEs. Thus, it is in the same spirit as Vernon (1966), but is different from the dynamic models that generate product cycles from the South’s imitation of Northern innovations (e.g., Grossman and Helpman (1991a, 1991b)).

Even though $z_1 > \tilde{z}$, the relative wage of Northern labor does not necessarily go up. As can be seen in Figure 3, this result arises because without technology transfer $w = A(\tilde{z})$ but with technology transfer $w = [1+rk(z_1)]$, where $A(z) > [1+rk(z)]$ for all *z* that is produced by *N* firms and MNEs.

The position of z_1 or w is determined by the balanced trade condition, but the presence of π_M makes the determination complicated. To illustrate our analysis, we consider a special case of the supply curve of T, namely, the supply curve is infinitely elastic. The case is analyzed in the Appendix, but the results can be summarized as

Preposition 5: Suppose that the supply of T is infinitely elastic at t_0 (i.e., all MNEs are equally efficient in technology transfer). Then in equilibrium technology transfer takes place via FDI if and only if $t_0<R(\tilde{z})$. Furthermore, $\tilde{z} < z_1, \tilde{w} > w$ and a decline in t_0 raises z_1 but lowers w.

Note that when the supply of T is infinitely elastic, there are no quasi-rents associated with technology transfer. An upward sloping supply curve will result in quasi-rents and higher welfare for N directly via additional GNP and indirectly via the terms of trade effect. This more general case is analyzed in the Appendix. It is shown there that an increase in the supply of T will raise z_1 unambiguously. If the system is stable, then r will decline.

Using S labor as the numeraire, we see from Figure 3 that the prices of all goods produced by MNEs are lower. The prices of goods produced in N are higher or lower than in the absence of technology transfer, depending on whether w has risen or fallen, respectively. As in the two-good Ricardian model analyzed in Section 3.2.1, where neither N nor S is relatively large, Southern labor gains from the presence of MNEs due to productivity gains, but may also lose due to a deterioration in its terms of trade. In the event that the supply curve of T is perfectly elastic, S's terms of trade improve because w declines. Northern labor gains from the technology transfer unless N's terms of trade deteriorate substantially relative to the lower prices of goods made by MNEs. In addition, N's total welfare also increases due to quasi-rents, which represent trade in services.

As in the two-good model, technology transfer in the continuum model expands the world's production frontier. Thus, at the prices under technology transfer, world output must be higher with than without transfer.

What about the volume of trade measured in terms of Southern labor? In equilibrium the South imports a fraction $L/(L+wL^*+\pi_M)$ of all of the goods produced in the North, whose total value is wL^*. The South exports enough goods in $[0, z_1]$ not only to pay for this import, but also to repatriate π_M to the North. By definition, the total trade in goods and services between N and S is equal to

$[LL^{*}w/(L+wL^{*}+\pi_M)] + \pi_M$.

The effect of technology transfer via MNEs on world trade in goods and services is through its impact on w and π_M. In the likely case that w falls but π_M rises with an increase in the supply of T, the effect on total trade measured in Southern labor is ambiguous. If the supply of T is perfectly elastic, then $\pi_M = 0$ and the volume of trade must decline as w decreases.

Since the real wage of Southern labor increases due to technology transfer, a decline in world trade measured in Southern labor is not inconsistent with an increase in world trade measured in terms of products or utility. Nevertheless, if technology transfer is increasingly free, then in the limit there will be no technological differences and zero trade.

6. Summary and Directions for Future Research

We have extended the traditional and continuum Ricardian models to feature both international trade and technology transfer via FDI by MNEs. Among others, we have shown that (a) world output increases in the presence of technology transfer by MNEs; (b) technology transfer may reverse the direction of comparative advantage; (c) the host country of the MNEs may gain or lose depending on the relative importance of productivity increases brought about by the MNEs and the deterioration of the host country's terms of trade, and (d) trade in goods and services are positively related to FDI by MNEs. In addition, an increase in the MNEs' ability of technology transfer over time will expand the volume of world trade, and in the continuum model it will cause increasingly sophisticated goods to go through the product cycle. If a way can be found to ascertain the increase in the supply of resources that are essential to technology transfer, then the above predictions can be empirically tested.[15]

If the South is small relative to the North, then the former gains from technology transfer if the MNEs are sufficiently efficient in technology transfer; the large Northern region always gains from quasi-rents. If the South is large while the North is small, then the former gains from productivity increases despite a deterioration in its terms of trade. If neither country is large relative to the other, both may gain but one of them may lose due to deterioration in its terms of trade.

To address the issue of income distribution, it would be useful for future research to allow for more than one factor of production. In the present model, MNEs may or may not produce simultaneously in both countries, so a second direction of future research is to consider vertically related production processes.[16]

A third direction of research is to extend the technology transfer model to many countries in order to capture the cascading pattern of FDI and trade, namely, that advanced countries invest in all economies while Newly Industrializing Economies invest in the developing economies.

Footnotes

1. For some evidence about the lack of a strong positive correlation between total capital flows and FDI flows, see Krugman (1998). As reported by Blomstrom and Kokko (1994), the main reason for FDI by Swedish firms has been technological advantages. Swedish MNEs expanded FDI despite limitation on financing such investment with funds raised in Sweden.

2. Bai, Tao and Wu (1999), in their study of 200 foreign joint ventures in China (whose average size of investment is US$ 12 million), 95% of the foreign partners provide patent, design, trademark and equipment, 56% provide technical training and 49% provide technical and management support.

3. Helpman and Krugman (1985, chapters 12 and 13) have a similar analysis and arrive at the same results.

4. If trade barriers and transportation costs are significant, MNEs may emerge depending on the cost of technology transfer. If such cost is relatively high, there will be no technology transfer and no MNEs.

5. The four groups of transfer costs are (1) the cost of pre-engineering technological exchanges; (2) the engineering costs associated with transferring the process design and product design; (3) the cost of R&D personnel during all phases of the transfer project for the purpose of solving unexpected transfer problems and adapting the technology, and (4) pre-start-up training costs and learning and debugging costs during the start-up phase.

6. According to Stewart and Nihei's (1987, Table 6-1) study of Japanese subsidiaries and joint ventures in Indonesia and Thailand, the Japanese expatriates accounted for 10-75% of total professional and managerial employment, but only 0.5-3.0% of total employment.

7. Similar assumptions are adopted in Cheng, Qiu and Tan (forthcoming).

8. An alternative assumption that Northern labor rather than Southern labor is used in the process of technology transfer may be explored, but not done so here.

9. The expression of the average unit cost follows from the linear supply curve of T.

10. The deterioration of S's terms of trade is equivalent to the effect of Hicks-neutral technical progress in an economy's exportable sector as analyzed by Findlay and Grubert (1959).

11. If S is really large relative to the supply of T, then its local firms in both the

manfactures and food industries co-exist with MNEs. The unit costs after technology transfer are the same as those before transfer, and the North's comparative advantage will not change. We ignore this case because the implications are obvious: The South gains nothing from technology transfer whereas the North exports manufactures and provides technology transfer services to the South.

12. The case in which both (3) and (4) hold as equality implies that technology transfer occurs in only one of the two industries. These cases were analyzed above in Sections 4.1 and 4.2.

13. In DFS (1977), A is defined as a^*/a, but the inverse of this ratio is more convenient for us.

14. A sufficient condition is that $R(z)$ is increasing in z and $R(0) < r < R(1)$.

15. Ekholm (forthcoming) analyzes the effect of trade in services associated with MNEs on measures of revealed factor abundance, and Goldberg and Klein (1999) examine the impact of FDI by MNEs on the pattern and volume of trade. Unlike our Ricardian models, however, Ekholm adopts the Heckscher-Ohlin model whereas Goldberg and Klein adopt the specific-factor model as their respective analytical frameworks.

16. A partial equilibrium model developed by us (1998) featuring two kinds of labor (skilled and unskilled) is used to explain vertical fragmentation of production between Hong Kong and South China with and without FDI.

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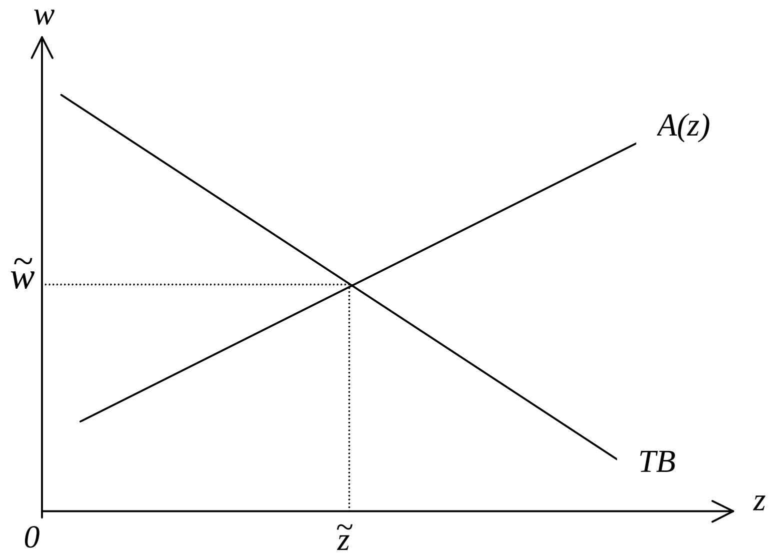
Appendix : An Analysis of the Continuum Model's Equilibrium

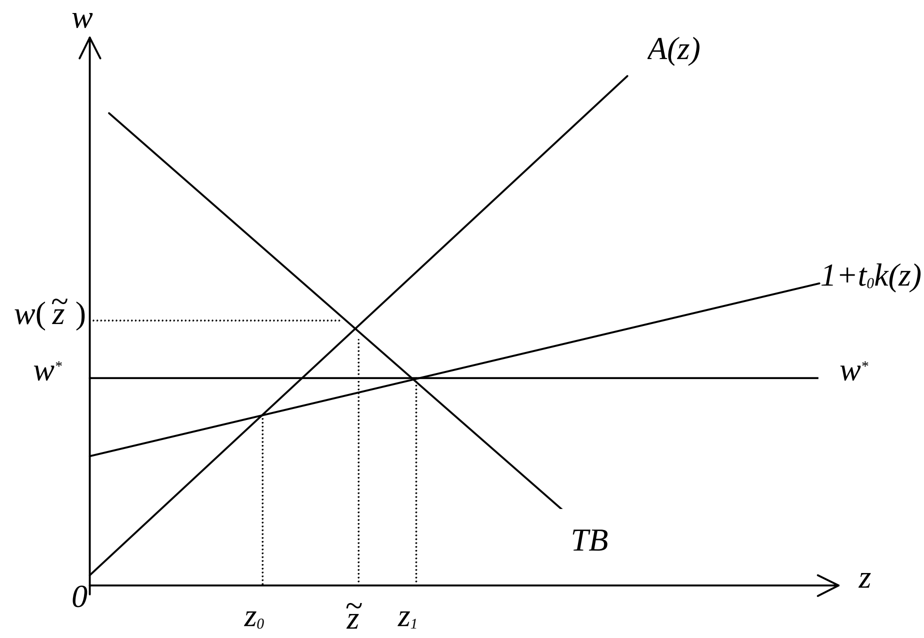
To set the stage for the case of a flat supply curve of *T*, let us recall that without technology transfer the balanced trade condition becomes

$$(1-z)\,(L+wL^{*}) = wL^{*} \qquad \text{(A1)}$$

which yields a downward sloping locus in the *(z,w)* space, denoted by *TB*. With no technology transfer, the equilibrium is determined by *TB* and *A(z)*, which is upward sloping.



With technology transfer, *A(z)* is replaced by min *[A(z),(1+rk(z))]*, and the locus *TB* may be changed due to π_M (it will be shown below that *TB* is governed by a quadratic equation). The special case of a flat supply curve of *T* is analytically convenient because when $r = t_0$, $\pi_M = 0$ and the *TB* is identical to the case of no technology transfer. There are two possibilities: (i) $t_0 \geqq R(\tilde{z})$, and (ii) $t_0 < R(\tilde{z})$, where $\tilde{z}$ is the "border good" in the model with no technology transfer. If $t_0 \geqq R(\tilde{z})$, *r* is too high to have any technology transfer. For technology transfer to occur, $t_0 < R(\tilde{z})$ and the situation is as depicted below.



As shown clearly in the above diagram, technology transfer has unambiguously resulted in a range of products that go through the product cycle (i.e., $[\tilde{z}, z_1]$) and lowered the relative wage from $\tilde{w}$ to w^*. A reduction in t_0 will lower z_0 and w^*, but raise z_1. These results are summarized in the text as Proposition 5.

If the supply curve of *T* is upper sloping, then $\pi_M>0$ and the position and shape of the *TB* locus may be affected. Let us return to this case by analyzing the properties of the *TB* locus.

To derive the effect of *r* on the equilibrium z_1 that satisfies the balanced trade condition (equation (20) in the text), let us use $w=1+rk(z_1)$ to rewrite the condition as $(1-z_1)\left(L + \frac{(r-t_0)^2}{2c}\right) = z_1(1+rk(z_1))L^*$, which can be further expressed as a quadratic equation

$$(r - t_0)^2 - 2\alpha(z_1)(r - t_0) - 2\beta(z_1)=0, \quad \text{(A2)}$$

where $\alpha(z_1)=cL^* z_1k(z_1)/(1- z_1)$, and $\beta(z_1)=cL^*z_1/(1- z_1)+ t_0\, cL^*z_1\, k(z_1)/(1- z_1) - cL$.

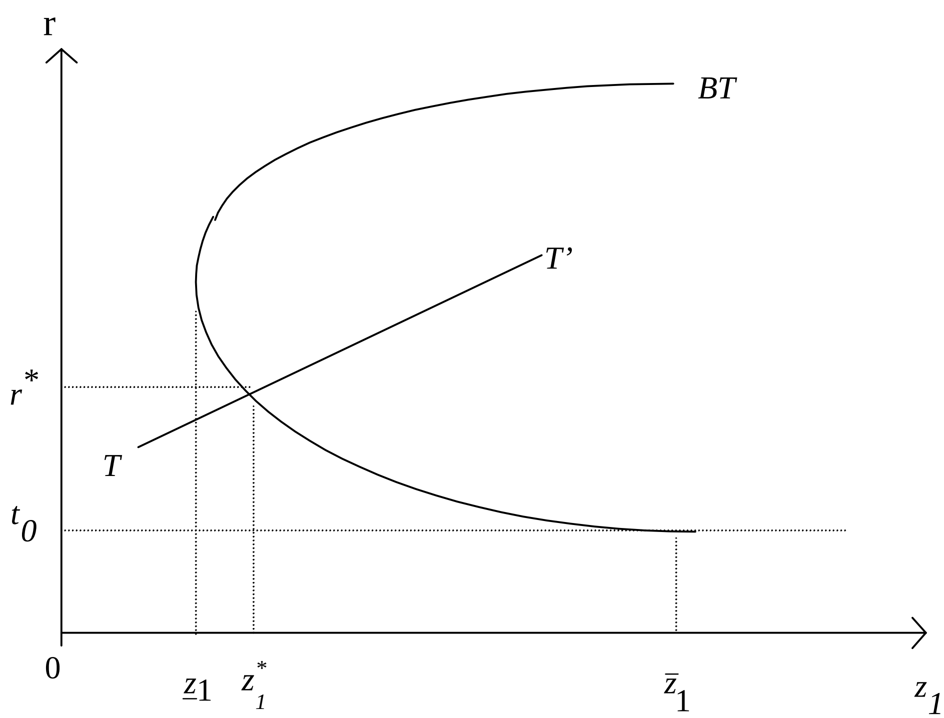
There exists $\underline{z}_1$ defined by $\alpha^2(\underline{z}_1)+2\beta(\underline{z}_1)=0$ such that for all $z_1>\underline{z}_1$, there are two solutions for $(r - t_0)$:

$$(r-t_0)=\alpha \pm \sqrt{\alpha^2+2\beta} \quad \text{(A3)}$$

and $(r - t_0) = \alpha$ if $z_1=\underline{z}_1$.

Because an increase in z_1 increases *N*'s wage income and the upper bound of the integral in (equation (20) in the text), it follows that an increase in z_1 shifts T_D outward.

Hence, an increase in z_1 leads to a larger equilibrium *r*. Thus, an upward sloping *TT'* locus.



In the above diagram, it is assumed that the *TT'* locus intersects the downward sloping portion of the *BT* locus. An increase in the supply of *T* in the sense of a reduction in t_0 or *c* shifts *TT'* downward and *BT* rightward. As a result, z_1^* increases unambiguously, i.e., more advanced goods are produced by MNEs in *H*. Even though the effect on *r* cannot be determined by the movement of the two loci, *r* will be lower if the system is stable in the sense that a change in the supply of *T* has a greater impact on *TT'* than on *BT*. Since $w = (1 + rk(z_1))$, the impact of an increase in the supply of *T* on *w* is ambiguous because *r* and *k* move in opposite directions.

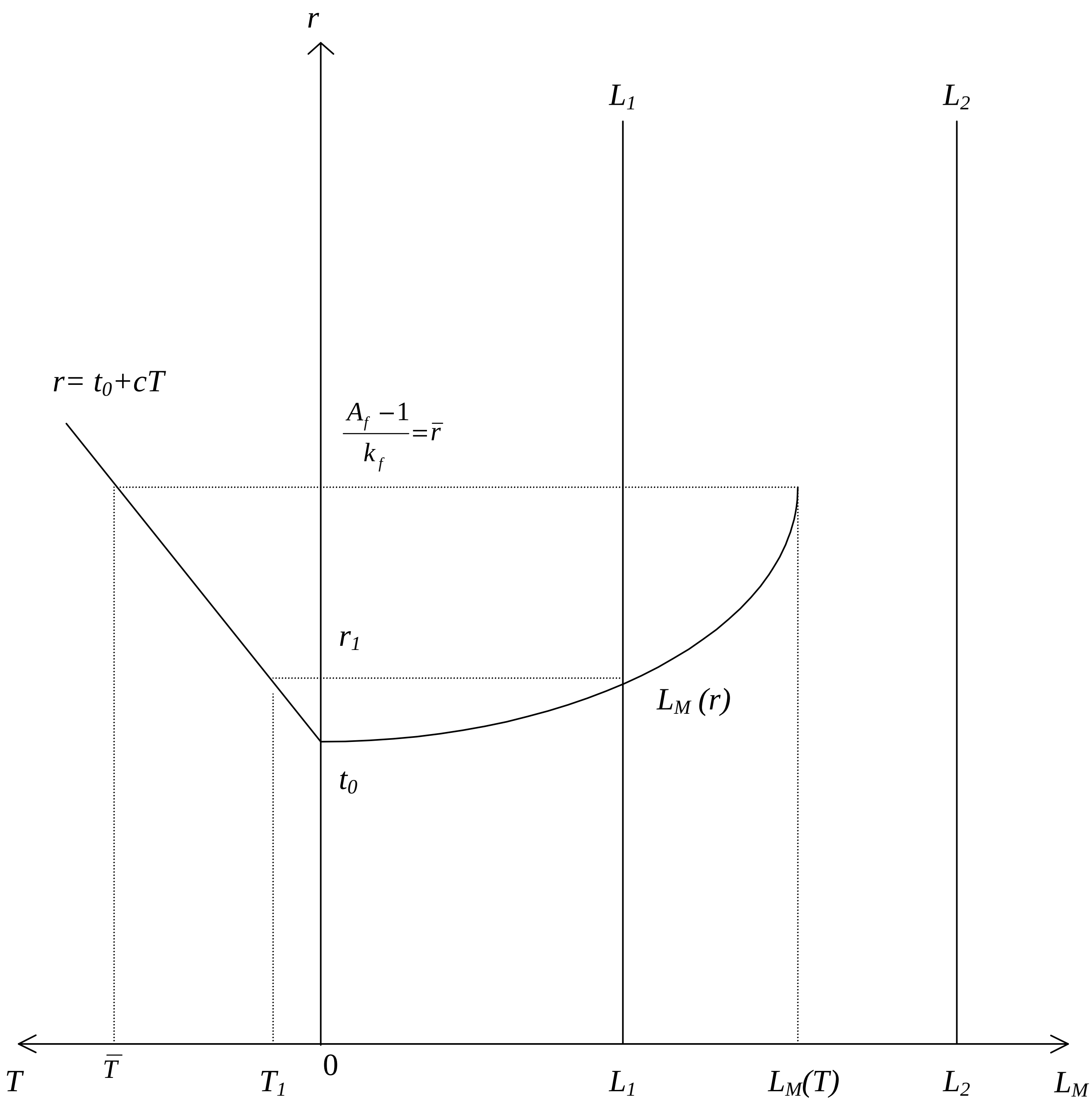


Figure 1: Equilibrium *T* and *r*

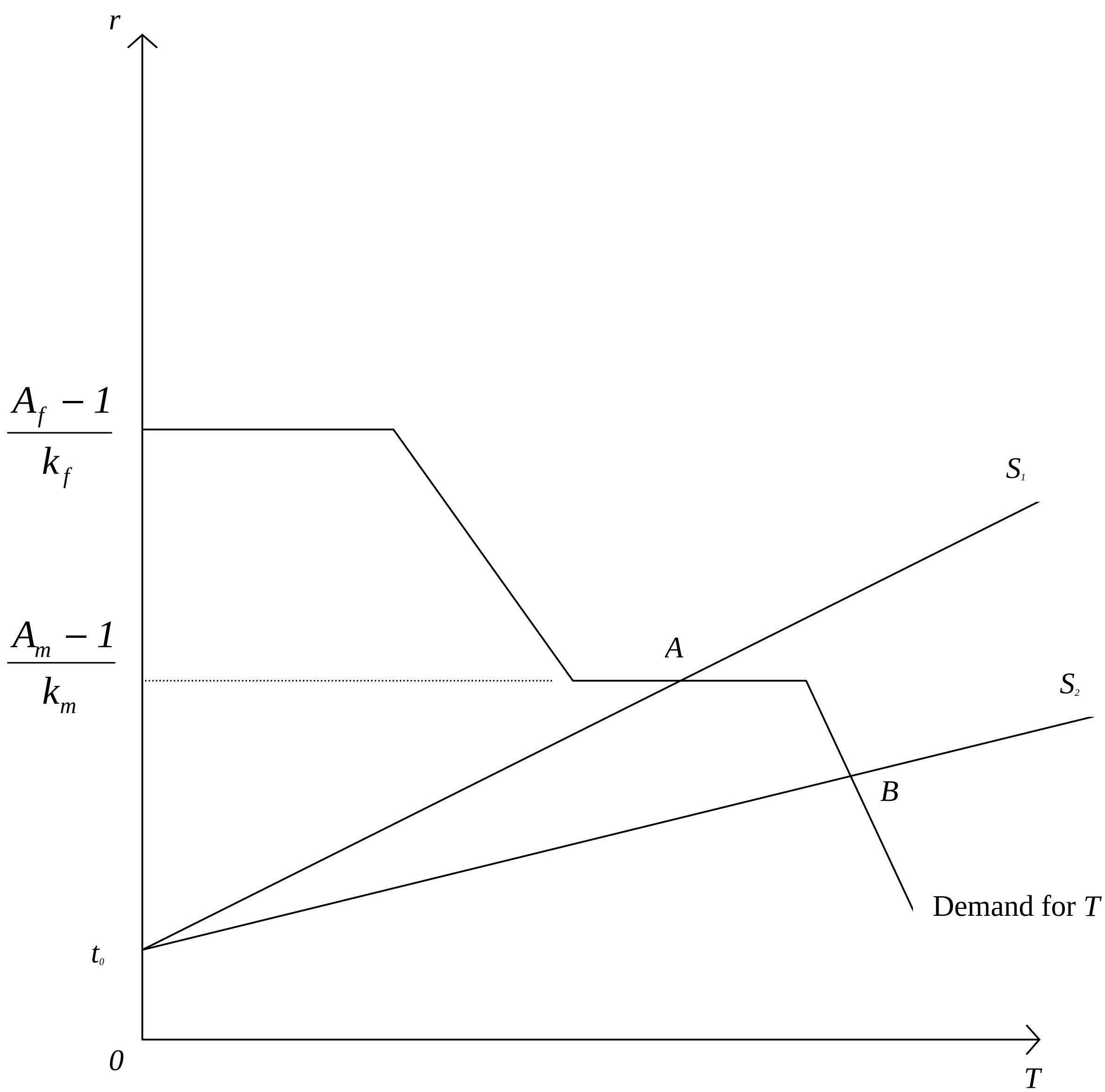


Figure 2: Technology Transfer to Both Industries

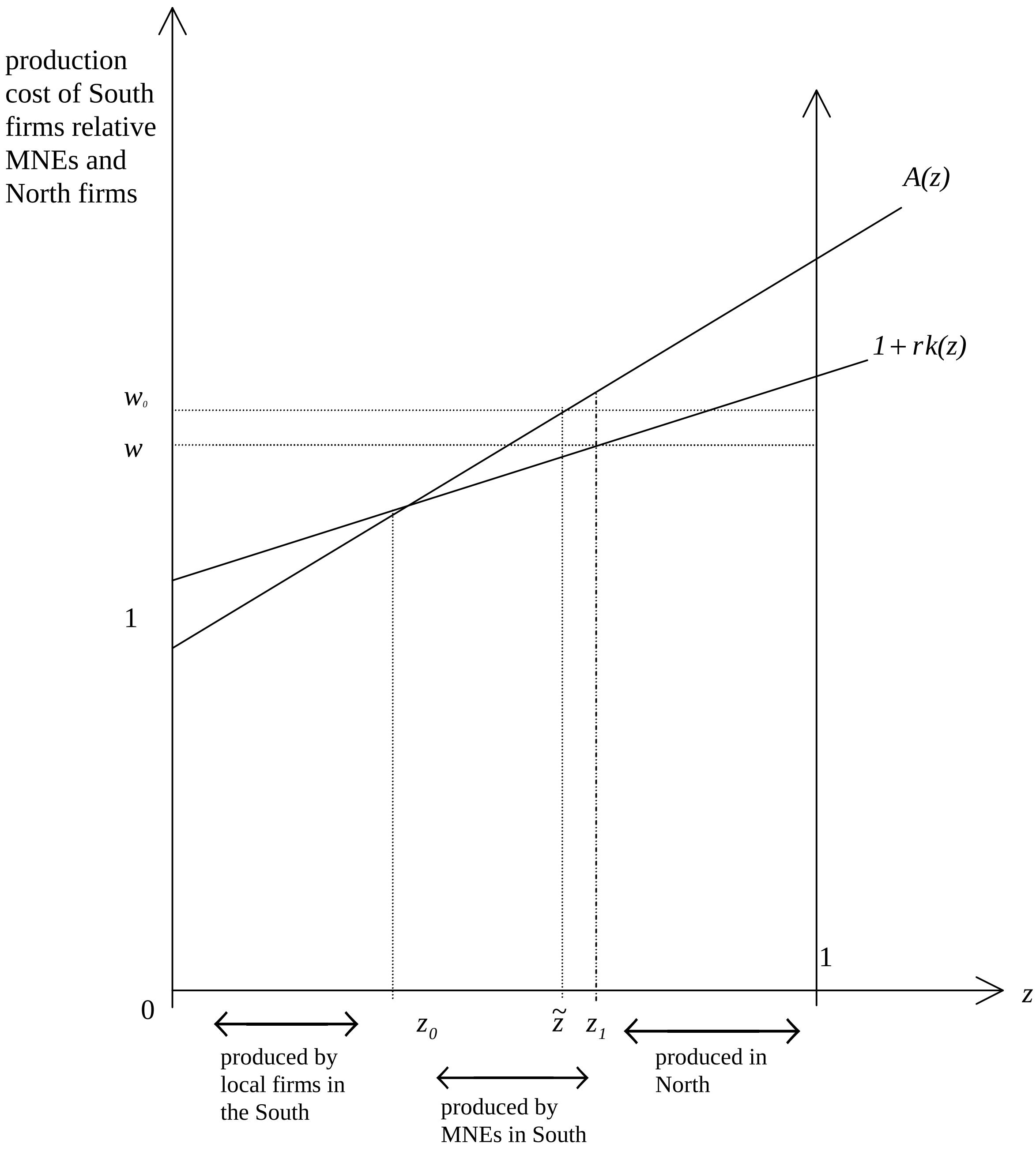


Figure 3: Distribution of production

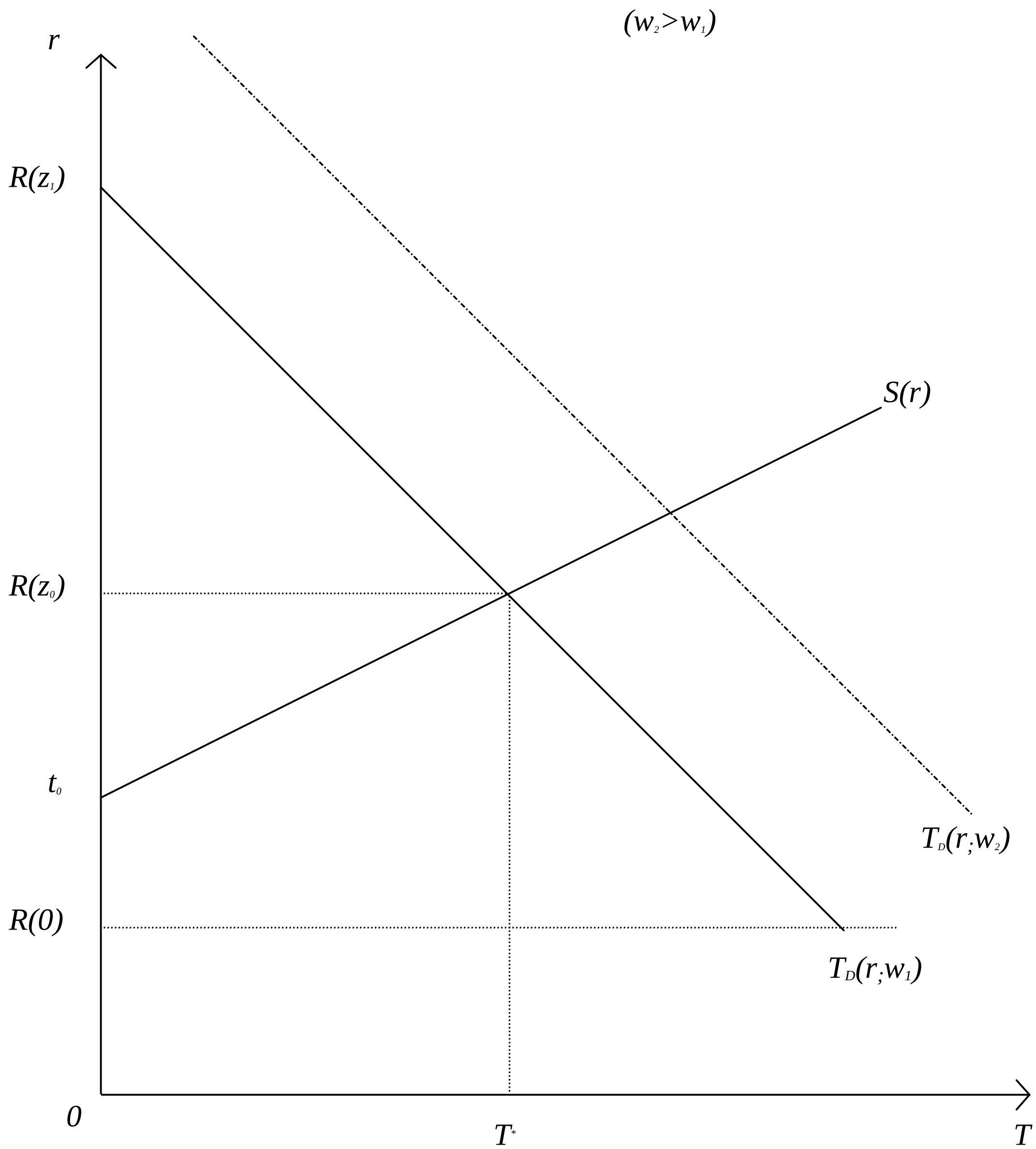


Figure 4: Equilibrium in the market for *T*