The Technology Transfer Paradox

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This paper examines whether a country that enjoys a superior technology in all commodities in a two-country, multi-commodity Ricardian setting could actually gain if its technology in which it possesses its greatest comparative advantage is stolen or transferred to the other country without any compensation. Such a paradoxical possibility is shown always to exist with strong Cobb-Douglas shared demand conditions for certain ranges of relative country size. Furthermore, such a paradox is arguably more likely as an outcome of such transfer the larger, relatively, is the less advanced country.

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One aspect of the current trend towards globalization concerns the increased ease of the international transfer of technology among countries. This may take the form of outright sales in arms-length market transactions or of transfer activities within a multi-national firm. Alternatively, there may be an illegal transfer, wherein technological knowledge possessed by a firm in one country is transferred to another country without any payment for the superior information. This latter kind of uncompensated technology transfer raises a critical question for the country originally the only possessor of the superior technology – could its real income actually be raised by such “outsourcing”? A positive answer would seem especially problematic in the case in which the technology that is stolen or given away is for a commodity the advanced country is exporting. Furthermore, how could such a paradoxical result be reconciled with the negative effects on an advanced country’s real income if a less developed country innovates or in any other fashion obtains a small improvement in its existing production of a commodity being exported by the advanced country? That is the setting and the conclusion reached in the recent article by Paul Samuelson (2004), in which a country such as China gets better at producing a commodity being exported by an advanced country such as the United States.¹ Without disagreeing with Samuelson’s findings, in this paper we show how the advanced country may nonetheless gain by an uncompensated technology transfer sufficiently great to drive the advanced country out of producing its best export commodity. We label this outcome The Technology Transfer Paradox.²

¹ This article proved to be controversial. For example, note the coverage in the New York Times (September 9, 2004) and in the subsequent article by Bhagwati, Panagariya and Srinivasan (2004).
² For the simple two-commodity case this paradoxical outcome has been illustrated by Ruffin and Jones (2005). However, a technology transfer in a multi-commodity setting reveals that the new export for the
International trade theory typically suggests that when a country experiences a loss in one export sector, a fall in its relative wage rate is required in order to create a new export opportunity. Novel in our discussion is that such an adjustment in relative wages may not take place when the country with the advanced technology (referred to as Home) loses an export sector because of technology transfer without compensation. Not only can Home gain, such a possibility for paradoxical gains must occur in the neighborhood of what we call turning points – values of relative country size for which Home in the initial situation would be an incipient producer of an imported commodity, so that if its relative size were to increase, it would become a new producer of that commodity.

The first section of this paper lays out the original equilibrium setting for the Ricardian multi-commodity model, followed, in Section 2, by an examination of the new equilibrium after a technology transfer, utilizing a general graphical illustration for the case of four commodities, with a particular numerical example in Section 3. The assessment of possible gains or losses is heavily dependent on relative country size and the profile of relative comparative and absolute advantage, as discussed in Section 4. Sections 5 and 6 examine, respectively, the consequences of a wider class of demand conditions and the alterations required depending upon which technology gets transferred. Section 7 asks how the technology transfer paradox is related to other famous paradoxes in trade theory while Section 8 concludes the paper.

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advanced country may be far removed in the ranking of comparative advantage from the export lost by technology transfer. Samuelson (2004) refers to an appendix for a three-commodity case in which China and the U.S. each produce a commodity in common as well as an additional commodity not produced by the other. Such a three-commodity case was also examined in Jones (1979). An earlier literature exists examining the transfer of technology for a commodity imported but not produced in the advanced country. See Kemp and Shimomura (1988), Beladi, Jones, and Marjit (1997), and Section 6 below.
1. Preliminary Comments on the Multi-Commodity Setting

A simple model setting is appropriate for these issues, and the time-honored competitive Ricardian trade model once again reveals its usefulness.\(^3\) We concentrate on a two-country setting in which the Home country possesses an *absolute* advantage in all \(n\) commodities and its greatest *comparative* advantage in the first commodity. Increasingly numbered commodities are associated with decreasing levels of Home comparative advantage, so that Home’s greatest comparative dis-advantage is in the \(n^{th}\) commodity. An extremely useful simplification is possible: All commodity units have been selected so that firms in Home take only a single unit of labor to produce one unit of each commodity. This implies that if the numeraire is always selected as a commodity produced at Home, Home’s nominal wage rate is always unity. As a consequence the *real* wage rate comparisons for Home now depend *entirely* upon commodity price levels, and *comparative* cost rankings are provided just by the *absolute* cost figures in Foreign.

Demand conditions are obviously important, but the focus is narrowed down to a situation that is both extremely neutral in its assumptions and also mirrors those adopted earlier by Samuelson (2004) and by Ruffin and Jones (2005): Free trade commodity prices are determined in world markets, and the two countries share the same Cobb-Douglas demand functions, with identical shares spent on each commodity \((1/n)\).

Given these assumptions, *relative* productivity comparisons between countries are revealed by the *absolute* labor input requirements abroad, which decrease monotonically as the commodity number gets larger. Letting \(a_k^*\) indicate the quantity of Foreign labor required if it were to produce a unit of the \(k^{th}\) commodity, the ranking is shown in (1):

\(^3\) This was the model setting used in Ruffin and Jones (2005), as well as that selected by Paul Samuelson (2004), and earlier in Jones (1979). The Ricardian model is often the model of choice for this and similar questions. For example, see Bhagwati (1984), Copeland and Taylor (1994), Krugman (1986), Matsuyama (2000) and Staiger (1988).
Home has an absolute advantage in all commodities and the greatest comparative advantage in the first.

A free-trade equilibrium in this Ricardian model must exhibit one of two possible production patterns: (i) Each country produces a distinct set of commodities (e.g. with Home producing commodities $1$ through $k$ and Foreign commodities $(k+1)$ through $n$), or (ii) Some commodity is produced in common, with all lower numbered commodities produced only at Home and higher numbered only in Foreign. Which of these cases is found in equilibrium depends entirely on technology and relative country size, $(L^*/L)$. If Foreign size grows relative to that at Home, Foreign must eventually reach out to produce commodities even further down on its profile of comparative advantage. This entails a sequence in which Foreign’s wage rate, $w^*$, falls as $(L^*/L)$ increases in case (i), or, in case (ii), $w^*$ remains on a plateau with Foreign producing relatively more of the commonly produced commodity.

Begin by letting the production sets be distinct between countries, with Home producing commodities $1$ through $k$ and Foreign the remaining set, $(k+1)$ through $n$. Given our strict demand assumptions, the value of national income produced in Foreign at this point, $w^*L^*$, expressed as a fraction of Home’s national income, $wL$ (or just $L$), reflects the ratio of the number of commodities produced in each country. That is,

\begin{equation}
(2) \quad w^*(L^*/L) = (n-k)/k
\end{equation}

Consider, now, the entire range of values of $(L^*/L)$ that allows this disparate pattern of production for given values of $n$ and $k$. At the low end of $L^*/L$, Foreign has just increased in relative size enough to become the only producer of commodity $(k+1)$, in which case its wage rate, $w^*$, reflects its productivity in producing this good when the
price of \((k+1)\) is still unity (with Home just having given up its production). That is, \(w^*\) is \(1/a_{k+1}\) and, by equation (2), \((L^*/L)\) has value \([n-k]/a_{k+1}\). At the higher end of Foreign’s size it has become an *incipient* producer of commodity \(k\), made possible by its wage rate having fallen to the value \(1/a_k\). That is, \((L^*/L)\) has increased to \([n-k]/a_k\).

Next, suppose Foreign relative size increases further along the range in which both countries produce commodity \(k\) (with \(w^*\) at a fixed value of \(1/a_k\)) until Foreign just becomes the *sole* producer of commodity \(k\). This is the setting in which the right-hand side of equation (2) has “\(k\)” replaced by “\(k-1\)”, with \(w^*\) still equal to \(1/a_k\).

To sum up the general possibilities, consider the values of \((L^*/L)\) in the intervals shown by the inequalities in (3):

\[
\begin{align*}
[(n-k)/k]a_{k+1}^* &< \{(n-k)/k\}a_k^* < \{(n-(k-1))/(k-1)\}a_k^* \\
\end{align*}
\]

In the first interval production patterns are completely distinct, as in (2), with Foreign’s wage rate falling from level \(1/a_{k+1}\) to the value \(1/a_k\), with such a fall being proportional to the increase in \(L^*/L\).\(^4\) In the second interval both countries produce commodity \(k\) in common, tying Foreign’s wage rate to the value \(1/a_k\). Figure 1 for the case of four commodities illustrates succeeding falls in Foreign’s wage rate, interrupted by plateaus in which \(w^*\) remains constant, both for the original technology setting and for the situation after the transfer of Home’s superior technology for producing the first commodity.

2. **The Possibility of Home Gains from Technology Transfer**

The technology transfer paradox is highlighted if we suppose Foreign is able to obtain Home’s technology for producing its best export commodity (the first) without any

\(^4\) The simple solution revealed for the discrete multi-commodity Ricardian model can be contrasted with that found in the continuum model of Dornbusch, Fischer and Samuelson (1977). The continuum case is more cumbersome to apply to technology transfers because single commodities have negligible weights (Jones, 1979; Krugman, 1986).
payment.\(^5\) (It is assumed that Home “blueprints” rather than labor skills or climate provide the source of superior technology). Thus it takes Foreign not \(a_l^*\) but only \(l\) unit of labor to produce a unit of the first commodity, which now heads the ranking according to comparative advantage for Foreign, thus completely wiping out Home’s first sector.\(^6\)

A basic proposition can be stated at the outset (when demand shares are equal): If before transfer Home is an incipient producer of the \(k^{\text{th}}\) commodity (which it imports), after technology transfer (of its best export) Home exports the \(k^{\text{th}}\) commodity. The price of the first commodity falls to \(1/a_k^*\) and all other commodity prices remain the same. Home gains from such transfer, even if uncompensated.\(^7\)

Figure 1 is useful in illustrating the general argument in the four-commodity case. For the original pre-transfer setting, the \(w_0^*-\text{locus}\) illustrates both the ranges in which increases in \((L^*/L)\) leave Foreign’s nominal wage unchanged on a plateau, as well as ranges in which increases in \((L^*/L)\) cause \(w_0^*\) to fall. The inequalities in (3) reveal the crucial values of \((L^*/L)\) for the original trade equilibrium in the four-commodity case:

\[
a_4^*/3 \leq a_3^*/3 \leq a_3^* \leq a_2^* \leq 3a_2^* \leq 3a_1^*
\]

(For example, the smallest value, \(a_4^*/3\), corresponds to that in (3) with \(n\) equal to 4 and \(k\) equal to 3). These values are indicated in the lower horizontal axis. A similar (but not identical) range of values is of relevance after commodity 1’s technology transfer:

\[
1/3 \leq a_4^*/3 < a_4^* < a_3^* < 3a_3^* < 3a_2^*
\]

Those values are indicated in the upper horizontal axis. The reader is warned that in

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\(^5\) Section 6 illustrates the similarity between such loss and that of technology for any other export.

\(^6\) This assumes Foreign is sufficiently large to be able to supply the world’s demand for \(I\) on its own.

\(^7\) Intuition for this result is aided by noticing that in both countries the supply curve for the \(k^{\text{th}}\) commodity is perfectly elastic so that as Home goes into commodity \(k\) (and Foreign goes out) wage rates do not change.
Figure 1’s depiction of the 4-commodity case great liberties have been taken in showing equal spacing between the critical values of \((L^*/L)\) before and after transfer.\(^8\)

The relationship between \(w_A^*\) and \((L^*/L)\), illustrated in Figure 1’s \(w_A^*\)-locus, is analogous to the original \(w_0^*\)-locus. Start with the extremes. If Foreign is relatively quite small it produces only its comparatively best product. After transfer this is the first commodity, and Foreign’s wage rate must be raised to unity as long as Home still produces some of the first commodity at a unit price. At what point will Foreign completely satisfy world demand for the commodity in which it has the greatest comparative advantage? The answer: At a lower relative Foreign size than before transfer. With \(w_A^*\) equal to unity at that point (because of Foreign’s new-found expertise in producing the first commodity), equation (2) suggests that \((L^*/L)\) must be equal to 1/3. In the pre-transfer situation Foreign would not be able to supply the world’s demand for commodity 4 at this relative Foreign labor force because of its absolute technological disadvantage, even in commodity 4; \((L^*/L)\) would have to increase to the value \(a_4^*/3\).

In Figure 1, the \(w_A^*\)-locus starts to descend when \((L^*/L)\) reaches 1/3, after which Foreign can start producing the next commodity in its comparative-advantage ranking, commodity 4, when \(L^*/L\) reaches \(a_4^*/3\). In such a manner higher values for \((L^*/L)\) lead alternatively to plateaus, along which Foreign and Home produce a commodity in common, and downward-sloping sections, along which production sets are distinct.

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\(^8\) For example, the value of \(3a_3^*\) is not shown as three times the distance from the origin as \(a_3^*\). Proper scales are shown in Figure 2 for the particular numerical example chosen. More generally, consider the range of values of \(L^*/L\) for which the inequalities in (3) have both countries producing a commodity, \(k\), in common. This, the spread between the second pair of terms, has width for \(L^*/L\) equal to \(n/k(k-1)\) \(a_k^*\). As \(L^*/L\) becomes larger, eventually both countries produce commodity \((k-1)\) in common, and the range of values of \(L^*/L\) for which such specialization pattern occurs is \(k/(k-2)\) \(a_{k-1}^*/a_k^*\) times the previous amount, \(n/k(k-1)\) \(a_k^*\). This multiple exceeds unity both because the foreign wage falls, inducing price falls that encourages greater world demand for all commodities produced in Foreign and because, as the foreign country gets larger, it produces more commodities.
When Foreign becomes relatively so large that it must produce all commodities, its nominal wage rate now is the inverse of its labor costs in producing commodity 2.

To capture the repetitive cycling of the relationship between original and after-transfer wage loci, four regions have been highlighted, and these regions are separated by values of relative labor supplies at which the two wage loci make contact. (These are the so-called turning points). Regions II and III each contain three segments, labeled a(i), b(i) and c(i), and Regions I and IV only possess two segments each, b(I) and c(I) for Region I and a(IV) and b(IV) for Region IV.

When Foreign is relatively too small to satisfy world demand even for the commodity in which it has its greatest comparative advantage, the b(I) segment of Region I, the two countries produce a commodity in common, both before the transfer (commodity 4) and after the transfer (commodity 1). This pattern is replicated in segment b(II). As already noted, in segment c(I) Home and Foreign no longer produce a commodity in common after transfer, although originally they did produce commodity 4 in common. Such specialization after transfer is also shown in segment c(II) (with Home in commodities 2 and 3, Foreign in 1 and 4) and segment c(III) (Home only in commodity 2, Foreign in the rest). This kind of asymmetry is reversed in segments a(i), with countries producing distinct sets of commodities in the original setting but producing a commodity in common after transfer.

The (arbitrary) assumptions made earlier that ensured that the nominal wage rate at Home was always unity imply that the real wage rate at home will improve if and only if the commodity price index falls. Given the special Cobb-Douglas assumption about equal shares for all commodities, the price index is the geometric mean of commodity prices. Therefore Home’s real wage (paradoxically) improves after the stealth of its
superior technology for producing the commodity in which originally it possessed the
greatest comparative advantage if and only if the product of commodity prices has been
reduced by the transfer.

Suppose the technology transfer raises Foreign’s nominal wage rate, \( w_A \). This leads
to a pair of contrasting effects on the price index: (i) The world price of the commodity
whose technology has been transferred to Foreign must fall since Foreign’s wage rate is
lower than that at Home.\(^9\) (ii) The prices of all commodities that it alone produces and
exports to Home must increase. Which effect dominates the price index? As will be
seen, the answer depends both upon relative country size and the shape and position of
the profile of Foreign (and therefore comparative and absolute) labor costs.

Does technology transfer always improve Foreign’s nominal wage rate? No. A
glance at Figure 1 suggests that if relative country size is at the point where segment c(i)
turns into segment a(i+1), transfer does not disturb Foreign’s wage rate.\(^10\) If such were
the case, effect (ii) noted above would not operate: After transfer no prices would have
been pushed up for other goods produced in Foreign; the reduction in the price of the first
commodity would be the only influence on Home’s real wage. The consequence: Home
must gain by the transfer. Such a favorable outcome for Home would also be obtained if
the post-transfer Foreign wage rate would be only slightly higher than originally since
then prices of commodities produced only in Foreign and thus exported to Home would
increase only fractionally. By contrast, there would be a finite fall in commodity 1’s
price since Foreign wages are lower than Home’s. This latter effect reflects the level of
Foreign’s wage rate (lower than that at Home), while the former effect (on the prices of

\(^9\) Unless Home is so large it must also produce some of the first commodity.
\(^10\) And thus leaves the double factorial terms of trade (i.e. the ratio of the two countries’ wage rates)
unaffected.
the remainder of commodities produced in Foreign) reflects the increase (if any) of the Foreign wage rate as a consequence of the transfer.

Note that in Figure 1 the $w_A^*-\text{locus}$ has been shifted upward and leftward compared with the original $w_0^*-\text{locus}$. Why is there not just an upward shift, in which case Foreign’s wage rate would unambiguously be raised by the technology transfer? Because the improved efficiency in producing the new commodity ($I$) that heads the after-transfer list of comparative advantage for Foreign implies that Foreign must start to produce its next-best commodity (now commodity 4) sooner as its relative size grows. Any such movement down the $w_A^*-\text{locus}$ requires Foreign’s wage rate to fall so that it can become competitive in producing the next commodity. The upshot is that there will be a series of isolated values for $(L^*/L)$ at which Foreign’s wage rate is unaltered by the technology transfer. These values we have labeled turning points, and it is useful to consider in more detail what is happening to production and trading patterns in their neighborhood.

For this purpose consider the particular point where $c(II)$ merges into $a(III)$, with $(L^*/L)$ equaling $a_3^*$ in Figure 1. To the immediate left of this turning point Home is still producing commodity 3 (along with Foreign) at unit price before the transfer, so that Foreign’s wage rate is $1/a_3^*$, while after transfer Foreign’s wage rate has almost been driven down to this level. To the immediate right of this point originally Foreign has satisfied the entire world demand for commodities 3 and 4 and its wage rate has just started to fall from its $1/a_3^*$ level, while after transfer Foreign has just joined Home in producing commodity 3 so that its wage is exactly $1/a_3^*$. Thus the world price of commodity 3 is close to unity in both scenarios. As a consequence Foreign’s wage rate must be close to $1/a_3^*$ before and after transfer. Finally, note that at this turning point the pattern of production and trade changes: Originally Home produces and exports the first
and second commodities and Foreign the third and fourth commodities. After transfer Home produces and exports the third and second commodities and Foreign the first and fourth commodities. That is, technology transfer has brought about a complete reversal of the trade pattern both for commodity 3 and for the commodity (1) whose technology has been transferred. At the turning point the price of the first commodity has fallen (to $1/a_3^*$) while the world price of the third commodity (unity) and the fourth commodity $(a_4^*/a_3^*)$ remain unchanged. Therefore the price index must fall and Home must gain by the transfer. For neighboring values of $L^*/L$ the technology transfer would bring about a slight improvement in Foreign’s wage rate, but not enough to cause the price index to increase. Home would still gain by transfer.

Points such as $a_3^*$ on the $(L^*/L)$ axis deserve the turning point label in part because transfer has brought about a complete reversal of the trading pattern. An additional rationale can be cited: turning points represent local maxima for the effect of transfer on Home real wages.

Foreign’s wage rate is unaltered by transfer if relative Foreign size is at a turning point. At the other extreme it is in segments b(i) in Figure 1 that the gap between the after-transfer wage rate, $w_A^*$, and the original Foreign wage rate, $w_0^*$, is greatest.\footnote{\textbf{11} A word of warning is necessary: In Figure 1 a point such as $a_4^*$ on the upper horizontal axis may not exceed $a_1^*/3$ on the lower axis, in which case segment b(II) would not exist. Segment a(II) would run into c(II) and the discrepancy between original and after-transfer Foreign wages would be less than indicated by b(II). The gap shown by b(II) would nonetheless serve as a useful maximal bound on the possible discrepancy between wage rates. Of course segments b(I) and b(IV), or more generally, b(N), always exist.} Thus Home can be harmed by the technology transfer somewhere in Region (i) only if it is harmed in the neighborhood of segment b(i).

To explore further, return to the general multi-commodity setting and let Home and Foreign produce commodity $k$ in common originally, whereas after transfer they produce
commodity \((k+1)\) in common.\(^{12}\) Home must gain by transfer if the after-transfer value of the product of commodity prices, designated \(\Pi_\Lambda\), is smaller than original value, \(\Pi_0\). In the original equilibrium the prices of commodities 1 through \(k\) are all unity, Foreign’s wage rate is \(I/a_k^*\), and the price of the \((k+1)^{st}\) commodity, produced only by Foreign, is \(a_{(k+1)^*}/a_k^*\) and so on until the price of the \(n^{th}\) commodity is \(a_n^*/a_k^*\). Therefore the product of original commodity prices is:

\[
\Pi_0 = \left\{ a_{(k+1)^*} a_{(k+2)^*} \ldots \ldots a_n^* \right\} / (a_k^*)^{(n-k)}
\]

This product is smaller than unity, given that ranking (1) implies that the price of every commodity produced in Foreign is less than unity (except for the \(k^{th}\) commodity).\(^{13}\)

The after-transfer situation in which Foreign (now the sole producer of the first commodity) also shares production of the \((k+1)^{st}\) commodity with Home can be analyzed in similar fashion. Thus:

\[
\Pi_\Lambda = \left\{ a_{(k+2)^*} a_{(k+3)^*} \ldots \ldots a_n^* \right\} / (a_{(k+1)^*})^{(n-k)}
\]

Foreign’s wage rate has been raised from \(I/a_k^*\) to \(I/a_{(k+1)^*}\), leading to a price increase for all commodities produced only by Foreign (except the first) by the factor \((a_k^*/a_{(k+1)^*})\).

Such price increases harm Home labor as they represent a deterioration in Home’s terms of trade. However, the price of the first commodity has been reduced from unity to the level of Foreign’s after-transfer wage rate, \(I/a_{(k+1)^*}\), and by itself this benefits Home labor. Thus Home gains by the theft of its superior technology in producing the commodity in which it has its greatest comparative advantage if:

\[
\Pi_\Lambda < \Pi_0 \text{ or } \left\{ a_{(k+1)^*} \right\}^{(n-k+1)} > (a_k^*)^{(n-k)}
\]

\(^{12}\) Foreign’s newly acquired comparative advantage in commodity 1 raises by one the numerical label of the commodity produced in common.

\(^{13}\) Because in autarky the product of commodity prices in Home was unity, free trade must have lowered the price index and brought about gains to Home (unless its large size caused it to produce all commodities in the original free trade equilibrium).
Of course there is no certainty that this condition will be satisfied. The term $a_{(k+1)}*$ is smaller than $a_k*$ (by equation (1)’s ranking), but it is raised to a power that is one higher.\footnote{Note that an increase in $n$ for given $k$ makes this inequality more difficult to be satisfied. This reflects the lower weight attached to the decrease in the world price of the first commodity, in which technology has been transferred to Foreign. Ruffin and Jones (2005) examined the two-commodity case; with $n = 2$ and $k = 1$: Home gains after transfer if $(a_2*)^2 > a_1*$.}

3. A Numerical Example for the Four-Commodity Case

The array of Regions in Figure 1 for the 4-commodity case is quite general (when it is the technology for Home’s best commodity that is transferred).\footnote{As warned in Footnote 10, some b(i) segments may not appear.} Thus to proceed with an illustration of possible gains and/or losses to Home by technology transfer we may focus on the more simple case of four commodities in Figure 2. In this illustration we specify a particular set of numbers for Foreign’s comparative advantage ranking of commodities, which, by our assumption of unit labor costs for Home, is given by the profile of the $a_j*$, all assumed greater than unity. The arbitrary ranking we select in this section is assumed to be linear, with $a_4*$ given a value of 1.5, $a_3*$ a value of 2.5, until $a_1*$ has the highest value of 4.5. With these numbers in hand we compute proper spacing for horizontal and vertical axes in Figure 2.

As Figure 2 illustrates in this chosen example, the value of $\Pi_A/\Pi_0$ varies with relative country size. Region I (always) consists only of two segments. In b(I) Foreign is relatively so small that Home must produce all four commodities so that both $\Pi_0$ and $\Pi_A$ have the same value (unity) in this segment, and indeed Home neither gains nor loses from trade. In the c(I) segment although Home still would not gain from trade in the original situation, after transfer it must gain because Foreign becomes the sole producer of the first commodity, whose price falls as $w_A*$ decreases from unity towards the value
of $l/a_4^*$ as $L^*/L$ increases from $1/3$ to $a_4^*/3$. Given the numerical values of Foreign’s technology, at the start of Region II (with $L^*/L$ equal to turning point $a_4^*/3$) the value of $\Pi_A/\Pi_0$ is 2/3, the same as Foreign’s wage rate.

Now consider Region II. The emerging gap between post- and pre-transfer values of Foreign’s wage rate reaches its maximum in Region II when segment b(II) commences. If Foreign’s relative labor force lies in the range of segment b(II), technology transfer lowers the price faced by Home’s consumers for the first commodity (from a value of unity to $l/a_4^*$ or 2/3) but raises the price Home consumers must pay for the fourth commodity. The latter effect dominates since $\Pi_A/\Pi_0$ is 10/9, greater than unity. Therefore in this range and the nearby neighborhoods Home would lose by an uncompensated transfer to Foreign of Home’s advanced technology.

Figure 2 illustrates that such a potential loss in Home real income eventually turns to a gain if Foreign becomes somewhat larger relative to Home. When $L^*/L$ reaches 2.5 (i.e. the value of $a_3^*$) there is a local minimum in the ratio $\Pi_A/\Pi_0$. This has the same value as the Foreign wage level, which has dropped to 40% of the wage rate in Home. For this turning point value of $L^*/L$ a transfer of technology leaves the Foreign wage rate unchanged so that the only effect on the consumer price index for Home workers stems from the reduced world price of the commodity whose production Home has lost to Foreign because of the technology transfer. Region III duplicates the cyclical behavior of $\Pi_A/\Pi_0$ found in Region II, except that now the highest value this ratio obtains is not only lower than the corresponding value in Region II but also lower than unity. As a consequence, if the relative size of Foreign’s labor force lies anywhere in Region III, Home must experience an improvement in its real wage rate and real income by an
uncompensated transfer of technology for producing its best commodity. And such a strong conclusion carries over to Region IV.

Several features of the dependence of the crucial $\Pi_A/\Pi_0$ ratio on the relative size of Foreign’s labor force are exhibited in Figure 2. First, consider the lower turning points at which the ratio $\Pi_A/\Pi_0$ reaches a local minimum. At these points ($a_4^*/3$, $a_3^*$, $3a_2^*$) the ratios of $\Pi_A/\Pi_0$ each equal the value of the corresponding Foreign wage rate ($1/a_4^*$, $1/a_3^*$, $1/a_2^*$). These wage rates are all less than unity and always descend in size. In the neighborhood of each Home must benefit by uncompensated technology transfer, and the associated neighborhoods become larger the greater is Foreign’s labor force relative to that at Home. In this sense the greater benefit Home is usually claimed to receive by trading with a Foreign country that is larger finds an analogy with a greater chance of technology transfer yielding gains the larger is Foreign relative to Home. However, such a remark needs to be heavily qualified because of the possible behavior of the b(i) segments in each Region. In Figure 2 these exhibit two properties that are linked to the numerical choice for the profile of comparative advantage between countries. The first of these is that Home sometimes loses (in the neighborhood of segment b(II)), and the second refers to the subsequent systematic fall in the height of the segment b(i) plateaus as $L^*/L$ increases. We now turn to the importance for these issues of the shape of the profile of comparative and absolute advantage.

4. The Significance of the Profile of Comparative Advantage

There is a special condition on the technology profile of comparative advantage that serves as the dividing boundary between the case in which plateaus (segments b(i)) fall

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16 In this numerical example the value of $\Pi_A/\Pi_0$ in b(III) is 0.78 and in b(IV) is 0.61.
monotonically in Figure 2 and that in which they would rise as Foreign’s labor force increases. In this special profile succeeding ratios of the type $a_k^*/a_{(k+1)}^*$ and $a_{(k+1)}^*/a_k^*$ are all equal. To investigate this question use (6) to solve for $\Pi_A/\Pi_0$ in (7)\textsuperscript{17}:

$$\Pi_A/\Pi_0 = (1/a_{(k+1)}^*)(a_k^*/a_{(k+1)}^*)^{(n-k)}$$

Consider, now, the value of this expression if $k$ is replaced by $(k-1)$:

$$(7') \{\Pi_A/\Pi_0\}' = (1/a_k^*)(a_{(k-1)}^*/a_k^*)^{(n-k+1)}$$

Multiply both expressions by $a_k^*$. This reveals that they are the same if and only if \{a_k^*/a_{(k+1)}^*\} equals \{a_{(k-1)}^*/a_k^*\}. The growth rate of Home’s comparative advantage is shown by succeeding ratios of the $a^*$’s (moving from $n$ towards $l$) and if these are all the same, so also would be the height of the b(i) plateaus. The successive heights would fall if the growth rates decline in moving from $n$ towards $l$.

The linear profile of comparative advantage used in Figure 2 has $a_3^*/a_4^*$ equal to $5/3$, with $7/5$ for $a_2^*/a_3^*$ and $9/7$ for $a_1^*/a_2^*$ so that the growth rate of Home’s comparative advantage as it moves from the fourth towards the first commodity falls. Thus the plateaus in Regions III and IV both descend from that in Region II. The plateau in Region II, however, was higher than in Region I. The role of absolute advantage possessed by Home over Foreign in all commodities is crucial here. Consider the ratio of $a_4^*$ to the value of unity (signifying no absolute dis-advantage). This has value $3/2$, smaller than $5/3$. Therefore the move from Region I’s b(I) plateau to b(II) represents an increase in value of $\Pi_A/\Pi_0$. Since the height of the b(I) plateau is always unity, this move causes technology transfer to harm Home in the neighborhood of b(II).\textsuperscript{18}

\textsuperscript{17} This form of the expression highlights the two conflicting effects of transfer on Foreign’s wage rate. The first term shows how the first commodity’s price has been lowered from unity to $1/a_{(k+1)}^*$ while the second term captures the fact that $(n-k)$ commodity prices have been raised by the factor $a_k^*/a_{(k+1)}^*$. 
\textsuperscript{18} Suppose an initial configuration for the ratios of comparative advantage such that succeeding ratios of $a_k^*/a_{(k+1)}^*$ and (lastly) $a_n^*/l$ are all equal. Then the height of the plateaus in regions b(i) would all be the same (equal to unity). Now consider raising this profile by a constant, which increases the extent of
Knowledge of the entire profile of comparative advantage is not necessary for a given size of relative labor forces. If both countries produce commodity \( k \) in the original equilibrium and commodity \((k+1)\) after transfer, the inequality shown in (6) is sufficient to ensure that Home gains for any relative labor force value in the Region that supports this plateau. Note especially that the inequality in (6) or (7) reveals that Home must gain in this Region if \( a_{(k+1)}^* \) has a value that is not much smaller than \( a_k^* \), regardless of the shape or position of the rest of the profile of comparative advantage.\(^{19}\)

5. The Role of Demand

Throughout we have adhered to the strong assumption about demand that tastes are of the same Cobb-Douglas pattern in the two countries, with equal expenditure shares on every commodity. Suppose, instead, that the share of income spent on commodity 1, (whose technology is transferred) is less than that of all the others. Consider the relationships shown in Figure 1 and how they are altered by this change in demand specification. In particular, concentrate on Region I in which before transfer Foreign produces its relatively best commodity, 4, at the Foreign wage rate, \( 1/a_4^* \), until it can satisfy the entire world demand for this commodity. The share of world demand for commodity 4 is now a bit larger than in our earlier discussion (thus lengthening the flat dashed locus in Region I) while that for the first commodity is a bit smaller. This implies that after transfer of commodity 1’s technology, Foreign can satisfy the world’s demand for commodity 1 at a lower relative country size than originally (i.e. less than \( 1/3 \)), so that the after transfer \( w_A^*-\text{locus} \) at the end of the \( c(1) \) stage hits the \( w_0^*-\text{locus} \) while it is still

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\(^{19}\) Similar productivity ratios are not that unrealistic according to the classic study by MacDougall (1951), p. 700, where Beer, Linoleum, Coke, and Hosiery have ratios of 2, 1.9, 1.9, and 1.8 respectively.

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Home’s absolute advantage by a constant for all commodities. Such a shift leads to the necessity that Home benefits from uncompensated transfer.
horizontal at a Foreign wage rate of $1/a_4^*$. What was originally a “turning point” becomes a “turning region”, a set of values for relative country size for which transfer does not lead to any increase in Foreign’s wage rate and thus leads unambiguously to real income gains for the Home transferring country.\footnote{Letting $\theta_k$ represent the sum of spending shares for commodities $I$ through $k$, the inequalities in (3) for values of $(L^*/L)$ can be generalized as: $[(1-\theta_k)/\theta_{k-1}]a_{k-1}^* \leq [(1-\theta_k)/\theta_{k}]a_k^* \leq [(1-\theta_k)/\theta_{k-1}]a_{k-1}^*$. If $w^*$ is $1/a_{k-1}$, $(L^*/L)$ is in the second range. After commodity $I$’s technology is transferred, the range for $(L^*/L)$ where $w^*$ is still $1/a_{k-1}$ becomes: $[(1-\theta_{k-1})/\theta_{k-2}]a_{k-2}^* \leq [(1-\theta_{k-1})/\theta_{k-1}]a_{k-1}^* \leq [(1-\theta_{k-1})/\theta_{k}]a_k^*$, where $\theta_{k-1}$ is defined as $\theta_{k-1} = b_k - (b_k - b_i)$ where $b_i$ is the spending share on the $i$th commodity, so that $\theta_{k-1}$ exceeds $\theta_{k-2}$ if the share of the transferred commodity $I$ is less than that of commodity $k$. Therefore the turning range is $[(1-\theta_{k-1})/\theta_{k-2}]a_{k-2}^* < L^*/L < [(1-\theta_{k-1})/\theta_{k}]a_k^*$} If, instead, the share commonly spent on the first commodity exceeds that spent on all others there would not be any turning points or regions in Figure 1. The technology transfer would always lead to an increase in Foreign’s wage rate. This, by itself, works to the detriment of any improvement in Home real incomes because world prices of all commodities newly produced by Foreign must increase. Set against this, however, is the fact that with transfer the world price of the first commodity (whose technology has been transferred) decreases (as before), but now this price fall carries relatively more weight in the price index.

6. Which Technology is Transferred?

Throughout our discussion we have assumed that it is the set of blueprints for Home’s best export commodity that is transferred without compensation. Would it matter if, instead, it were the technology for a different export commodity, or perhaps the technology for a commodity that originally is being imported by Home that is transferred abroad without compensation?

First, we provide a more general argument that regardless of which export commodity is selected to have its technology transferred to Foreign, the turning points remain the
same. Let the technology for commodity \( j \) be transferred, where Home originally
produces commodities \( 1 \) through \( k \) (which includes \( j \)), and Foreign the remaining set,
\( (k+1) \) through \( n \). If Home is an incipient producer of commodity \( (k+1) \) before transfer,
after transfer Foreign produces the \( j^{th} \) commodity and becomes an incipient producer of
\( (k+1) \) at the wage rate \( 1/a_{k+1}^* \), the same wage rate as before the transfer. Thus the
turning points remain the same although the commodity taken over by Foreign changes.

To illustrate in the 4-commodity case, Figure 3 is like Figure 1 in showing the
original and after-transfer wage profiles, but now with Home’s superior technology in
producing commodity 3 being transferred instead of the relatively even more superior
technology Home possesses for producing the first commodity.\(^{21}\) From very small values
of Foreign relative size, until \( L^*/L \) reaches \( a_3^* \), the after-transfer wage locus is the same
as if technology for the first commodity were transferred, as illustrated in Figure 1. For
example, in the earliest segment, \( b(I) \), both countries produce commodity 3 after transfer,
which serves to raise Foreign’s wage to unity just as, in Figure 1, it did with commodity
\( I \)’s transfer.\(^{22}\) The possibility of Home gain can only materialize when Foreign’s relative
size is large enough to allow Home to stop producing one or more commodities. This
occurs when \( L^*/L \) reaches \( I/3 \), as before, with relative Foreign size in the \( c(I) \) section
once again pushing Foreign’s wage rate after transfer towards its productivity in
producing the fourth commodity, \( I/a_4^* \). (The fourth commodity is second on the list of
Foreign’s comparative advantage after transfer whether the transfer is of commodity \( I \)’s
technology or that for commodity 3.) When it reaches \( a_4^*/3, L^*/L \) is once again at a

\(^{21}\) Note in Figure 3 that the top horizontal axis has a different array of crucial points for \( L^*/L \) than does
Figure 1. In particular, the values of \( a_3^* \) and \( 3a_3^* \) have been deleted from Figure 1, and values \( a_2^* \) and
\( 3a_1^* \) added, the latter pair corresponding to points at which, after transfer of Home’s superior technology
for the third commodity, the \( w_A^* \)-locus stops falling and becomes a plateau.

\(^{22}\) In either case transfer has left real incomes at Home unchanged (since Home does not gain from trade in
either scenario).
turning point, and in the neighborhood of such a point Home must gain by transfer, as illustrated in Figure 2. Transferring 3’s technology to Foreign yields the same results on the price level and Home’s real wage as does a transfer of 1’s technology.

In the case we considered previously, not only was \( a_3/3 \) a turning point, so was the value for \( L^*/L \) given by \( a_3^* \). This is no longer the case, and for higher values of relative Foreign country size the after-transfer \( w_A^* \)-locus merges with that of the original \( w_0^* \)-locus when it is commodity 3’s technology that is being transferred. This differs from Figure 1’s depiction of the after-transfer locus when commodity 1’s technology is transferred. In the latter case at \( a_3^* \) Foreign is an incipient producer of the third commodity after transfer (see Figure 1), so that the Foreign wage would stay at \( 1/a_3^* \). In Figure 3 we show that it is indeed the case that the wage rate is also at \( 1/a_3^* \) when \( L^*/L = a_3^* \), but it does not remain there for higher values of \( L^*/L \). What Figure 3 reveals is that if Foreign’s relative size exceeds the value at which originally Home would have ceased to produce commodity 3, the transfer of Home’s technology to Foreign is a transfer of a technology not being used at Home. When a commodity other than the best is transferred, it is a potential import commodity. As earlier literature has confirmed, in cases such as this Home must gain by technology transfer.

Return to the question: Does it make a difference which commodity’s technology is transferred to Foreign? Yes and no. No, if Home originally produces the commodity; Yes, otherwise. A technology transfer for an export commodity changes the pattern of trade, whereas a technology transfer for an import commodity not produced at home has no impact whatsoever on the allocation of labor. Home (and Foreign) must gain.

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A Ricardian 3-commodity model is analyzed in Jones (1979). Inter alia it considers a case in which the numeraire is the middle good produced in common by both countries and one country (Foreign) experiences a technological improvement in that commodity small enough (infinitesimal) that both
7. What Kind of Paradox?

One of the striking features of the theory of international trade is the rather large collection of paradoxes it can exhibit, e.g. that of immiserizing growth, the transfer welfare paradox, and the Lerner and Metzler paradoxes associated with tariffs. They all share something in common, *viz.* the manner in which secondary effects working through the price mechanisms of general equilibrium have the power to offset the primary effect of a disturbance such as growth, a gift or a tariff on equilibrium welfare or prices. How does the paradoxical result discussed in this paper fit into this pantheon of trade paradoxes? The transfer welfare paradox (for gifts of commodities) depends upon countries exhibiting different taste patterns, whereas here tastes are similar between countries. The immiserizing growth paradox entails an outward shift in Home’s transformation curve. Here Home’s transformation surface is not affected.

If a country gives away its better technology in producing a commodity imported (but not produced) at Home, the country clearly gains by an improvement in its terms of trade. But having a superior technology in one of its *export* goods be stolen or given away is a different matter. If only *some* of its technology is transferred, so that Home’s production does not shut down, Home’s terms of trade deteriorate and Home’s real wages must fall. The paradox is that if sufficient technological secrets are transferred so that

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continue to produce the same commodity. In Foreign the wage rate increases, driving up the price of the commodity not produced at Home, with no offsetting price fall in the commodity in which there has been technological progress. (This asymmetry is just opposite to that found at *turning points*, where the price of Home’s original export commodity falls, but those of other export goods from Foreign do not). In Figure 3 suppose initially relative country size is between $a_3/3$ and $a_3$ with both countries producing commodity 3. A slight improvement in Foreign’s technology for producing commodity 3 raises the $w_3^*$-*locus* (slightly) above the $w_0^*$-*locus* and Home would lose. This is equivalent to the Samuelson (2004) argument that in such a case Home would lose for small Foreign technology improvements.

24 One of the most famous of the paradoxes, the Leontief paradox, is deleted from this list.

25 The issue of trade paradoxes involving income effects is explored in more detail in Jones (1985).
Home is completely driven out of production, Home may end up a gainer, and such a result cannot be understood without taking into account the shift in trading patterns. Technology transfer lowers the relative world price of Home’s original export commodity, but if the transfer is sufficiently great to alter trade patterns and wipe out Home’s original export sector, Home becomes an importer and may end up a net gainer. Unlike the standard trade paradoxes, the possibility of this technology transfer paradox crucially depends on a realignment of the pattern of trade.\textsuperscript{26}

8. Concluding Remarks

Most developed countries have experienced changes in their patterns of production and international trade over time. By their own investment activities new positions of comparative advantage are acquired, accompanied by their losing their comparative advantage in other commodities. This loss is an inescapable consequence of success in new ventures raising their real wage rates and of less developed countries acquiring new technology and skills in producing commodities such as textiles, steel, or automobiles. Years ago Ray Vernon (1966) sketched out a product cycle theory describing this evolution of production and trading patterns.

It has recently been emphasized by Samuelson (2004) and others that if foreign countries develop increased expertise in commodities that a Home developed country is exporting, at Home real incomes will fall with a deterioration in Home’s terms of trade. Thus increasing degrees of globalization that are characterized by Foreign technological

\textsuperscript{26} Suppose the best export commodity is transferred. In the two-commodity case the advanced country moves to its next best (i.e. other) commodity, and net gains depend on how close its absolute advantage in this next good is to the transferred commodity. In general net gains depend upon a technological comparison of, say, the $k^{th}$ and $(k+1)^{th}$ commodity, far from that of the transferred good.
advances rather than those at Home can do damage to income levels at Home. In this paper we consider improvements in Foreign technology that surpass, in scope, those considered either by Samuelson or by critics of globalization. We stack the deck in asking whether an advanced country can actually gain by an uncompensated transfer to a foreign country of its advanced technology in producing the export commodity in which it possesses its greatest comparative advantage. The answer most often given by economists to questions of this sort is: it depends. The answer we give in this case of technology transfer is yes, it depends, but if relative country size is in particular ranges and demand shares are all alike, the advanced home country must gain by such unrequited transfer near the so-called turning points.

A crucial question concerns the effect of such transfer on the relative wage rates of Home and Foreign (i.e. the double factorial terms of trade). At the critical turning points relative wage rates are not affected by the transfer, whereas for other values of relative country size the technology transfer raises Foreign’s wage rate, which serves as well to increase the prices faced by Home labor for all commodities produced by Foreign and imported by Home. If Foreign’s wage rate does increase as a consequence of transfer, there emerge two conflicting effects on the consumer price index facing Home’s workers, viz. a falling price for the commodity whose technology has been transferred, on the one hand, and an increase in prices of other goods imported by Home on the other. Our normalization assumption, whereby all input-output labor coefficients for Home are set at unity (by appropriate choice of commodity units), leading as well to a unit value for Home’s wage rate, coupled with strong Cobb-Douglas assumptions regarding taste patterns, suffice to show that if the product of world commodity prices falls, Home laborers must experience an increase in real income (real wages).
When the popular media talk about globalization, the point often emphasized is that *unemployment* will develop in those industries in which foreign countries are experiencing technological progress. The scenario we envisage, in which Foreign takes, without compensation, our advanced blueprints for our best export sector (or any other export sector), results not merely in job losses in that sector, but the complete devastation of that industry. Economists employing the models of international trade theory (such as the Ricardian model), typically go beyond the stage of initial unemployment in the affected sector in order to allow a reallocation of resources to their new best use. As a consequence, net gains to the Home country are not precluded by an initial set of job losses. What is striking in our scenario is that it is precisely the *complete loss* of Home’s original best industry that allows a reduction in its world price and thus works in favor of the increase in real wages at Home. In many advanced countries workers have benefited, as consumers, from lower priced and better quality TV sets, cameras, automobiles and electronic goods after Foreign has taken over their production. Without denying the importance of new technological developments in advanced countries, of the type envisaged by Vernon (1966), what we have argued is that even *without* such advances, pure improvements abroad, such as represented by stealth or uncompensated acquisition of some of our better technology, may serve to raise real wages and incomes in the advanced home country. Trade patterns are altered, and the subtle mechanisms of comparative advantage can yield net gains to the advanced country.

There is a *cyclical* pattern of gains and losses to Home that depends on Foreign’s relative size. There are repeated neighborhoods of such relative size in which technology transfer *must* yield net gains to Home, and these neighborhoods get increasingly larger the greater the relative size of the Foreign labor force.
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FIGURE 1. Original and After-Transfer Foreign Wage Rates
FIGURE 2. Home Possible Gains After Transfer
FIGURE 3. Technology for Commodity 3 Transferred