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TECHNOLOGICAL DETERMINANTS OF TRADE

by

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1 Introduction

International trade flows are guided by a variety of forces, including tastes, technologies, factor endowments, and domestic and foreign policies. Early classical writers emphasized cross-country differences in technological capabilities as the principal cause of trade. But models focusing on disparities in factor endowments came to dominate thinking about international trade in the twentieth century, following the seminal writings of the Swedish economists, Eli Heckscher and Bertil Ohlin. Interest in the technological determinants of trade came back into vogue in the 1980s, with the emergence of a 'new trade theory', and even more so in the early 1990s, when this theory became a building block for the 'new growth theory'.

There is plenty of evidence – from case studies of multinational corporations to industry studies of total factor productivity to aggregate studies of trade flows – to suggest that technological capabilities do indeed differ around the globe. These differences help to explain the cross-country variation in standards of living and in decade-long (or more) growth rates. Many important issues in the current policy debate also relate to technological disparity, such as the oft-heard complaints of firms in the industrialized countries about lax protection of intellectual property rights in the less developed countries, or the discussions in the United States and Europe about the causes and appropriate responses to the widening income gap between skilled and unskilled workers. To address these issues and others, it is important to have a good understanding of the technological forces that shape international trade and the ramifications of the interdependence between trade and technology.

Much interesting research has been directed at these topics in the past fifteen years. Our aim here is to provide a brief review of some of the main areas of research and the chief findings. By focusing on technological explanations of trade flows, we do not mean to downplay the usefulness of alternative theories, such as those based on factor proportions or static scale economies. Rather, we believe that trade is driven by a variety of forces and that scholars would be mistaken to adopt a narrow view of the relevant theory. Nevertheless, it is analytically useful when studying a particular determinant of trade to isolate this single cause while ignoring all others. That is the approach we shall follow in this paper.

In the next section, we review some recent descendents of Ricardo's venerable theory of comparative technological advantage. These modern renditions still treat technology as exogenous, but they contain some interesting dynamics and provide useful insights into North-South trade. In Section 3 we review new trade models that build on learning-by-doing. Much of this work bears a close relationship to recent advances in the theory of economic growth. Section 4 contains a discussion of the trade literature that considers endogenous innovation and endogenous technology transfer. This literature sheds new light on international competition in technology-intensive industries and on the product life cycle.

There is a common thread running through the studies reviewed in this paper. All pay close attention to the dynamic forces that shape long-run trading patterns.

2 Ricardian Trade

David Ricardo's model of international trade is so familiar that it hardly bears repeating in any detail. We briefly present its central features in a framework with a continuum of goods in order to lay the groundwork for some of our later discussion. Following Dornbusch, Fischer and Samuelson (1977) we imagine a world economy producing a continuum of goods indexed by z, $z \in [0,1]$. Firms in the home country require $a(z)$ units of labor to produce a unit of good z. Firms in the foreign country require $a^*(z)$ units of labor to produce the same good. If the wage rates are w and w^* in the home and foreign countries, respectively, then firms in the home country enjoy a cost advantage in producing all goods (and only goods) for which $wa(z) < w^*a^*(z)$. It follows that under free trade, the home country specializes in producing all goods for which $w^*/w > M(z) \equiv a(z)/a^*(z)$, where the function $M(z)$ describes the relative labor requirements.

Figure 1 depicts a rising relative input-requirement curve, which arises after we have listed the goods in order of declining comparative advantage for the home country. Demand conditions together with the curve $M(z)$ determine the equilibrium relative wage rate and the pattern of specialization. To find the equilibrium point, it is necessary to combine demand conditions with factor-market clearing conditions to derive a downward sloping curve, such as $D(z)$, which depicts combinations of the relative wage and the pattern of specialization consistent with supply equal to demand in all goods and factor markets. Equilibrium prevails at the intersection of the two curves at point E. In the free-trade equilibrium, the relative wage rate is w_E/w_E^*, and all goods with indexes $z < z_E$ are produced in the home country, while those with indexes $z > z_E$ are produced in the foreign country.[1]

Building on this version of Ricardo's theory, Krugman (1986) developed a model in which technologies improve exogenously and specialization and trade are determined by nation-specific technology gaps. Suppose there is a best-practice technology for producing good z at time t, which calls for $A^{-1}e^{-g(z)t}$ units of labor per unit output. Let the function $g(z)$ be positive and increasing in z. With this specification, the best-practice labor requirement falls over time for all goods, but goods with higher indexes experience faster technological progress. We can therefore interpret the index z as gauging the technological sophistication of the product.

Now assume that all actual and potential producers in the home country lag γ years behind the technological frontier while those in the foreign country lag γ^* years behind the technological frontier, with $\gamma > \gamma^*$. This means that the foreign coun-

[1] It is common to assume Cobb-Douglas preferences in these types of models. With a continuum of goods such preferences can be represented by an increasing function $B(z)$ that describes the fraction of income spent on all goods with an index less than or equal to z. When both countries have the same Cobb-Douglas preferences, the function $D(z)$ takes the simple form $[1 - B(z)]\, L/B(z)L^*$, where L is the labor force of the home country and L^* is the labor force of the foreign country. Wilson (1980) treats more general cases.

try is more advanced technologically, and the gap between them is $\gamma - \gamma^*$ years. Under these conditions, the labor needed to produce a unit of good z at time t is $a(z,t) \equiv A^{-1}e^{-g(z)(t-\gamma)}$ in the home country, and $a^*(z,t) \equiv A^{-1}e^{-g(z)(t-\gamma^*)}$ in the foreign country. The momentary relative labor requirement is given by $M(z) \equiv a(z,t)/a^*(z,t) = e^{g(z)(\gamma-\gamma^*)}$, which is increasing in z, as in Figure 1. Notice that, despite the ongoing technological progress, the curve does not shift over time; in other words, the pattern of comparative advantage is fixed in Krugman's model. Using output and factor market-clearing conditions, we can once again derive a curve such as $D(z)$. The equilibrium point E then determines relative wages and the pattern of specialization at every moment in time. Evidently, the leading (foreign) country specializes in producing and exporting the technologically more sophisticated products, while the lagging (home) country specializes in producing and exporting the technologically less advanced products. The patterns of trade remains fixed through time.

The larger is the technology gap $\gamma - \gamma^*$, the higher is the $M(z)$ curve, and the lower is the equilibrium value of z_E and the higher is the equilibrium relative wage of the foreign country. It follows that a larger technology gap generates a wider real income gap between the advanced and the lagging country, and a narrower range of specialization in the latter nation.

We can use Krugman's model to illustrate some important points about the welfare effects of technological progress. For example, technological progress in one country may adversely affect its trade partner. Suppose the lagging country experiences "catch-up"; i.e., it somehow narrows the gap between itself and the technologically leading country. In the figure, this would correspond to a downward shift and clockwise rotation of the $M(z)$ curve. Of course, the relative wage of the lagging country rises and the range of goods it produces in equilibrium grows. The productivity improvement in the initially marginal sector (z_E) exceeds the fall in the leading country's relative wage, so the leading country sees a rise in its purchasing power relative to this marginal good. But for goods less technologically sophisticated than the marginal one (i.e., those with $z > z_E$) the extent of productivity improvement resulting from a narrowing of the technology gap is not so great. For some of these goods, the leading country will see its purchasing power decline. If the number of such goods is large enough and the terms of trade change is great enough, then the lagging country's gains will come at the leading country's expense.

Second, the model illustrates how technological progress might spell the deterioration of a country's own terms of trade. Suppose the leading country experiences a burst of scientific advance, which allows local producers to operate closer to the technological frontier. This of course means a widening of the gap between this country and its lagging trade partner. In the figure, the $M(z)$ curve shifts upward and rotates in a counterclockwise direction. The relative wage of the leading country rises, but not by so much as the productivity improvement in the marginal good. The productivity improvement for goods originally exported by the leading country (i.e., those with $z < z_E$) is even greater. This means that the relative price of all goods originally exported by the leading country falls relative to the price of the goods the country originally imported; i.e., its terms of trade deteriorate. Of course, we know from Bhagwati (1958) that the adverse impact of such a terms-of-trade deterioration can be so severe that the country experiencing the technological progress may be "immiserized" as a consequence.[2]

If both countries move closer to the technological frontier in such a way as to leave the technology gap between them unchanged, then both must gain. In terms of Figure 1, an equal fall in γ and γ^* leaves the $M(z)$ curve unaffected. Therefore, neither the relative wage nor the pattern of specialization changes. The cost of every

[2]In Krugman's model, the lagging country must benefit from a movement of the leading country closer to the technological frontier. The country's purchasing power improves in terms of all goods that it originally imported, as well as in terms of some goods near the margin that it originally exported but does so no longer. Its purchasing power in terms of goods that it continues to export remains unchanged. Thus, its real income unambiguously rises.

good falls in terms of the wage in either country, which implies an increase in welfare for all workers. This may provide an argument for leading countries to share their scientific gains with those trailing in the technology race.

Flam and Helpman (1987) have developed a different model of Ricardian trade to address the relationship between vertical product differentiation and the distribution of income. Individuals consume a homogeneous product in variable quantities and one unit of a differentiated product that comes in different qualities. Preferences are given by $ye^{\alpha z}$, $\alpha > 0$, where y is the quantity of the homogenous product and $z \in [0, +\infty)$ is the quality of the vertically differentiated product. Higher quality products are more expensive to produce, hence more costly to purchase. Since quality is a "normal good" in this specification of preferences, individuals with higher income consume a better quality product. This implies that the composition of demand in a country depends on its distribution of income. A country with a high median income demands a preponderance of high-quality products, although its poorer households will consume low quality products. Similarly, a country with a low median demands mostly low quality products, but its upper classes will want to buy the superior goods.

On the production side, Helpman and Flam assume that firms in both countries can produce one unit of the homogeneous good y with one unit of labor. In the differentiated product industry, firms in the home country require $a(z) = A^{-1}e^{\beta z}$ units of labor to produce a unit of output of quality z, while firms in the foreign country require $a^*(z) = (A^*)^{-1} e^{\beta^* z}$ units of labor to produce output of this quality. For a differentiated good of quality z, the relative input requirement is given by $M(z) = (A^*/A)\, e^{(\beta-\beta^*)z}$, which is upward sloping, assuming that $\beta > \beta^*$; i.e., that the foreign country has a comparative advantage in producing high quality products.

Although there is an unbounded set of qualities that can be produced, each country specializes in equilibrium over an interval of qualities of finite length. The foreign country specializes in a range of higher-quality goods, while the home country produces goods lower on the quality spectrum. The identities of the goods produced in equilibrium depend upon the parameters describing the tastes and technologies and the distribution of income in each country. Technological progress shifts the ranges of produced goods. In particular, an increase in A^* at the rate γ^* coupled with an increase in A at the rate γ leaves the number of products produced in each country unchanged, while causing both countries to upgrade their quality mixes. The two countries abandon their lowest quality products and upgrade their highest quality products at exactly the same rate in this case. It follows that the home country continually takes over product lines that were previously abandoned by its trade partner. In short, the model predicts a product cycle; ever higher-quality products are initially manufactured by the more advanced country and later by the less advanced one.

Significant extensions of this model, allowing for more general structures of preferences and technologies, were developed by Stokey (1991a). She has shown that, these generalizations notwithstanding, the characterization of the pattern of specialization and trade remains as described here.

3 Learning-by-Doing

The Ricardian trade model takes the distribution of technologies and any technological progress as exogenous. Much of the research in recent years has attempted to endogenize technological progress, in order to investigate the links between international trade and the pace and pattern of technical change. The literature has identified two potential sources of technological progress: progress that is an accidental by-product of manufacturing activities and progress that is the deliberate result of investment activities. In this section we discuss some of the writings on learning-by-doing, wherein experience itself acts as a teacher and firms gain wisdom from the actions of the others. Here, we assume that each firm takes its technological opportunities as exogenous, but the evolution of technology reflects the equilibrium decisions of the whole.

Consider again a Ricardian technology with a continuum of goods. Let the home country's labor-input requirement for a unit of output of good z be $\tilde{a}(z,t) = A(z,t)^{-1}\hat{a}(z)$ at time t and let the corresponding input coefficient for the foreign country be $\tilde{a}^*(z,t) = A^*(z,t)^{-1}\hat{a}^*(z)$. Here the productivity parameters $A(z,t)$ and $A^*(z,t)$ depend upon cumulative past output as a reflection of the prior learning-by-doing. We shall distinguish between two cases, one in which the technology level for producing good z in each country depends upon cumulative output of z in the world economy, and the other in which the technology level for producing good z in a country depends on the cumulative production of z by firms located there. In the first case, the spillover benefits from learning-by-doing are global in scope, while in the second these benefits are confined to the country of origin.

First, let $A(z,t) = A(z)Q^w(z,t)$ and $A^*(z,t) = A^*(z)Q^w(z,t)$, where $Q^w(z,t)$ is cumulative world output of good z from the distant past up to time t. The relative input-requirement curve is given by $M(z) = a(z)/a^*(z)$, where $a(z) = A(z)^{-1}\hat{a}(z)$ and $a^*(z) = A^*(z)^{-1}\hat{a}^*(z)$. This curve remains fixed through time. By indexing the goods in order of decreasing comparative advantage for the home country, we obtain an upward sloping $M(z)$ curve, just as in Figure 1. Output and factor market-clearing conditions then determine a $D(z)$ curve, and an equilibrium obtains at an intersection point such as E in the figure. Importantly, as time goes by this equilibrium point remains in place, in spite of the endogenous learning that is taking place in all sectors in both countries. Since the pace of technological progress in each industry is the same in both countries, the global learning-by-doing does not alter the pattern of comparative advantage. The initial pattern of specialization and trade is replicated forever, and real wages grow at the same rate worldwide.

Next consider the more common specification in which the technology for producing good z in a particular country reflects the cumulative experience of firms in that country in producing the good. This represents a situation where the diffusion of knowledge is geographically limited.[3] Then we can write $A(z,t) = A(z)Q(z,t)$ and $A^*(z,t) = A^*(z)Q^*(z,t)$, where $Q(z,t)$ is cumulative output of good z in the home country up to time t and $Q^*(z,t)$ is cumulative output in the foreign country up to the same moment in time. Let $M(z,t) = \tilde{a}(z,t)/\tilde{a}^*(z,t)$. With this new specification of the technology levels, the foreign country's relative labor requirement for producing good z at time t is proportional to the relative cumulative experience of the two countries $Q^*(z,t)/Q(z,t)$. The factor of proportionally depends on the product index z, but does not change over time. It follows that the initial pattern of comparative advantage is reinforced over time by the pattern of specialization in a trading equilibrium (see Krugman (1987)). To demonstrate this result in a simple way, we order the goods so that at time $t = 0$ the relative labor-requirement curve is upward sloping, as in Figure 1. The output and factor-market clearing conditions are once again represented by $D(z)$, so that E is the initial equilibrium point. The home country specializes in all goods $z < z_E$ and the foreign country specializes in all goods $z > z_E$. As a result of this pattern of specialization, firms in the home country gain further experience in manufacturing the goods with indexes $z < z_E$ while firms in the foreign country do likewise for goods with indexes $z > z_E$. In the next instant, the curve $M(z,t)$ is lower for all $z < z_E$ and higher for all $z > z_E$. Evidently, the equilibrium point E does not change. As time passes, the relative labor-requirement curve shifts further down to the left of z_E and further up to its right. This increases each country's comparative advantage in the goods it initially produced. We conclude that the initial pattern of comparative advantage persists forever, as nation-specific learning-by-doing locks in the pattern of specialization and trade.

Our discussion up to this point has assumed unbounded opportunities for learning-by-doing. But, as Young (1991) points out, the empirical evidence indicates that continued repetition of the same manufacturing activities does not sustain productivity

[3]Of course there can be intermediate cases where a part of the experience in each country spills over to the other, or where the benefits of learning by doing eventually spill over to producers in the opposite country, but only with a lag.

improvement forever. It may seem, therefore, that learning-by-doing cannot be an engine of sustained growth. But Stokey (1991b) and Young (1991) highlight a mechanism by which even bounded learning-by-doing can sustain ongoing technological progress, provided that there are technological spillovers between different manufacturing activities. Consider a setting in which products are vertically differentiated, and high-quality goods are initially prohibitively expensive to produce. We may think in terms of different "generations" of a products, such as early and later personal computers, early and later camcorders, etc. Now suppose that there is bounded learning-by-doing in producing any product, but that the cumulative experience in producing some generation of a product also lowers the cost of manufacturing the next generation. Then, over time, the learning in one generations can make feasible the introduction of the next generation, and the economy might continue to climb the quality ladder.

How does international trade interact with this process of sustained learning? Suppose there are two sectors, a traditional sector with no prospects for learning-by-doing, and a second sector with vertically differentiated products and the type of intergenerational spillovers described above. Also suppose that there are two identically-sized countries, home and foreign, which have access to the same production and learning opportunities, but that the benefits from learning-by-doing are nation specific. Let the foreign country be the one that happens to have greater prior experience in producing the vertically differentiated goods at a given moment of time.

As a consequence of their greater experience, firms in the foreign country can produce a better quality (i.e., later generation) product. This gives the foreign country a momentary comparative advantage in the vertically-differentiated sector. With free trade, the home country specializes (relatively or absolutely) in producing traditional goods. As a result, it foregoes opportunities for productivity growth in the sector characterized by learning-by-doing.[4] As in Krugman (1987), the initial patter

[4]If the lagging country happened to be larger than the leading country, it might be able to

of trade becomes locked-in; but, this time, it means that one country's growth rate is slower than it would have been in the absence of trade.

This does not necessarily imply that the home (lagging) country would be made better off by shutting its borders. Trade affords its consumers access to a better quality of differentiated product, at lower cost in terms of the traditional good. Moreover, with the specialization engendered by trade, the foreign country gains experience more rapidly than otherwise, and so world productivity growth in the vertically-differentiated sector accelerates. This too benefits the home country as its terms of trade will improve through time. However, the home country does bear a cost from having to play its role as producer of traditional goods in the trade equilibrium. The country sacrifices its opportunity for productivity improvements. So, unlike the static Ricardian model (or one with exogenous technological progress), gains from trade for all trading countries are not assured in a world of nation-specific learning-by-doing.

We have reported results so far that are bearish on the prospects for technologically lagging countries. But Bresiz, Krugman and Tsiddon (1993) show why pessimism may not always be warranted. Indeed, they describe forces that can generate "leapfrogging" in the world economy: i.e., a sequence of phases in which the world's technologically lagging country inevitably catches up and forges ahead of its partner, only to see its relative position later reversed again.

Consider a setting similar to the one described above, but with two differences. First, there are no spillovers of learning from one generation to another, only bounded learning within the production life of each generation. Second, the knowhow to produce new and better goods comes along exogenously, at infrequent intervals. When

specialize relatively in producing the traditional product, and still have an absolutely larger sector producing the vertically-differentiated goods. In the event, the technological gap between the two countries would close, and eventually the larger country would take over production of the technology-intensive products. This is similar to what can happen when growth is driven by innovation, and productivity in the industrial research lab depends on prior national experience in R&D. See Grossman and Helpman (1991, chap. 8).

the technology for producing a new generation of good becomes available, productivity is initially quite low until some amount of experience has been gained. In this setting, the country that produces the state-of-the-art differentiated product has the higher wage. It also accumulates substantial experience in using the leading technology. When a new technology comes along, it may not be adopted by firms in the leading country, because they cannot compete profitably with others there who have thoroughly mastered the older methods. But in the initially lagging country, where wages are lower, firms may be able to compete using the new technology, and so begin to accumulate the requisite experience. Over time, the new-generation product might completely displace the old, and the countries will have traded places. Here, trade accelerates the pace of adoption, and it necessarily raises lifetime welfare for (infinitely-lived) residents of each country.

4 Innovation and Imitation

We turn now to endogenous technological progress that is the result of deliberate efforts by profit-seeking firms. Firms might devote resources to an activity called "R&D" in an attempt to develop new products, better products, or better methods for manufacturing existing products. Firms might also alter their short-run production decisions in order to accelerate learning that takes place on the shop floor. Learning-by-doing becomes just like R&D, if at least some of the benefits from such learning can be appropriable

Investments in knowledge are made with an eye toward future rewards. And often the cost of the investment is unrelated to the scale of the subsequent output.. That is, once a technology has been mastered, it can be used to produce a small amount or a large amount of output. All of this means that intentional learning will not take place in perfectly competitive markets. Firms must be able to reap some monopoly profits in order to justify their up-front investment costs. But indeed, as Schumpeter emphasized, learning that generates private knowledge often creates the monopoly power that serves as its own reward.

To study endogenous innovation, then, we need general-equilibrium models that admit imperfect competition. Such models were developed in the early 1980's to provide a basis for understanding intra-industry trade (see, for example, Helpman and Krugman (1985)). These models of monopolistic competition have been modified in recent years to allow an examination of the relationship between trade and R&D-driven growth.

We sketch first a model of a closed economy. The economy produces varieties of a horizontally-differentiated product using labor alone. Once the technology for producing a variety z is known, its production requires one unit of labor per unit output. There are infinitely many conceivable varieties; i.e., $z \in [0, +\infty)$. However, at time t, the economy has only managed to acquire the know-how for producing a measure $n(t)$ of these goods. We order the (otherwise symmetric) goods so that those with known technologies have indexes in the range $[0, n(t)]$. Over time, $n(t)$ might rise, if firms in the economy devote resources to learning to master new technologies.

Let the representative household have preferences at a point in time represented by the utility indicator $u = [\int_0^n c(z)^\alpha dz]^{1/\alpha}$, $0 < \alpha < 1$, where $c(z)$ is consumption of variety z and α is a parameter describing the degree of substitutability between different brands. Consumption and the range of available products may vary over time, but we have dropped the time index for simplicity. The posited utility function features a constant elasticity of substitution equal to $1/(1-\alpha)$ between every pair of existing and not-yet invented brands. The intertemporal preferences at time t are described by $U(t) = \int_t^\infty e^{-\rho(\tau - t)} [\log u(\tau)] \, d\tau$, where $\rho > 0$ represents the subjective rate of time preference.

Now suppose that the economy's laws and institutions are such that a firm that develops a new brand receives an infinitely-lived patent granting it the sole right to produce that good. Then each patent holder will be a monopolist in a market niche. A typical profit-maximizing producer sets the price $p = w/\alpha$, where w is the wage rate. In equilibrium, all varieties are equally priced and each patent earns an instantaneous return equal to $\pi = (1-\alpha)wC/\alpha n$, where $C = nc$ is aggregate consumption at the time. In a steady state, a prospective innovator at time t calculates the present value of the future stream of profits as $\pi(t)/(\rho + g)$, where g is the rate of growth in the number of competitors; i.e., $g = \dot{n}/n$, the *rate of innovation.* The prospective innovator compares this reward with the cost of inventing a new brand.

Next suppose that a firm that employs one unit of labor in a research lab develops $A_I(\cdot)$ new products per unit time. Then the per-variety cost of invention is $w/A_I(\cdot)$. In an economy with an active R&D sector, these costs must equal the reward to a parent, which implies

$$\frac{(1-\alpha)C}{\alpha n}A_I(\cdot) = \rho + g. \tag{1}$$

In (1), the left-hand side is the dividend rate (the ratio of profits to the value of a patent), while the right-hand side is the real effective cost of capital.

In equilibrium, labor supply must equal labor demand. Supply is fixed at L. Demand by the manufacturing sector totals C, while demand by the R&D sector amounts to $\dot{n}/A_I(\cdot) = gn/A_I(\cdot)$. Thus, factor-market clearing requires

$$\frac{gn}{A_I(\cdot)} + C = L. \tag{2}$$

The first thing to observe is that whenever the productivity of labor in the research lab is bounded above, there can be no steady state with active innovation. In a steady state, aggregate consumption C must be constant. Therefore, whenever $A_I(\cdot)$ stops growing, the left-hand side of (1) goes to zero as n grows large. In other words, as the number of competitors increases, the profits earned by each one falls, and eventually the dividend rate is too small to justify the private expenditure of further resources on R&D. At this point, the economy stops growing.

If, however, the economy can continue to improve its research techniques, then sustained innovation may be possible. Unbounded learning from research experience sounds more plausible, one might argue, than unbounded learning from repeated manufacturing. After all, inventive activities often generate discoveries that prove useful for later innovations. Sometimes, as in the case of the steam engine or the digital computer, the forward spillovers from invention can be enormous. In any event, there is no reason to expect that our prospects for improving our inventiveness are bounded.

A simple way to represent unbounded learning from research activities is to assume that $A_I(\cdot) = n/a_I$, where $a_I > 0$ is a parameter. Here the productivity of labor in the research lab is proportional to the economy's cumulative experience in R&D. Substituting this expression for $A_I(\cdot)$ in (1) and (2), we find the following simple equilibrium conditions for aggregate consumption and the rate of innovation:

$$\frac{(1-\alpha)C}{\alpha a_I} = \rho + g, \tag{3}$$

$$a_I g + C = L. \tag{4}$$

These equations imply a constant steady-state rate of innovation given by

$$g = (1-\alpha)\frac{L}{a_I} - \alpha\rho. \tag{5}$$

The rate of innovation is larger the smaller is the subjective rate of time preference (i.e., the smaller ρ), the smaller is the elasticity of substitution between brands (i.e., the smaller α), and the more productive is labor in the research lab (i.e., the smaller a_I).

Importantly, aggregate consumption C, which measures the *physical quantity* of consumer goods, does not represent a true measure of welfare here. Welfare depends not only on quantity, but also on the diversity of the available consumption options. In the momentary equilibrium, a household achieves utility $u(t) = n(t)^{(1-\alpha)/\alpha}C(t)$ at time t. Evidently, with C and g constant in the steady state, the household's utility level and thus its real income grow at the constant rate $[(1-\alpha)/\alpha]\, g$.[5]

[5]Real income here should be defined, as usual, as nominal income divided by an ideal price index.

Returning to the theme of this review, we direct our attention to the interaction between international trade and the evolution of technology. The simplest case arises when there are two similar countries that differ only in size. Suppose the home country has L workers while the foreign country has L^* workers. How does trade affect their allocations of labor to the research activity, and the resulting pace of technological progress? The answer depends on whether innovators in one country benefit from the accumulated wisdom generated by R&D experience in the other country. To see the difference that the geographic scope of spillovers makes, let us consider the alternative extreme cases in which productivity in a nation's research labs improves as the result of R&D activity worldwide and in which it improves only as a result of R&D activity that takes place within the nation's borders.[6]

Under the first set of research conditions, $A_I(\cdot) = A_I^*(\cdot) = (n + n^*)/a_I$. Thus, prospective innovators in any country have the same ability to conduct R&D. If goods can be manufactured only in the country where they are invented, then the long-run rates of innovation must be the same in the two countries, and equal to $(1 - \alpha)(L + L^*)/a_I - \alpha\rho$. Comparing this with (5) (and its foreign analog), we see that economic integration speeds up the rate of innovation in both countries. It does so both because each country devotes more labor to the research activity, and because the productivity of the labor in the research lab is higher at every moment in time. It is not so much "trade" that promotes innovation here, but rather the cross-country flow of technical knowledge.

In the opposite extreme case, each country's research ability improves only as the result of its own research experience. Then $A_I(\cdot) = n/a_I$ and $A_I^*(\cdot) = n^*/a_I$. Then, as Feenstra (forthcoming) shows, the effects of trade may not be so benign. The larger

An alternative way to reach the same conclusion is to think of the varieties of differentiated products as intermediate inputs into the production of a single final good, with manufacturing subject to a CES production technology. With this interpretation, u is the quantity of final output, and its growth rate is immediately seen as growth in real output.

[6]See, however, Grossman and Helpman (1990) for a discussion of intermediate cases.

country will introduce new products more rapidly. As a result, its ability to perform research will improve faster than in the smaller country. Prospective innovators in the smaller country will face ever more intense competition from the rapidly expanding set of rivals in the large country, without any corresponding benefit in terms of a more quickly declining research cost. Thus, incentives for innovation in the smaller country will be dulled, and this country will devote fewer resources to R&D than it would in the absence of trade. Trade necessarily retards its growth, though its welfare may rise or fall. The larger country, on the other hand, devotes more resources to R&D as a result of trade, because firms there see their profit opportunities enhanced by the opportunity to sell abroad. The larger country grows faster with trade than without, except in the longest of runs when the difference goes to zero.

The possibility that trade might depress innovative activity in one country is even more evident when the trading economies can engage in an alternative activity that does not generate any technical advance. Suppose, for example, that in addition to inventing and manufacturing horizontally-differentiated products, firms can also produce a "traditional" good under competitive conditions. Let the labor requirement for producing this good be the same in both countries and give households Cobb-Douglas preferences over the traditional good and an aggregate measure of consumption of the differentiated products. Then, if the countries happen to be equal in size, the one with the initial productivity disadvantage in the research lab will come to specialize in producing traditional goods (see Grossman and Helpman (1991, chap.8)).[7] Innovation will cease in this country, because prospective innovators there cannot compete with their more-knowledgeable foreign rivals. This result is of course reminiscent of the one described above, for the case where externalities from learning-by-doing are confined to the country in which they originate.

Some research has examined how the forces of endogenous innovation and the

[7] More precisely, it produces the traditional product and possibly a finite measure of differentiated products, but the latter activity absorbs a negligible fraction of its labor force in the long run.

traditional forces of comparative advantage interact. Consider, for example, a world economy with two factors of production that are used with different intensities to produce a traditional good, to produce a set of horizontally differentiated varieties, and to perform R&D. Call the factors human capital and unskilled labor, and suppose that R&D is the most human capital intensive activity and that traditional manufacturing is the least so. Initially, the trade pattern will be influenced by history. A country that lacks the knowhow to produce but a few differentiated products will be a net importer of the technology-intensive goods, even if the country happens to have factor endowments well suited to creating and using new technology. What happens in the longer run depends upon the geographic scope of the spillovers from the research lab. If these spillovers are national in scope, then a country with an abundance of human capital may find itself trapped in an inefficient pattern of specialization where it continues to produce traditional products because it lacks the research experience to compete in high technology. On the other hand, if the spillovers from R&D are international in reach, then factor endowments fully determine the long-run trading pattern (see Grossman and Helpman (1991, chap. 7)). A country rich in human capital will enjoy a comparative advantage in research, even if it cannot initially manufacture many differentiated products. Over time, it will develop blueprints for many varieties, and will eventually take over as a net exporter of these goods.

Thus far, we have assumed that innovators can fully protect their intellectual property rights. We have imagined patents that are infinitely lived and perfectly airtight. In reality, governments cannot and do not provide such broad protection. For example, all countries limit the duration of their patents. And in many instances it is possible for rival firms to "invent around a patent"; i.e., to manufacture a product that is a close substitute for an innovative good, but sufficiently different so that the holder of the original patent cannot legally prevent the competition.

In recent year, many companies have complained that they find it difficult to enforce their intellectual property rights in jurisdictions beyond their national boundaries. Individuals and firms in less developed countries, especially, have been accused of infringing on intellectual property rights, creating a contentious problem for international trade relations. But the phenomena of imitation in the "South" is more widespread than just the illegal violations of patent laws that sometimes escape government prosecution. Much of the growth in output and exports of the newly industrialized countries can be traced to lawful learning by local entrepreneurs about technologies developed in the "North." Imitation has become a sufficiently important part of the North-South trading landscape, that it deserves to be investigated as a distinctive cause of trade.

Krugman (1979) was the first to develop an international trade model with both innovation and imitation, in his effort to provide theoretical underpinnings for the "product cycle" phenomenon observed by Vernon (1966). He used the specification of product differentiation that has been described above. His model features two regions, which he terms North and South. New products are developed in the North at an exogenous and constant rate g. Technology transfer also occurs exogenously, with firms in the South always learning to produce a given fraction of the goods that only the North knew how to produce the moment before. In other words, if at time t there are $n_N(t)$ products that firms in the South cannot yet produce, then the technology for producing an additional $mn_N(t)dt$ products will become available in the South in the next (short) interval of length dt. We may think of m as the *rate of imitation*; Krugman takes it to be constant.

The exogenous rates of innovation and imitation imply that a fixed fraction $g/(g+m)$ of the differentiated products will be produced in the North in the long run. Evidently, the steady-state share of Northern goods is larger, the larger is the rate of innovation and the smaller the rate of imitation. The pattern of trade is obvious: The North exports "new" goods in exchange for "old" goods. Each good experiences a product life cycle.

One can use the Krugman model to ask whether product-cycle trade of this sort enhances welfare in each region (see Helpman (1993)). Fairly obviously, the trade is beneficial to the South. By assumption, this region would have no access to new products without technology transfer from the North. An increase in the rate of imitation m spells lower prices for a fraction of products at every moment in time (assuming that the wage of the South is strictly lower than the wage of the North, as would be the case in a realistic equilibrium) and an improvement in the South's terms of trade. Less obviously, the North can also benefit from trade of this sort. On the one hand, imitation means a loss of national monopoly power. On the other hand, it means that some goods can be produced with lower-cost labor. Helpman shows that the North must gain when m rises from a very low level, but that it loses when m rises from an initially high level. The overall effect of product-cycle trade on its welfare is therefore ambiguous.[8]

Grossman and Helpman (1991, chap. 11) have extended Krugman's model to allow for endogenous innovation and endogenous imitation. They assume that innovation takes up resources and that each potential innovator compares the expected present value of monopoly profits with the cost of product development. Each extant Northern producer faces a constant risk that its product will be imitated by an entrepreneur in the South. In the event, the innovator and the successful imitator engage in Bertrand (price) competition, which leaves the Northern firm with zero profits in view of its production-cost disadvantage. Of course, when a potential innovator calculates the expected profit from a new product, she takes into account the uncertain duration of the profit stream.

Grossman and Helpman model imitation as analogous to innovation; i.e., as a costly investment activity similar to R&D. Each Southern imitator targets a not-

[8]Helpman also considers an equilibrium where the rate of innovation is endogenous, as new products are developed in the North by profit-seeking entrepreneurs. Here, too, an increase in the (exogenous) rate of imitation will improve welfare in the North, if the initial rate of imitation is slow. Thus, tighter enforcement of intellectual property rights might harm all agents, even in a setting where innovation drives growth.

previously-copied Northern product at random, and uses labor and knowledge (deterministically) to learn the technology. The rate of imitation is such as to equate the present discounted value of Bertrand-duopoly profits with the cost of mastering the technology. The duopoly profits, in turn, are either the same as monopoly profits (if the Northern wage is so high as to make competition from the Northern firm irrelevant) or the profits that derive when the Southern firm perpetually undercuts the cost of its Northern rival by epsilon.

In this setting, the equilibrium rate of innovation is always faster with product-cycle trade than it would be without. This finding is perhaps surprising, because the imitation reduces the average duration of monopoly profits, which implies, *ceterus paribus*, a diminished incentive for innovation. But imitation also reduces the number of products manufactured in the North at any moment in time, which allows surviving producers to hire more labor and make more sales. As a result, the innovative firms earn higher profits for as long as they survive. It turns out that, with CES preferences, the latter effect dominates, and the expected present value of profits in the North rises with the rate of imitation, m. As a result, so does the steady-state rate of innovation.[9] Put differently, the imitation by the South frees some Northern labor from the manufacturing sector, and these resources ultimately find their way into the research lab.

5 Concluding Remark

Now that trade economists are able to handle dynamic models with endogenously evolving technologies, there are many more interesting issues that could be addressed. Does endogenous innovation and imitation spell an inevitable worsening of the income

[9] This result, however, is not a perfectly general one. Grossman and Helpman (1991, chap.12) consider the interaction between Southern imitation and Northern innovation, when the latter entails the discovery of superior varieties of vertically-differentiated products. In this setting, they show that product-cycle trade can slow the steady-state rate of growth.

distribution in the currently-rich countries? How does trade policy affect the direction and pace of technological change? What are the growth implications of the increasing globalization of the production process? When do firms choose to make direct foreign investments, and how do these investments affect the local rate of learning in the host country? What will be the place of the transition economies of Eastern Europe in the long-run pattern of innovation and trade? These and other questions are the focus of fascinating, ongoing research.

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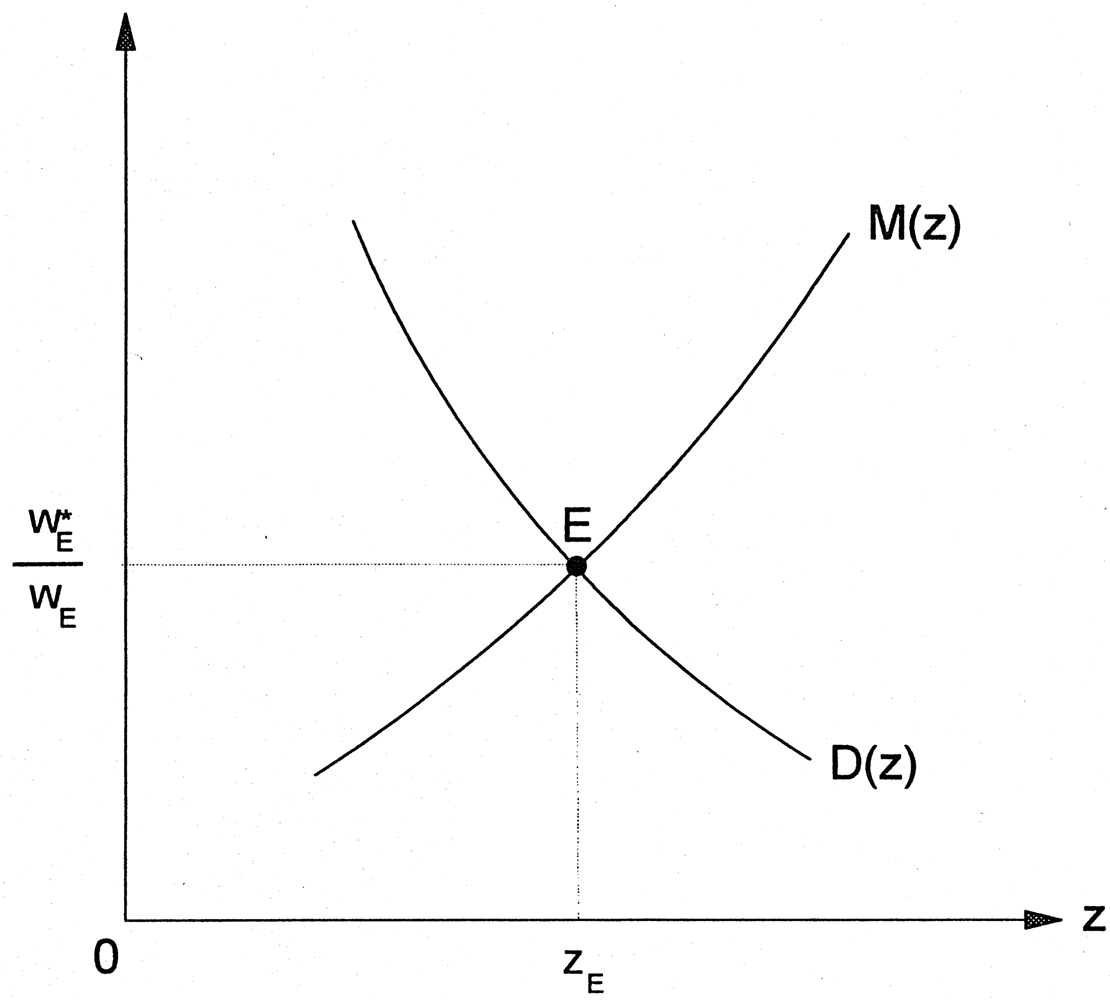
Figure 1



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