Boston University

Institute for Economic Development

A Rising Tide Raises All Ships: Trade and Diffusion as Conduits of Growth

Jonathan Eaton and Samuel Kortum

IED Discussion Paper Series
Number 82
June 1996

A Rising Tide Raises All Ships:

Trade and Diffusion as Conduits of Growth

Jonathan Eaton and Samuel Kortum[1]
Boston University and NBER

June 1996

[1]Department of Economcis, Boston University, 270 Bay State Road, Boston, MA 02215, USA. e-mail: jeaton@bu.edu, kortum@bu.edu.

Abstract

Measures of innovative activity show it to be concentrated in a small number of countries. Yet the benefits of innovation are experienced broadly. International trade is one conduit through which the benefits of innovation in one country can flow abroad. Technological diffusion is another. In this paper we develop a model of technology and trade to explore these alternatives. An implication of the model is that increased trade will itself affect observed productivity as well as real wages. We analyse data on trade, research, and productivity from five major industrial economies in light of the model. Trade alone can explain observed cross-sectional patterns of innovation and productivity quite well. Nonetheless, trade fails to explain why productivity growth is as high in countries where less inventive activity occurs. An implication is that diffusion rather than trade is responsible for the similarity in growth rates across major industrial countries.

1 Introduction

Technology can flow from one country to another through at least two conduits. One is the diffusion of technological knowledge itself. Another is the exchange of goods embodying technological advances.[1]

Our previous work (Eaton and Kortum (1994, 1996, 1997)) focussed purely on the first mechanism. Coe and Helpman (1995) take the opposite tack and relate technology flows to trade flows. Neither provides an encompassing framework in which both mechanisms were allowed to operate. In this paper we develop a model of trade and technology to examine theoretically and empirically the connections among innovation, productivity, and trade.[2]

Empirical work does suggest a connection between technology flows and trade. In Eaton and Kortum (1996) we find that flows of ideas (estimated on the basis of a model of world growth making use of data on international productivity and patenting) are in part explained by trade patterns, although the elasticity is small. Ben-David (1993) provides enticing evidence that trade leads to convergence of income levels. A model to draw out these connections is not provided in either case, however.

Our purpose here is to develop a model of trade and productivity to examine the connections between the two. A major implication of our analysis is that not only does productivity have important implications for trade (as suggested by Ricardo), but that trade can have implications for observed productivity as well. Indeed, trade can lead to convergence of countries' productivity levels even though

[1] Grossman and Helpman (1995) survey the literature on technology and trade.

[2] Keller (1996) explores Coe and Helpman's results further, showing that trade patterns do not play as important a role as the original analysis would suggest.

they exchange no ideas. The reason is that trade pushes countries to concentrate on those activities that they do best, so that trade will tend to raise observed productivity everywhere.. Given population, the effect is more pronounced in backward countries, whose measured productivity may then exaggerate their true command of technology.

Our model implies that trade barriers will force average productivity to be higher in industries that serve export markets relative to those that serve the home market. Higher productivity is needed to offset these barriers. This result is consistent with other evidence on the relationship between productivity and trade. For example, Bernard and Jensen (1996) find that firms that export have higher productivity than other firms in the United States. Moreover, they find that this relationship is largely explained by selection, i.e., only good firms can survive in export markets.

While reducing trade barriers allows less efficient firms to export, competition from abroad drives out the least efficient producers for the domestic market. The net effect is that lower trade barriers generally enhance productivity. The idea that global exposure is good for productivity is in fact a major theme of the McKinsey Global Institute's (1993) monumental study of manufacturing productivity in Germany, Japan, and the United States.

Section 2 which follows presents the model itself. Section 3 calibrates the model to the five leading research economies, and provides rough calculations of the gains from trade and technological advance. The final section discusses the implications of our model for the question raised in our title: Does trade by itself provide an adequate explanation for the patterns of inventive activity and productivity growth across countries over time?

2 Productivity and Trade

Consider a world consisting of $n = 1, \ldots, N$ countries and a continuum of goods indexed on the unit interval, which in principle can be produced in any country. A worker in country i can produce $z_i(j)$ units of good j. Hence the cost of producing a unit of that good in that country is $w_i/z_i(j)$ where w_i is the wage there.

2.1 The domestic technological frontier

We first characterize what a country can do on its own. We describe a country's state of productive knowledge in terms of the distribution over goods of the parameter z,which we refer to as the domestic technological frontier. We think of this frontier as reflecting the history of ideas about producing goods in that country, with $z(j)$ the best idea for producing good j. We make the specific assumption that the quality of an individual idea for producing a good is a random variable Q drawn from the cumulative Pareto distribution, $F(q) = 1 - q^{-\theta}$.[3] The good j to which the idea applies is drawn from the uniform distribution on $[0, 1]$.[4] We use μ_n to denote the stock of ideas that have arrived in country n. As we show in Eaton and Kortum (1994) the cumulative distribution of the state of the art given

[3]Bental and Peled (1992) and Kortum (1997) also use the Pareto distribution to characterize the pool of undiscovered techniques from which researchers draw. The Pareto distribution has the convenient feature that, if we truncate the distribution at some level z, then the random variable Q/z (≥ 1) inherits the Pareto distribution. The average inventive step implied by the distribution is $\theta_s/(\theta_s - 1)$. Hence sectors where inventions are more potent have smaller θ_s's.

[4]The continuum allows us to abstract from randomness in aggregate outcomes. To simplify further, we ignore the possibility that research could be aimed at improving the quality of a specific good.

μ_n is then:[5]

$$H(z|\mu_n) = e^{-\mu_n z^{-\theta}} \tag{1}$$

Note that the domestic technological frontier in a country depends only on the total stock of ideas there regardless of where they came from or when they arrived. A higher value of θ implies less heterogeneity in quality across goods. A critical simplifying assumption is that the distribution of productivities is independent across countries.

2.2 International trade

We make Samuelson's standard and convenient "iceberg" assumption about transport costs, that a fraction $1/d_{ni}$ units of what country i exports arrives in country n. We normalize $d_{nn} = 1$ for all n.[6]

Assuming perfect competition, the cost of good j in country n imported from country i is $p_{ni}(j) = w_i d_{ni}/z_i(j)$, where we measure the wage in each country in terms of final output in that country. The fraction of country i's goods whose price in country n would exceed p is $H(c_{ni}/p|\mu_i)$, where $c_{ni} = w_i d_{ni}$. Let $p_n(j)$ denote the lowest price for good j available in country n. The distribution of $p_n(j)$ across goods is given by:

$$1 - \prod_{i=1}^{N} H(c_{ni}/p|\mu_i) = 1 - e^{-\tilde{\mu}_n p^{\theta}} = 1 - H(p^{-1}|\tilde{\mu}_n). \tag{2}$$

[5] That the best available technology for producing each good has this distribution across goods follows directly from our assumption that the qualities of ideas are drawn from a Pareto distribution. However, its functional form is one of only three possible limiting distributions of extrema of random sampling. See, for example, Billingsley (1986).

[6] See Krugman (1995) for a discussion of this assumption.

Here:

$$\bar{\mu}_n = \sum_{i=1}^{N} \mu_i c_{ni}^{-\theta},$$

is the sum of each source country's stock of technologies adjusted by their wage cost and the cost of transporting to country n. This term, which we can think of as the trade-augmented stock of knowledge, shows how the possibility of international trade enlarges the stock of technologies available domestically with those available from other countries. Note that if transport costs are zero then this stock, and the consequent price distribution, is the same for all countries, while if international transport costs are prohibitive it reduces to $\mu_n w_n^{-\theta}$.

Remarkably, the distribution of $p_n(j)$ is the same as the distribution of $p_{ni}(j)$ conditional on $p_{ni}(j) = p_n(j)$. That is, the goods actually sold by any country i in country n have the price distribution 2, regardless of source. The probability that a good from country i will be the cheapest one available in country n is $\mu_i c_{ni}^{-\theta}/\bar{\mu}_n$,which corresponds to the fraction of goods used by country n provided by country i.[7] Hence the fraction of goods provided by each source country corresponds to that country's contribution to the destination country's trade-augmented stock of knowledge..

[7]The distribution of prices in country n of goods produced in countries other than i is $1 - H(p^{-1}|\bar{\mu}_{n,-i})$ where $\tilde{\mu}_{n,-i} = \tilde{\mu}_n - \mu_i c_{ni}^{-\theta}$. The probability that a good from country i is imported by n, given that its price is p, is the probability that no other country provides the good more cheaply, or $H(p^{-1}|\bar{\mu}_{n,-i})$. From 1, goods potentially imported from country i would have a cost in country n with density given by $f_{n,i}(p|\mu_i) = \frac{d}{dp}[1 - H(c_{ni}/p|\mu_i)] = \theta p^{\theta-1}\mu_i c_{ni}^{-\theta} \exp(-\mu_i p^{\theta} c_{ni}^{-\theta})$. The probability that a good from i is the cheapest available in country n is therefore $\int_0^{\infty} f_{n,i}(p|\mu_i) H(p^{-1}|\bar{\mu}_{n,-i}) dp = \mu_i c_{ni}^{-\theta}/\bar{\mu}_n$. The prices of goods actually sold by country i in country n have density $f_{n,i}(p|\mu_i) H(p^{-1}|\bar{\mu}_{n,-i}) / \left(\mu_i c_{ni}^{-\theta}/\bar{\mu}_n\right)$. which, by equation 2 is also the density of prices in country n.

To derive implications about production and trade volumes we need to specify preferences. We assume that the utility of a representative individual in any country is Cobb-Douglas with each good having equal share,

$$u_n = \int_0^1 \ln[x(j)]dj, \tag{3}$$

where $x(j)$ is consumption of good j. An implication is that aggregate spending on each good equals income Y. Aggregate income in country n equals wage payments, $Y_n = w_n L_n$, where L_n is labor supply in country n. Hence spending on goods from country i is just the measure of goods imported from there times income, or :

$$X_{ni} = (w_i d_{ni})^{-\theta} \left(\frac{\mu_i}{\bar{\mu}_n}\right) w_n L_n \tag{4}$$

This relationship links knowledge and export share: Given wages and transport costs, countries with larger μ's will have larger market shares while, given knowledge, countries with higher factor costs will have lower market shares. Given that country n purchases a particular good j from country i, then the physical amount that it purchases will be:

$$x_{ni}(j) = Y_n/p_{ni}(j) = z_i(j) w_n L_n / c_{ni},$$

which will require employing $d_{ni} x_{ni}(j)/z_i(j) = w_n L_n / w_n$ workers.[8]

[8]Note that even though our structure is Cobb-Douglas, countries face higher than unit elastic demand for their exports. An increase in unit cost reduces demand through two channels: The first is the unit elastic effect on the demand for each good still purchased. The second is through the loss in share of inputs provided. Here our model bears a close resemblence to the analysis in Dornbusch, Fischer, and Samuelson (1977).

2.3 Factor-Market Equilibrium

Total employment in country i for production of exports to country n is just $L_{ni} = X_{ni}/w_i$. Summing across countries gives total demand for country i's labor. Equating demand to supply gives the conditions for labor-market equilibrium in each country:

$$L_i = \frac{\mu_i}{w_i^{1+\theta}} \sum_{n=1}^{N} \frac{d_{ni}^{-\theta} w_n L_n}{\bar{\mu}_n} = \frac{\mu_i}{w_i^{1+\theta}} \sum_{n=1}^{N} \frac{d_{ni}^{-\theta} w_n L_n}{\sum_{k=1}^{N} \mu_k (w_k d_{nk})^{-\theta}} \quad i = 1, ..., N \qquad (5)$$

By Walras' Law, one equation is redundant. Hence this set of equations determines $N-1$ relative wages as functions of the labor forces, stocks of knowledge, and transport costs.

While 5 constitutes a highly-nonlinear set of equations, note that they are homogeneous of degree 0 both in all countries' labor forces and in all countries' stocks of knowledge. Hence *relative* wages are not affected by proportional increases in labor forces or in technologies across all countries.

For reasons that are familiar to students of the Ricardian model of trade, the effects of trade on relative wages depend on relative country size: Smaller countries gain relatively more from trade. A useful benchmark case extracts from this effect by considering countries with identical levels of autarky GDP, which is proportional to $\mu^{1/\theta}L$. In this case, with a common cross-country transport cost d, relative real wages are proportional to $\mu_i^{1/\theta}$,which can seen from substitution into 5.

2.4 Prices and Real Wages

Since the costs of goods varies across countries, so does the cost of living. The price index appropriate to our utility function is simply the geometric mean of prices, which is proportional to:

$$P_n = \widetilde{\mu}_n^{-1/\theta}. \tag{6}$$

The real wage in country n, which measures the standard of living there, is w_n/P_n. The numerator reflects productive efficiency as well the accessibility of export markets. The denominator reflects access to cheap goods. This distinction breaks down in the special cases of autarky (all d_{ni}'s infinite for $n \neq i$) and free trade (all d_{ni}'s one). Under autarky the system of equations 5 is vacuous and the real wage, determined by 6, is given by $w_n/P_n = \mu_n^{1/\theta}$. Under free trade, $P_n = P$ since $\widetilde{\mu}_n = \widetilde{\mu}$ for all n. Note also that in this special case we can rearrange 5 as:

$$Y_i = \phi_i Y$$

where Y is world income and

$$\phi_i = \frac{\mu_i w_i^{-\theta}}{\sum_{n=1}^{N} \mu_n w_n^{-\theta}} = \mu_i \left(\frac{w_i}{P}\right)^{-\theta}.$$

Under free trade, a country's share of world income depends on its stock of knowledge relative to its real wage.

Except in these limiting cases, however, the concepts of consumption per worker, as reflected by the real wage, and production per worker diverge. We now turn to worker productivity.

In general, it is hard to infer much analytically about the role of technology and transport costs from these expressions. Hence we provide a numerical analysis below. When countries are of equal size (as measured by $\mu^{1/\theta}L$) with a common cross-country transport parameter d the expression for the real wage reduces to:

$$w_i/P = \mu_i^{1/\theta} \left[1 + (N-1)d^{-\theta}\right]^{1/\theta}.$$

Increasing a country's own stock of knowledge and its number of trading partners raises its real wage, as does reducing trade barriers.

2.5 Productivity

A natural measure of productivity in a country is the average number of units of goods produced per worker. A question is whether we should look at the average of what country i would produce under autarky, or at what it actually produces given its patterns of trade. The first depends on the stock of ideas available to country i, μ_i. Taking the geometric average over the state of the art technologies available in country i, from equation (1) productivity is proportional to $\mu_i^{1/\theta}$. This concept ignores the fact that those goods that the country is relatively poor at producing it will import instead, while it will employ more workers to produce those goods where it is relatively most advanced. The second concept, which is closer to what is actually measured in available productivity statistics, takes into account the actual allocation of labor across the different goods.

To construct this second measure, we observe that the prices of goods sold by country i in country n have the distribution given by (2) above. The productivities corresponding to these prices have distribution $H(z/c_{ni}|\tilde{\mu}_n)$. The average productivity of goods sold by country i to country n is consequently proportional to $\tilde{\mu}_n^{1/\theta} w_i d_{ni}$. Observe that the more expensive it is to ship goods to country n's market, the more productive country i must be in making those goods in order to compete there. Country n's weight in the sales of country i,which is also the share of country i's labor used to produce for country n, is $\varphi_{ni} = d_{ni}^{-\theta}\tilde{\mu}_n^{-1}Y_n / \left[\sum_{j=1}^{N} d_{ji}^{-\theta}\tilde{\mu}_j^{-1}Y_j\right]$. Combining the two elements to form a geometric average we get as an index of overall productivity:

$$A_i = w_i \prod_{n=1}^{N} \left(\tilde{\mu}_n^{1/\theta} d_{ni} \right)^{\varphi_{ni}}. \tag{7}$$

In the polar case of autarky, this measure reduces to $\mu_i^{1/\theta}$. At the other pole of free trade it becomes $w_i \tilde{\mu}^{1/\theta}$, which is also the real wage in that case. At either of these poles, relative productivities are exactly proportional to the domestic stocks of knowledge. This is not the case in general, however, since countries that are more distant from their markets will have lower wages relative to productivity in order to compensate for transport costs.

Where countries are identical in size as measured by autarky GDP (proportional to $\mu^{1/\theta} L$) and where d is common to all cross-national country pairs this expression reduces to:

$$A_i = \mu_i^{1/\theta} \left[1 + (N-1) d^{-\theta} \right]^{1/\theta} d^{(N-1)/(d^\theta + N - 1)}.$$

which is decreasing in d. Hence, increasing transport costs unambiguously lowers both the real wage and measured productivity. Increased transport costs force a country to specialize in a more select set of goods in which it is on average more productive in serving export markets. But reduced exposure to foreign competition allows less productive domestic industries to serve the domestic market, which is the effect that dominates. From a situation of unimpeded trade ($d = 1$), the real wage falls faster than productivity as transport costs rise, since workers have to pay more for the goods that they import. As transport costs become large enough to bring the world towards autarky, however, however, productivity levels converge to the autarky real wage.

2.6 Asymmetric Countries

More interesting are situations in which countries differ in terms of their overall size. Unfortunately we cannot obtain closed-form solutions for this case. We instead turn to numerical simulations to explore how international trade between unequally-sized countries influences the relationship between a country's stock of technical knowledge and its measured productivity and real wage.

To illustrate the effect of openness on relative wages and productivity we consider a world of two countries with equal labor forces but in which one country (country 1), under autarky would have a 20 per cent productivity advantage over the other (country 2). We fix the parameter $\theta = 2$, based on estimates from our other work (Eaton and Kortum (1994)). To illustrate the effects of openness we consider values of d ranging from 10 (at which countries buy 99 per cent of their output at home) to 1 (at which point international trade is costless). Figure 1 illustrates the effects of varying d over this range on: (1) the fraction of domestic output sold at home in each country (the two descending curves), (2) productivity levels in each country (the top and second-from-the-bottom ascending curves), and (3) the real wage in each country (the second-from-the-top and bottom ascending curves). Note that:

1. As transport costs fall the real wage and measured productivity generally rise in both countries (although productivity in country 2 falls slightly as d approaches unity), by a factor of about 2 for country 1 and 2.4 for country 2.

2. As with countries of equal size, lowering transport costs affects productivity earlier than it affects the real wage. Real wage gains are slow to emerge

until d has reached about 2, at which point trade is about 20 per cent of output. At that point there is a dramatic effect of openness on real wages. In contrast, productivity rises more steadily over the range of transport costs that we consider. Over the whole range from essential autarky to free trade, for any given country, the real wage and productivity rise by exactly the same amount.

3. In contrast with counties of equal size, as transport costs fall, cross-country differentials in real wages and productivity decline in percentage terms, illustrating how trade can convey the benefits of one country's more advanced technology to a less advanced country with equal physical resources. An implication is that productivity measures may give a small, open country the appearance of having more technological sophistication than it really possesses. Only under autarky would productivity measures fully reveal a country's state of technology as measured by μ.

Going back to Ricardo, economists have examined the implications of productivity for trade. This model illustrates the implications of trade for observed productivity. Since trade allows a smaller country to specialize in a narrower range of activities, it can be more selective in the ones that it chooses, so can appear more advanced than a larger country with equal know how.

3 An Application to Five Countries

Can our model explain observed trade and productivity patterns, and if it can, what does it say about the impact of trade on real wages and productivity? We examine the situation of 5 countries, the United States, Germany, France, the United Kingdom, and Japan, in light of our model.

To see how well trade alone can explain productivity patterns we wish to examine a world in which there is no technology diffusion between countries. Hence knowledge stocks would solely reflect ideas arising from domestic research. For this purpose we take the domestic *R&D* stocks calculated by Coe and Helpman (1995) to represent a country's stock of technology, along with (approximate) labor forces.[9] As a ratio to the U.S. level, these data are as follows:

Country	*R&D Stock*	*Labor Force*
United States	1.00	1.00
Germany	.17	.25
France	.11	.25
United Kingdom	.14	.25
Japan	.25	.50

Note that the distribution of *R&D* stocks is much more skewed than that of labor forces. As we show below, if *R&D* stocks correspond to the μ's of our model, with our estimate of $\theta = 2$, we would predict, under autarky, a much more unequal distribution of productivity levels than what we actually observe. A higher value of θ would, of course, imply more equality, but gets us into trouble when we also try to predict trade volumes.

3.1 A Crude Calibration

We choose transport costs in order to approximate relative import shares among these five countries, with the diagonal representing 1 minus the total import share

[9]Coe and Helpman (1995) derive this measure from domestic *R&D* expenditures using a perpetual inventory model. While our earlier work (Eaton and Kortum, 1994) provided alternative estimates of μ, these estimates were based on a model in which international technology diffusion occurred.

(from Coe and Helpman (1995)). We set two values of d, one applying to trade within the Europe and Pacific regions, ($d^{intra} = 3$) and another to trade between these regions ($d^{inter} = 5$). Again we set $\theta = 2$. Table 1 reports the amount of trade predicted by these parameter estimates compared with actual trade (in parentheses).[10]

Destination\Source	*U.S.A.*	*Germany*	*France*	*U.K.*	*Japan*
United States	.91 (.89)	.013 (.018)	.012 (.010)	.013 (.013)	.055 (.068)
Germany	.079 (.57)	.73 (.75)	.073 (.092)	.078 (.053)	.043 (.048)
France	.084 (.046)	.086 (.12)	.79 (.77)	.083 (.043)	.046 (.025)
United States	.081 (.070)	.083 (.10)	.075 (.060)	.72 (.73)	.044 (.037)
Japan	.16 (.073)	.021 (.013)	.019 (.088)	.020 (.007)	.78 (.90)

Overall, the model captures observed trade patterns surprisingly well given the crudeness of the calibration. We do, however, overstate Japan's import levels substantially.[11]

The relative productivities predicted by our model, compared with productivity (value added per hour in manufacturing in 1990) (from van Ark (1995)) are as follows:

Country	*predicted*	*actual*	*autarky*
United States	1.00	(1.00)	1.00
Germany	.79	(.86)	.41
France	.69	(.91)	.33
United Kingdom	.75	(.66)	.37
Japan	.76	(.78).	.50

[10]Obviously we are ignoring the rest of the world. We do so by allocating each country's trade with the rest of the world to the four other countries in proportion to actual trade with the country.

[11]Increasing the cost of importing into Japan to 5 noticably improved the fit, but we preferred to stick with symmetric transport costs.

In the third column we give the productivity levels predicted by the model in the case where d is infinite for all cross-country pairs.

The main thing to note is that introducing trade into a model with no international technology diffusion goes a long way toward bringing predicted productivity levels into line with actual ones. The distribution of productivity under autarky would be extremely unequal compared with actual measures while our model implies about the right amount of dispersion. Obviously, under any assumptions about d our model has trouble explaining why France is as productive as it is, since its *R&D* stock is so small. Similarly it has trouble understanding why the United Kingdom is not more productive.

3.2 The Gains from Trade

With parameter estimates in hand, we can ask how different the world would be if international trade barriers were eliminated, and if it were completely closed to international trade. We report below the absolute productivity levels that would emerge in each case. We also report the real wage under our base case. (In the cases of autarky and free trade, the real wage and productivity measures coincide.)

Country	*Autarky*	*Base prod.*	*Base wage*	*Free Trade*
United States	1.00	1.22	1.05	1.42
Germany	.41	.96	.48	1.24
France	.33	.85	.40	1.08
United Kingdom	.37	.92	.45	1.18
Japan	.50	.93	.56	1.12

Our model suggests that actual productivity measures are more than half way toward their free trade levels from an initial autarky position. For the real wage the opposite is the case. Further movement toward free trade would further concentrate the distribution of productivity somewhat, with more pronounced implications for real wage inequality.

3.3 The Gains from Innovation

What are the benefits of technological advance, and how are they shared? We consider the effect of increasing by 20 per cent the stock of technological knowledge in the United States (the largest country where the stock is already highest) and in France (one of the three smallest where the stock is the lowest). The implications for productivity and the real wage are as follows:

	base	*case*	*raise*	*USA*	*raise*	*France*
Country	*prod*	*rw*	*prod.*	*rw*	*prod*	*rw*
United States	1.22	1.05	1.33	1.15	1.22	1.05
Germany	.96	.48	.98	.48	.97	.48
France	.85	.40	.86	.40	.90	.43
United Kingdom	.92	.45	.93	.45	.92	.45
Japan	.93	.56	.95	.57	.93	.57

Starting with the United States, the 20 per cent increase in the stock of knowledge translates into an approximately 10 per cent increase in productivity and the real wage, what one would predict in the case of autarky given our value of $\theta = 2$. Other countries experience about a 1-2 per cent gain in productivity and only a negligible gain in real wage.

The effect of the change in France is much less pronounced. The French themselves get about a 5 per cent productivity gain and a 3 per cent gain in the real wage. The effect elsewhere is negligible.

4 Conclusion: Trade or Diffusion?

Our model's relative success in explaining observed productivity and trade levels on the basis of measured *R&D* inputs might lead us to conclude that diffusion is not needed to fit the facts. As far as explaining levels of international productivity this may be the case. However, if one relies on trade as the sole vessel to convey technological advances across countries, one runs aground trying to explain why countries that do very little research grow, on average, as fast as the major research economies.

An implication of our expressions for the real wage and productivity is that these magnitudes will grow faster in countries whose research efforts are greater or growing at faster rates. In fact, productivity growth among our 5 countries has not differed that much in the last decade, and there is little evidence that major research economies have been growing much faster than the others. For this reason we think that technological diffusion is central to any story that seeks to explain comparative productivity growth.

In previous work we have developed a series of models of innovation and diffusion with the implication that, in steady state, countries all grow at the same rate, with each country's relative income level determined by its ability to absorb innovations from at home and abroad. This work ignored international trade, however. The analysis in this paper indicates that trade cannot substitute for diffusion as the vessel transporting innovations abroad. Rather, it shows how productivity and technological diffusion cannot be studied in isolation from their interactions with international trade.

References

1. van Ark, B. (1995), "Productivity and Competitiveness in Manufacturing: A Comparison of Europe, Japan, and the United States," forthcoming in *International Productivity Differences: Measurement and Explanation.* K. Wagner and B. van Ark, editors. Amsterdam: North-Holland.

2. Ben-David, D. (1993), "Equalizing Exchange: Trade Liberalization and Income Convergence" *Quarterly Journal of Economics*: 108: 653-679.

3. Bental, B. and D. Peled (1995), "Endogenous Technical Progress and Growth: A Search Theoretic Approach." *International Economic Review.*

4. Billingsley, P. (1986), *Probability and Measure,* 2nd edition. New York: John Wiley & Sons.

5. Coe, D.T. and E. Helpman (1995), "International R&D Spillovers," *European Economic Review,* 39: 859-887.

6. Dornbusch, R., S. Fischer, and P.A. Samuelson (1977), "Comparative Advantage, Trade, and Payments in a Ricardian Model with a Continuum of Goods," *American Economic Review,* 67: 823-839.

7. Eaton, J. and S. Kortum (1994), "International Patenting and Technology Diffusion," *NBER Working Paper No. 4931.*

8. Eaton, J. and S. Kortum (1996), "Trade in Ideas: Productivity and Patenting in the OECD," *Journal of International Economics,* 40: 251-278.

9. Eaton, J. and S. Kortum (1997), "Engines of Growth: Domestic and Foreign Sources of Innovation," *Japan and the World Economy,* 9: 235-259.

10. Grossman, G.M. and E. Helpman (1991), "Quality Ladders and Product Cycles," *Quarterly Journal of Economics,* 106: 557-586.

11. Grossman, G.H. and E. Helpman (1995), "Technology and Trade," in G.M. Grossman and K. Rogoff, editors, *The Handbook of International Economics, Volume III.* Amsterdam: North-Holland.

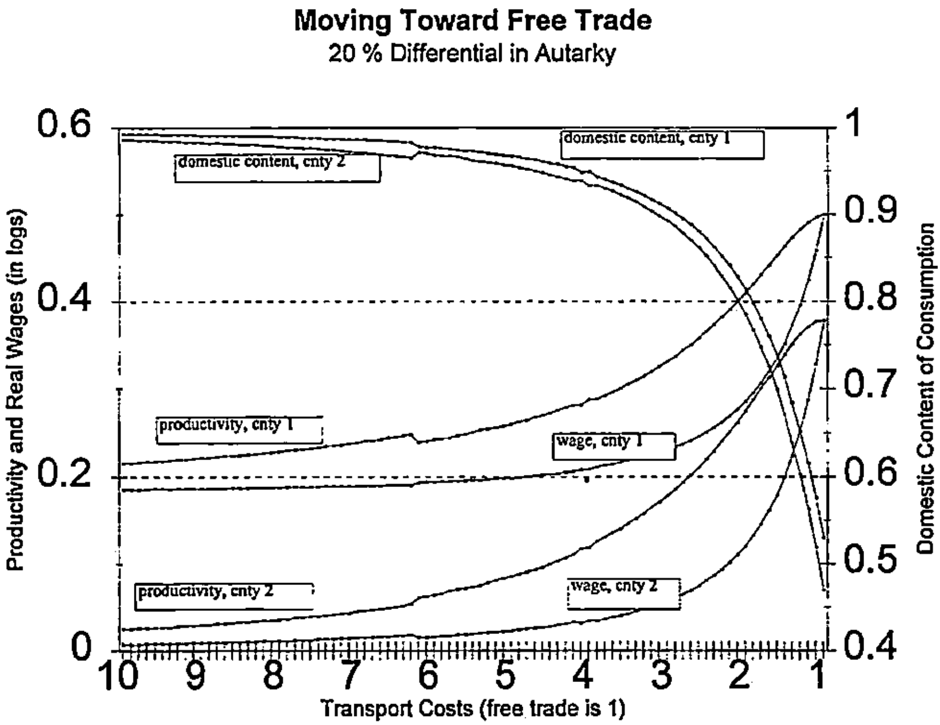
12. Keller, W. (1996), "Are International R&D Spillovers Trade Related? Analyzing Spillovers among Randomly Matched Trade Partners" mimeo, University of Wisconsin.

13. Kortum, S. (1997), "Research, Patenting, and Technological Change," *Econometrica,* 65: 1389-1419.

14. Krugman, P.R. (1995), "Increasing Returns, Imperfect Competition, and the Positive Theory of International Trade," in G.M. Grossman and K. Rogoff, editors, *The Handbook of International Economics, Volume III.* Amsterdam: North-Holland.

15. McKinsey Global Institute (1993), *Manufacturing Productivity,* Washington, DC.

16. Summers, R. and A. Heston (1991), "The Penn World Table (Mark V): An Expanded Set of International Comparisons," *Quarterly Journal of Economics,* 106: 327-368.


Moving Toward Free Trade
20 % Differential in Autarky
0.6
0.4
0.2
0
1
0.9
0.8
0.7
0.6
0.5
0.4
10
9
8
7
6
5
4
3
2
1
Productivity and Real Wages (in logs)
Domestic Content of Consumption
Transport Costs (free trade is 1)
domestic content, cnty 1
domestic content, cnty 2
productivity, cnty 1
wage, cnty 1
productivity, cnty 2
wage, cnty 2