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INNOVATION, DIFFUSION, AND TRADE

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ABSTRACT

We explore the determinants of research specialization across countries and its consequences for relative wages. Using a dynamic Ricardian model we examine the effects of faster international technology diffusion and lower trade barriers on the incentive to innovate. In the absence of any diffusion at all, countries devote the same share of resources toward research regardless of trade barriers or research productivity. As long as trade barriers are not too high, faster diffusion shifts research activity toward the country that does it better. This shift in research activity raises the relative wage there. It can even mean that, with more diffusion, the country better at research ends up with a larger share of technologies in its exclusive domain.

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1 Introduction

Research indicators reveal strong and consistent patterns of specialization in innovation. Table 1 reports the number of business sector research scientists per thousand workers in industry among OECD and selected non-OECD members, in descending order of research intensity. By virtue of their size and high research intensity, most research is done in the United States and Japan. Research-intensive countries tend to be wealthy, but some wealthy countries, such as Australia and Italy, don't do much private sector research. Moreover, with the exception of the recent emergence of Finland as a research center, patterns of research specialization have remained very stable over time. The countries contributing the most to innovation now are mostly the same ones as half a century ago.[1]

What characteristics of a country determine specialization in research, and how does openness affect the incentive to innovate? This question has been posed in a number of contexts in which openness has meant different things. It could refer to the absence of trade barriers, but also to the absence of barriers to the diffusion of ideas themselves. While trade allows consumers in another country to benefit from an innovation by importing a good that embodies the idea, technology diffusion allows them to benefit through local production making use of that idea. Expanding one conduit or the other may have very different implications for the incentive to innovate in either location. A related question is the role of country characteristics in determining international patterns of specialization in innovative activity. Do large countries, for example, naturally do more research because their inventors have quicker access to a large internal market?

The literature on international technology diffusion is large. Keller (2004) provides a comprehensive survey. A number of papers have looked at the effect of one type of openness taking the degree of openness of the other type as given. Examples are Helpman (1993), Eaton, Gutierrez, and Kortum (1998), Eaton and Kortum (henceforth EK) (1999), and EK

[1] Eaton, Gutierrez, and Kortum (1998), Eaton and Kortum (1999), Eaton and Kortum (2001a) provide further analysis of research indicators across countries and over time.

(2001b). Helpman (1993), for example, finds that, with no trade costs, faster diffusion to an imitating country can spur innovation by reducing the wage, and hence the cost of innovation, in the innovating country. In a model with no diffusion, EK (2001b), find that the degree of openness to trade has no effect on innovative activity: While exporting increases the size of the market that a successful innovator can capture, it also means that an innovator faces a higher hurdle in terms of competition from abroad through imports. The two forces exactly offset each other. In their model, unlike Helpman's, all countries engage in innovative activity.

To explore these issues further we develop a two-region model, like Helpman's, of innovation and diffusion. In contrast to much of the literature, innovation can in principle take place in either region, although research productivities may differ. Ideas can diffuse between locations, but with a lag. We allow for an arbitrary level of trade barriers, with costless trade a special case. We then explore the incentives to innovate under different assumptions about the speed of diffusion and about the magnitude of trade barriers.

While our model could be extended to analyze the implications of imperfect protection of intellectual property, that is not our purpose here. To isolate the effects of geographical barriers to the movement of goods and ideas, we make the simplest assumption for our purposes, that innovators can appropriate the entire returns to their innovation at home and abroad.[2]

We proceed as follows:

Section 2 develops a static two-country model of technology, production, and trade along the lines of the Ricardian model developed in EK (2002). In their many-country model, the distribution of technologies is treated as independent from country to country. Such an outcome is consistent, for example, with a world in which each country relies on its own innovations for production, or one in which an innovation applying to a particular good in one country applies to some different good where it diffuses. Here we consider the more natural, but much more complicated, case in which an innovation, when it diffuses, applies to the same

[2] The role of intellectual property protection was a main concern of Helpman (1993). The issue has been revisited recently by Gancia (2003) and by Dinopoulos and Segerstrom (2005).

good. This extension forces us to distinguish between innovations that are in the exclusive domain of the innovating country, and those that have diffused to a common pool that both countries can access. Because of the many different situations that can arise, we limit ourselves to a two-country case. Even here we need to distinguish among situations in which: (i) one country uses only those technologies that are exclusive to it, leaving the common technologies to the other country, (ii) both countries use common technologies, with one country exporting goods produced using these technologies to the other country, and (iii) both countries use common technologies, with no trade in goods produced using them. The first case replicates the situation in EK (2002), since the technologies that each country actually uses are drawn from independent distributions. Diffusion has no impact on the extent of trade. In the second two cases, diffusion substitutes for trade, as at least a range of the goods produced with the common technology are nontraded. Nontradedness arises not because transport costs for these goods are higher, but because similarities in efficiency between countries have eliminated any scope for exploiting comparative advantage.

Section 3 introduces simple dynamics into the analysis. Each country innovates at an exogenous rate, and ideas diffuse from one to another at exogenous rates. The processes of innovation and diffusion generate a world steady-state growth rate in which the two countries, depending on their abilities to innovate and to absorb ideas from abroad, have (except by coincidence) different relative income levels. The framework can deliver "product cycles," as in Krugman (1979), in which the innovator initially exports the good using the technology it has developed, but later imports it once the technology has diffused abroad. In our model other outcomes are also possible. If the innovation is sufficiently small, before diffusion, the other country may continue to produce the good on its own using inferior technology rather than import the good from the innovator. In fact, its own technology could even be superior, so that the innovation is never useful outside the country of innovation.

Section 4 endogenizes inventive activity. It first calculates the value of ideas in each country, which determine the returns to innovation. The trade-off between the returns to innovation and to production governs the extent of inventive activity in each country. We consider the role of openness in the form of (i) lower trade barriers and (ii) faster diffusion on inventive activity in each country. A special case is no diffusion, returning us to EK (2001): Each country allocates the same share of resources to invention regardless of its size or research productivity. Turning to the other extreme of immediate diffusion, we find that the same result emerges if the trade barrier exceeds the ratio of research productivities. But if the trade barrier is lower than the ratio of research productivities, the more efficient researcher specializes in innovation along Ricardian lines.

Section 5 offers some concluding remarks.

2 A Model of Technology, Production, and Trade

Our production structure is Ricardian. Following Dornbusch, Fischer, and Samuelson (1977, henceforth DFS), we consider a world with a unit continuum of goods, which we label by $j \in [0, 1]$. There are two countries, which we label N (for North) and S (for South). Each country has a set of available technologies for making each of the goods on the continuum. Some technologies, denoted N, are available only to the North while another set, S, are available exclusively to the South. A third set C are commonly available. A technology is the ability to produce $z_i(j)$ units of good j with one worker, where, depending on which type of technology we are talking about, $i = N, S, C$. (It is convenient for us to use i to index both the three types of technologies $i = N, S, C$ and the two countries $i = N, S$ that have exclusive knowledge of technologies $i = N, S$ respectively.)

We treat the $z_i(j)$'s as realizations of random variables Z_i drawn independently for each j from the Fréchet distributions:

$$F_i(z) = \Pr[Z_i \leq z] = \exp[-T_i z^{-\theta}] \tag{1}$$

which are independent across $i = N, S, C$. In this static context the T_i's reflect the average efficiencies across the three sets of technologies. (We consider how these distributions arise from a dynamic process of innovation and diffusion in Sections 3 and 4.)

The best technologies available in country i are realizations of:

$$Z_i^* = \max\{Z_i, Z_C\} \quad i = N, S.$$

Thus the random variable Z_i^* has distribution:

$$F_i^*(z) = \Pr[Z_i^* \le z] = \exp[-T_i^* z^{-\theta}]$$

where $T_i^* = T_i + T_C$. The T_i^* reflect the average efficiencies across the set of technologies available to country $i = N, S$.

EK (2002) consider a case in which there is no common technology, so that $T_C = 0$. An implication is that the distributions of efficiencies available to each country are independent. Here there is independence across the exclusive technologies, but the common technologies induce a positive correlation between Z_N^* and Z_S^*. Because of this correlation we will find it easier to work with the three independent technology distributions of Z_N, Z_S, and Z_C.

As is standard in a Ricardian setting, workers are identical and mobile across activities within a country, but cannot change countries. The wage is w_N in the North and w_S in the South. We take the wage in the South to be the numeraire, although we leave w_S in formulas for clarity. Labor market clearing conditions, introduced below, establish the relative wage. Without loss of generality we will impose restrictions on exogenous variables so that in equilibrium $w_N \ge w_S$.[3]

As in DFS, demand is Cobb-Douglas, which we further simplify by assuming that expenditure shares are the same across goods. Hence expenditure in country i on good j is:

$$X_i(j) = X_i,$$

where X_i is total expenditure.[4]

[3] Below we consider the case in which technologies and the labor forces evolve over time. Since in this section we solve the static equilibrium given these magnitudes, we omit time subscripts for now.

[4] A generalization to CES preferences is straightforward. See, for example, Bernard, Eaton, Jensen, and Kortum (2003).

Also as in DFS, goods can be transported between the countries, but in order to deliver one unit to the destination $d \geq 1$ units need to be shipped from the source (the standard "iceberg" assumption). Unfortunately, even in low-dimensional Ricardian problems, taxonomies are inevitable. There are three cases to consider: (1) If $w_N > w_S d$ then the commonly available technologies are used only in the South; the North uses only those technologies unique to it. (2) If $w_N = w_S d$ then the commonly available technologies may be used in both countries, but goods produced using these technologies are exported only by the South. (3) If $w_N < w_S d$ then each country will use the commonly available technologies. Goods produced using these technologies aren't traded since it's more expensive to import the good than to make it oneself.

2.1 Cost Distributions

To mitigate the proliferation of special cases, we introduce the term w_{ni} to indicate the effective wage, inclusive of transport cost, for goods sold in country n produced using technology i. Here $n = N, S$ and $i = N, S, C$. Taking the case of the Northern market, $w_{NN} = w_N$ and $w_{NS} = w_S d$, while $w_{NC} = \min\{w_S d, w_N\}$ is the wage paid to labor producing goods using the common technologies and sold in the North (including transport cost should the South be the sole user). Hence $w_{NC}/z_C(j)$ is the cost of selling good j in the North if it is produced using a common technology. In the first case above $w_{NC} = w_S d < w_N$, in the second $w_{NC} = w_N = w_S d$, and in the third $w_{NC} = w_N < w_S d$. For the Southern market $w_{SS} = w_{SC} = w_S$ and $w_{SN} = dw_N$.

The lowest cost for good j in the North is thus:

$$
\begin{aligned}
c_N(j) &= \min\{w_N/z_N(j), w_{NC}/z_C(j), w_S d/z_S(j)\} \\
&= \min_{i=N,S,C}\{w_{Ni}/z_i(j)\}
\end{aligned}
$$

while in the South it is:

$$
\begin{aligned}
c_S(j) &= \min\{w_N d/z_N(j), w_S/z_C(j), w_S/z_S(j)\} \\
&= \min_{i=N,S,C}\{w_{Si}/z_i(j)\}.
\end{aligned}
$$

Note that, for all goods j, the ratio of costs is bounded above and below by $d \geq c_S(j)/c_N(j) \geq 1/d$, with equality on the left if N exports j to S and equality on the right if S exports j to N.

For $i = N, S$, the lowest cost $c_i(j)$ is the realization of a random variable C_i whose distribution derives from the distribution of the underlying technologies Z_i. We denote the cost distribution in i by $H_i(c) = \Pr[C_i \leq c]$. The cost distribution in the North is:

$$\begin{aligned} H_N(c) &= 1 - \Pr[Z_N \leq w_N/c] \Pr[Z_S \leq w_S d/c] \Pr[Z_C \leq w_{NC}/c] \\ &= 1 - F_N(w_N/c) F_S(w_S d/c) F_C(w_{NC}/c) \\ &= 1 - \exp\left[-\Phi_N c^\theta\right] \end{aligned}$$

where

$$\Phi_N = T_N w_N^{-\theta} + T_S (w_S d)^{-\theta} + T_C w_{NC}^{-\theta}.$$

Similarly, for the South:

$$H_S(c) = 1 - \exp\left[-\Phi_S c^\theta\right]$$

where

$$\Phi_S = T_N (w_N d)^{-\theta} + T_S w_S^{-\theta} + T_C w_S^{-\theta}.$$

We can summarize these results on the cost distributions, for $n = N, S$, as

$$H_n(c) = 1 - \exp\left[-\Phi_n c^\theta\right]$$

where

$$\Phi_n = \sum_{i=N,S,C} T_i w_{ni}^{-\theta}.$$

As in EK (2002), the probability that country n will find technology of type i the lowest cost source for some good is:

$$\pi_{ni} = \frac{T_i w_{ni}^{-\theta}}{\Phi_n} \tag{2}$$

where $n = N, S$ and $i = N, S, C$. The difference from EK (2002) is that the sources are not necessarily countries, but rather sets of technologies.

2.2 Trade Patterns and Wages

We now complete the description of the static equilibrium by describing how labor market clearing determines wages in each country, and characterize patterns of trade. We posit that each country i has L_i^P production workers $i = N, S$. To keep things simple, here we assume perfect competition, introducing Bertrand competition in Section 4 where we endogenize innovation.

Under many standard assumptions about market structure (including perfect competition or Bertrand competition), π_{ni} defined in (2) is the fraction of country n's expenditure devoted to goods produced with technology of type i. If X_n is total spending by country n, spending on labor producing goods using exclusively Northern technologies is:

$$w_N L_N^E = \pi_{NN} X_N + \pi_{SN} X_S. \tag{3}$$

Here L_N^E is the measure of Northern workers using exclusively Northern technologies.

We now need to distinguish among the three kinds of equilibria:

2.2.1 Case 1: The North uses only its Exclusive Technologies

In this case, $L_N^E = L_N^P$, where L_N^P are all Northern workers engaged in production. Since only the South uses commonly available technologies, $w_{NC} = w_S d$. The solution needs to satisfy $w_N > d w_S$ in order for the North not to use them.

Under perfect competition, all L_i^P workers in each country are engaged in production and labor is the only source of income, so that $X_i = w_i L_i^P$. In this case expression (3) above, combined with expression (2) for the trade share π_{ni}, becomes:

$$\frac{w_N}{w_S} = \left[\left(\frac{T_N / L_N^P}{T_S^* / L_S^P} \right) \frac{T_N w_N^{-\theta} + T_S^* \left(w_S d \right)^{-\theta}}{T_N (w_N d)^{-\theta} + T_S^* w_S^{-\theta}} \right]^{1/(1+\theta)}. \tag{4}$$

where, as defined above, $T_S^* = T_S + T_C$. While the equation does not admit an analytic solution, it is easy to solve numerically.

Since the North does not use the common technologies, all goods produced are equally tradeable regardless of which type of technology they employ. The fact that the North has access to common technologies is irrelevant since it doesn't use them. The outcome is isomorphic to one in which the North knows only the technologies that are exclusive to it, while the common technologies are exclusive to the South, as in EK (2002).

2.2.2 Case 2: The North and the South both use Common Technologies, with Trade in Some Goods Produced using Them

In this case $w_{NC} = w_N = w_S d$. Hence the relative wage is pinned down by the transport cost, since $w_N/w_S = d$. The demand for workers using exclusively Northern technologies is:

$$\frac{L_N^E}{L_N^P} = \frac{T_N}{T_W} + \frac{T_N d^{-2\theta}}{T_N d^{-2\theta} + T_S^*} \frac{L_S^P}{dL_N^P} \tag{5}$$

where $T_W = T_N + T_C + T_S$, a measure of world technology. For this case to emerge parameter values must be such that L_N^E/L_N^P not exceed one. Otherwise we are in Case 1 above. We also need the demand for workers using the South's exclusive technologies L_S^E not to exceed the supply of Southern workers. This condition requires that the ratio

$$\frac{L_S^E}{L_S^P} = \frac{T_S}{T_W} \frac{dL_N^P}{L_S^P} + \frac{T_S}{T_N d^{-2\theta} + T_S^*}$$

not exceed one. Otherwise we are in Case 3 below.

In Case 2 the range of goods produced using common technologies in the North are not traded. Hence, unlike case 1, technology diffusion results in less trade than otherwise. Diffusion substitutes for trade.

2.2.3 Case 3: Goods Produced with Common Technologies are not Traded

In this case $w_{NC} = w_N < w_S d$. Labor market equilibrium requires a wage w_N that solves:

$$w_N L_N^P = (\pi_{NN} + \pi_{NC})X_N + \pi_{SN} X_S,$$

which, using (2), becomes:

$$\frac{w_N}{w_S} = \left[\left(\frac{T_N/L_N^P}{T_S/L_S^P} \right) \frac{T_N^* w_N^{-\theta} + T_S (w_S d)^{-\theta}}{T_N (w_N d)^{-\theta} + T_S^* w_S^{-\theta}} \right]^{1/(1+\theta)}.$$

where, as defined above, $T_N^* = T_N + T_C$ and $T_S^* = T_S + T_C$. Again, there is no analytic solution, but solving for the wage numerically is straightforward.

Here all goods produced with common technologies are not traded. Technology diffusion reduces the scope for trade even further.

2.3 Trade and Prices

What is the relationship between technology, wages, and prices in each of these cases? In Cases 1 and 2 the wage in the North is higher than that in the South by a factor of at least d while the prices of goods produced using common technologies are higher by a factor of exactly d. Hence the real wage in the North is higher.

In Cases 2 and 3, some or all goods made with the common technologies are produced in both countries. Since the wage is higher in the North these goods are more expensive there, delivering the (Balassa-Samuelson) implication that the relative price of untraded goods is lower in the South.

3 Simple Technology Dynamics

We have so far considered the static equilibrium in which parameters of the technology distribution are given. Over time, however, we can envisage processes of innovation and diffusion governing the evolution of the T_{it}'s (introducing a time subscript). We first follow the specification in Krugman (1979), for example, which allows us to stick with perfect competition: Each country innovates at an exogenous rate that is proportional to its current knowledge, and ideas flow from the exclusive to the common pool at rates that are proportional to the stocks of exclusive ideas. We introduce four parameters, ι_N, the rate at which the North innovates, ι_S, the rate at which the South innovates, ϵ_N, the rate at which the South learns about exclusively Northern ideas, and ϵ_S, the rate at which the North learns about exclusively Southern ideas:

Thus T_{Nt}, T_{St}, and T_{Ct} evolve according to:

$$\begin{aligned}
\dot{T}_{Nt} &= (\iota_N - \epsilon_N)T_{Nt} + \iota_N T_{Ct} = \iota_N T^*_{Nt} - \epsilon_N T_{Nt} \\
\dot{T}_{St} &= (\iota_S - \epsilon_S)T_{St} + \iota_S T_{Ct} = \iota_S T^*_{St} - \epsilon_S T_{St} \\
\dot{T}_{Ct} &= \epsilon_N T_{Nt} + \epsilon_S T_{St}.
\end{aligned}$$

While the analytic solution to this dynamic system is complex, it is straightforward to show that as long as the innovation and diffusion parameters are strictly positive and the initial value of at least one T_i is positive, the system evolves to a steady state in which all three types of knowledge grow at the same rate.

In general, the resulting growth rate of technology is the solution to an unpleasant cubic equation. It can be shown, however, that the steady-state growth rate is increasing in both the innovation and diffusion parameters (see, e.g., EK, 1999). In the special case of symmetry, $\iota_N = \iota_S = \iota$, and $\epsilon_N = \epsilon_S = \epsilon$, the steady-state growth rate is merely quadratic:

$$g_T = \frac{\iota - \epsilon + \sqrt{(\iota - \epsilon)^2 + 8\iota\epsilon}}{2},$$

strictly increasing in ι and ϵ. A world with more innovation but also more diffusion grows faster. Krugman (1979) considers a special case in which only the North innovates, so that $i_S = 0$ and the growth rate is just ι_N while $T_S = 0$.

4 Endogenizing Innovation

We now extend the model to endogenize innovation. We continue to assume that exclusive ideas flow into common knowledge at a common exogenous rate ϵ.

As in Kortum (1997), we model innovation as the production of ideas. An idea is a way to produce a good j with output per worker q. We assume that an idea is equally likely to apply to any good in the unit interval, and that q is the realization of a random variable Q drawn from the Pareto distribution:

$$\Pr[Q \leq q] = 1 - q^{-\theta} \qquad q \geq 1. \tag{6}$$

Only an idea that lowers the cost of serving a market will be used.

This distribution of the efficiency of new ideas is consistent with our distributional assumption in Section 2 about the best technologies culled from past ideas. To see why, consider how one new idea will interact with the set of existing technologies in $i = N, S, C$. It adds to that set if and only if $Q > Z_i$, which occurs with probability:

$$\begin{aligned}
\Pr[Q &> Z_i] = \int_0^\infty \Pr[Q > z] dF_i(z) \\
&\approx \int_0^\infty z^{-\theta} \theta T_i z^{-\theta-1} e^{-T_i z^{-\theta}} dz \\
&= \int_0^\infty (x/T_i)\, e^{-x} dx = 1/T_i,
\end{aligned}$$

where the approximation is arbitrarily close for large T_i. We can use this result to derive the distribution of Q conditional on $Q > Z_i$:

$$\begin{aligned}
\Pr[Q &\leq q | Q > Z_i] = \int_0^q T_i \Pr[q \geq Q > z] dF_i(z) \\
&= \int_0^q T_i \left(z^{-\theta} - q^{-\theta}\right) \theta T_i z^{-\theta-1} e^{-T_i z^{-\theta}} dz \\
&= \int_{T_i q^{-\theta}}^\infty x e^{-x} dx - T_i q^{-\theta} e^{-T_i q^{-\theta}} \\
&= -e^{-x}(x+1)|_{T_i q^{-\theta}}^\infty - T_i q^{-\theta} e^{-T_i q^{-\theta}} \\
&= e^{-T_i q^{-\theta}} = F_i(q).
\end{aligned}$$

Thus, conditional on joining the set of best technologies, the quality of a new idea inherits the distribution of the quality of existing technologies. The Fréchet distribution is passed along over time as its parameter T_i increases with innovative effort.

Initially, ideas from country n are usable only for production there. Hence, for an idea from country n to lower the cost of producing good j for the home market, q must satisfy:

$$w_n/q \leq c_n(j) = \min_{i=N,S,C} \{w_{ni}/z_i(j)\}$$

where $z_N(j)$, $z_S(j)$, and $z_C(j)$ represent the states of the art in the exclusively Northern, exclusively Southern, and commonly available technologies, respectively. (Recall that w_{ni} is the transport cost-inclusive wage applying to technology i in market n.) To lower the cost of of producing good j for the foreign market $m \neq n$ it must satisfy:

$$w_n d/q \leq c_m(j) = \min_{i=N,S,C} \{w_{mi}/z_i(j)\}.$$

Given the current local cost $c_n(j)$ of good j, the probability that a local innovation will lower cost is:

$$\Pr[w_n/Q \leq c_n(j)] = \Pr[Q \geq w_n/c_n(j)] = [w_n/c_n(j)]^{-\theta}$$

while given the cost in the foreign market m, $c_m(j)$, the probability that it lowers cost abroad is:

$$\Pr[w_n d/Q \leq c_m(j)] = \Pr[Q \geq w_n d/c_m(j)] = [w_n d/c_m(j)]^{-\theta}.$$

Since, with the possibility of trade, the cost of a good can never differ between countries by a factor greater than d, and can differ by less, the criterion for exporting is tougher. Small innovations may be used to produce only for the home market, while larger ones will be used for export as well.

4.1 The Distribution of the Markup

We need to introduce an incentive for innovation. We follow the quality-ladders framework (Grossman and Helpman, 1991, Aghion and Howitt, 1992) and posit that the owner of an innovation has the ability to use it to produce and sell a product at the highest price that keeps the competition at bay. With Cobb-Douglas preferences, this price equals the unit cost using the next best technology. The resulting markup of price over unit cost on a particular good is the ratio of the cost of producing it using the previous technology to the cost of producing it using the latest technology.

Consider some new idea in technology class $i = N, S, C$ which could be used to produce a particular good for market $n = N, S$. The idea may or may not be of any economic value. The *latent* markup using the idea is $M^*_{nit} = C_{nt}/(w_{ni}/Q)$ (where capital letters denote random variables). The efficiency of the idea, Q, is drawn from the distribution (6) while the cost using the previous technology, C_{nt}, is drawn independently from the relevant cost distribution:

$$H_{nt}(c) = 1 - \exp\left[-\Phi_{nt} c^{\theta}\right].$$

If the latent markup is less than one, of course, the idea will not be used in market n at all. If the latent markup exceeds one the idea will be used, the good will sell at price C_{nt} in market n, and the actual markup there will equal the latent markup.

The probability that the latent markup exceeds some value m is:

$$\begin{aligned}
b_{nit}(m) &= \Pr[M^*_{nit} \geq m] = \Pr[C_{nt} \geq w_{ni} m/Q] \\
&= \int_1^{\infty} \Pr[C_{nt} \geq m w_{ni}/Q | Q = q] \theta q^{-\theta-1} dq \\
&= \int_1^{\infty} \exp\left[-\Phi_{nt} (m w_{ni})^{\theta} q^{-\theta}\right] \theta q^{-\theta-1} dq \\
&\approx \frac{m^{-\theta}}{\Phi_{nt} w_{ni}^{\theta}},
\end{aligned}$$

where the last approximation becomes exact as Φ_{nt} gets large. (Since we consider a steady state in which w_{ni} is constant, we do not index it by t.) For the good to be sold, of course, requires $M \geq 1$, which occurs with probability:

$$b_{nit}(1) = \frac{1}{\Phi_{nt} w_{ni}^{\theta}}$$

which, using (2), we can rewrite:

$$b_{nit}(1) = \frac{\pi_{ni}}{T_{it}}.$$

The distribution of the markup is equal to the distribution of the latent markup conditional on $M^* \geq 1$. This conditional distribution is simply

$$G(m) = \frac{b_{nit}(1) - b_{nit}(m)}{b_{nit}(1)} = 1 - m^{-\theta} \quad n = N, S;\ i = N, S, C,$$

the Pareto distribution with parameter θ, for $m \geq 1$. Note that the distribution of the markup is invariant to the technology class i, the market n, or the date t.

Integrating across the markup distribution $G(m)$, the expected flow of profit from an idea conditional on selling in country n is:

$$X_{nt}\int_{1}^{\infty}(1-m^{-1})dG(m)=\frac{X_{nt}}{1+\theta};\quad n=N,S$$

which is also the total profit generated in country n. The fraction of total profit earned by using technology of type $i=N,S,C$ in market n is π_{ni}. Taking into account the probability that an idea will be useful in that country, the expected profit in market n of an idea from technology i at time t is:

$$\Pi_{nit}=\frac{1}{1+\theta}\frac{\pi_{ni}X_{nt}}{T_{it}}.$$

As time passes, X_{nt} and T_{it} both grow. The first causes expected profit from an idea to rise over time as the size of the market grows. The second causes expected profit from the idea to fall over time through the hazard of losing the market to a cheaper source of production. Conditional on still being of value, one idea is just like any other in terms of the distribution of its quality Q, regardless of when it was invented.

We denote the aggregate price level in country n at time t by P_{nt}. Cobb-Douglas preferences dictate that the price level be calculated as the geometric mean of individual prices in country n. The price of each good in country n is the product of the unit cost of producing it and its markup. Thus,

$$\begin{aligned}P_{nt} &= \exp\{E[\ln(M_{nt}C_{nt})]\}=\exp\{E[\ln(M_{nt})]+E[\ln(C_{nt})]\}\\ &= \exp\left[\int_{1}^{\infty}(\ln m)\theta m^{-\theta-1}dm+\int_{0}^{\infty}(\ln c)dH_{nt}(c)\right]\\ &= \exp\left(\frac{1-\gamma}{\theta}\right)\Phi_{nt}^{-1/\theta},\end{aligned}$$

where γ is Euler's constant (.5772...).[5]

With these expressions in hand we are now armed to calculate the value of ideas.

[5] Another way to derive this expression for the price level is to note that with Bertrand competition, the price of a good is the second lowest cost of producing it, which we denote by $C_{nt}^{(2)}$. This second lowest cost in country n has distribution:

$$H_{nt}^{(2)}(c)=1-\left(1+\Phi_{nt}c^{\theta}\right)\exp(-\Phi_{nt}c^{\theta}).$$

(See equation (8) of Bernard, Eaton Jensen, and Kortum, 2003, setting $c_1=c_2$.). The price level in country n

4.2 The Value of Ideas

Taking into account possible diffusion, as well as changes in the price level, the expected real value of an idea developed in country i over its lifetime is:

$$\begin{aligned} V_{it} &= \int_t^\infty \frac{P_{it}}{P_{is}} e^{-\rho(s-t)} \\ & \left[e^{-\epsilon(s-t)} \left(\frac{\pi_{Ni} X_{Ns} + \pi_{Si} X_{Ss}}{(1+\theta) T_{is}} \right) + \left[1 - e^{-\epsilon(s-t)} \right] \left(\frac{\pi_{NC} X_{Ns} + \pi_{SC} X_{Ss}}{(1+\theta) T_{Cs}} \right) \right] ds. \end{aligned} \quad (7)$$

where ρ is the discount rate. The expression $\pi_{Ni} X_{Nt} + \pi_{Si} X_{St}$ is total spending on goods made with technologies of type i.

We assume that both labor forces grow at rate g_L, with $L_N = \lambda L_S$. We require that $g_L/\theta < \rho$. In steady state, wages and the π_{ni} are constant, while the T's grow at rate g_T, so that prices fall at rate g_T/θ. Profit is a constant share of income, which also grows at rate g_L.

Because of royalty payments on technologies used for domestic production that were invented abroad, we need to distinguish country i's income X_{it}, which includes net royalty income from abroad, from its output, which we denote Y_{it}. We can write the income of country i, X_{it}, in terms of outputs Y_{it} and Y_{nt}, $n \neq i$, as:

$$X_{it} = (1 - \frac{\omega_{in}}{1+\theta}) Y_{it} + \frac{\omega_{ni}}{1+\theta} Y_{nt}$$

where ω_{ni} is the share of the technology used in country n owned by inventors from country i. Since labor income from production in country i is $w_i L_{it}^P$, where L_{it}^P denotes production workers, we can relate output to labor income as follows:

$$Y_{it} = w_i L_{it}^P + \frac{Y_{it}}{1+\theta} = \frac{1+\theta}{\theta} w_i L_{it}^P.$$

Hence:

$$X_{it} = \frac{1}{\theta} \left[(1 + \theta - \omega_{in}) w_i L_{it}^P + \omega_{ni} w_n L_{nt}^P \right]. \quad (8)$$

at date t is therefore:

$$P_{nt} = \exp\{ \int_0^\infty (\ln c) dH_{nt}^{(2)}(c) \} = \exp\left(\frac{1-\gamma}{\theta} \right) \Phi_{nt}^{-1/\theta}.$$

We use these expressions for income in deriving the value of ideas in the various cases we consider below.

4.3 The Rate of Innovation

As is common in the endogenous growth literature, we introduce a production function for innovation, with country i having research productivity $\alpha_i,\ i = N, S$. The rate at which ideas in technology i are created is thus $\alpha_i r_{it} L_{it}$, $i = N, S$, where r_i is the share of country i's labor force doing research and L_i is its total labor force. We assume that an idea transits from either exclusive technology into the common technology with a common hazard ϵ.

We define the ratio of technology exclusive to country i to country i workers at time t as $t_{it} = T_{it}/L_{it}$. It evolves according to:

$$\begin{aligned}\frac{\dot{t}_{it}}{t_{it}} &= \frac{\dot{T}_{it}}{T_{it}} - \frac{L_{it}}{L_{it}} \\ &= \frac{\alpha_i r_{it} L_{it}}{T_{it}} - (g_L + \epsilon).\end{aligned}$$

In steady state both r_i and t_i are constant, so that $t_i = \alpha_i r_i/(g_L + \epsilon)$ and $g_T = g_L$. Finally, defining $t_{Ct} = T_{Ct}/(T_{Nt} + T_{St})$, the ratio of common to exclusive technologies, t_C evolves according to:

$$\dot{t}_{Ct} = \epsilon - t_{Ct}\frac{\dot{T}_{Nt} + \dot{T}_{St}}{T_{Nt} + T_{St}}.$$

Thus in steady state t_C is constant and equals ϵ/g_L.

Since in steady state $g_T = g_L$, our expression for the value of ideas (7) becomes:

$$\begin{aligned}V_{it} &= \frac{1}{\rho + \epsilon - g_L/\theta}\frac{\pi_{Ni}X_{Nt} + \pi_{Si}X_{St}}{(1+\theta)T_{it}} \\ &\quad + \left(\frac{1}{\rho - g_L/\theta} - \frac{1}{\rho + \epsilon - g_L/\theta}\right)\frac{\pi_{NC}X_{Nt} + \pi_{SC}X_{St}}{(1+\theta)T_{Ct}}.\end{aligned} \tag{9}$$

where the X_{it} are given by (8) above, where $i, n = N, S,\ i \neq n$.

In an equilibrium in which workers in a country engage simultaneously in production and in innovation, the return to each activity should be equal. More generally, the conditions for labor market equilibrium are that:

$$\begin{aligned} \alpha_i V_{it} &= w_{it} \quad r_{it} \in [0,1] \\ \alpha_i V_{it} &\leq w_{it} \quad r_{it} = 0 \\ \alpha_i V_{it} &\geq w_{it} \quad r_{it} = 1 \end{aligned} \tag{10}$$

for $i = N, S$.

A steady-state equilibrium is a solution for r_N, r_S, and w_N/w_S consistent with (10) and product market clearing as derived in Section 2.

4.4 Steady State Research and Growth

Because of the taxonomy of situations that can arise, we avoid trying to provide a general analytic solution. But under each of four particular assumptions about diffusion and trade barriers the model yields insight into the effects of globalization on research: (i) no diffusion ($\epsilon = 0$), (ii) instantaneous diffusion ($\epsilon \to \infty$), (iii) no trade. ($d \to \infty$), and (iv) costless trade ($d = 1$). As these four cases circumnavigate the full range of possibilities, they provide insight into the general solution:

4.4.1 No Diffusion

Setting $\epsilon = 0$ gives us EK (2001b). Each country has to use its own ideas for production. Hence, spending on goods produced with ideas exclusive to country i corresponds with the total production of country i, $Y_{it} = \pi_{Ni} X_{Nt} + \pi_{Si} X_{St}$. Substituting this expression into value of ideas above and solving for labor market equilibrium in each country gives:

$$r = \frac{g_L}{\rho\theta}.$$

In steady state all countries do the same amount of research relative to their labor forces regardless of their size or their research productivity. Since there are no common technologies, we are in Case 1 above.

We now explore how much international technology diffusion upsets this stark result.

4.4.2 Instantaneous Diffusion

Consider the opposite case in which diffusion is instantaneous ($\epsilon \to \infty$). Now all ideas are common, so that $\pi_{nC} = 1$, $n = N, S$. Since all ideas diffuse immediately they have the same value regardless of their origin. We can write the value of an idea from either country as:

$$V = \frac{1}{\rho\theta - g_L} \frac{w_N L_N(1 - r_N) + w_S L_S(1 - r_S)}{T_C}.$$

Since the South can use all the same technologies as the North, for the North to engage in production requires that $w_N \leq w_S d$. (Remember that $w_N \geq w_S$ throughout our analysis.)

What happens depends on the relative size of α_N/α_S and d:

1. Say that $\alpha_N/\alpha_S \geq d$. Then, as long as the North continues to produce, $w_N = w_S d$ and we are in Case 2 above. The North does all the research ($r_S = 0$). The share of workers in the North doing research is:

$$r_N = \frac{g_L}{\rho\theta}(1 + 1/d\lambda) \tag{11}$$

   (which cannot exceed one). Note that, compared with the case of no diffusion, the amount of research is higher in the North in proportion to the relative size of the South ($1/\lambda$) discounted by the trade barrier ($1/d$). Because of this discounting, the number of people engaged in research in the world is smaller than with no diffusion. But since $\alpha_N/\alpha_S \geq d$, effective research is higher since Northern research workers are more productive. This condition is what ensures that if the North is both producing and doing research then the South does not find research worthwhile. In this equilibrium the South runs a trade surplus with the North to pay for the ideas it uses in production. The location of production of any particular good is indeterminate.[6]

[6] If the South is very large compared to the North (λ near 0) then the value of r_N in expression (11) can exceed one. In this case the North will specialize completely in research ($r_N = 1$) and w_N can exceed $w_S d$. Depending on parameter values, the South might find research worthwhile as well. We leave this case as an exercise.

2. Say instead that $\alpha_N/\alpha_S \leq d$. We are in Case 3 above. Both countries will do research, and the relative wage will reflect research productivity, i.e., $w_N/w_S = \alpha_N/\alpha_S \leq d$. Since the trade barrier exceeds the wage difference, each country will produce its own goods. Since there is no goods trade, royalty payments must balance, which requires that $r = r_N = r_S$. For each country to find research worthwhile requires that:

$$r = \frac{g_L}{\rho\theta} \tag{12}$$

as in the case of no diffusion.

Hence our Ricardian assumptions yield starkly Ricardian results. If research productivity differences exceed trade barriers, countries specialize in research according to comparative advantage. But if differences in research productivity fall short of trade barriers, countries do their own research, while making use of each other's ideas. Knowledge flows rather than good flows are how countries benefit from each other's innovation.

What about the more realistic scenario in which ideas cross borders, but only with delay? Special situations without trade and with costless trade deliver insight, although the results are not as clean, demanding numerical simulation.

4.4.3 No Trade

Say that trade barriers are so high that there is no trade ($d \to \infty$). This assumption was implicit in the model used to estimate innovation and diffusion among the top five research economies in EK (1999).[7]

Without trade in goods, royalty payments need to balance, so that $X_n = Y_n$, $n = N, S$. We can also set: $\pi_{nn} = T_n/(T_n + T_C)$, $\pi_{ni} = 0$, $n \neq i$, and $T_{nC} = T_C/(T_n + T_C)$, $i, n = N, S$.

[7] The model in EK (1999) differs in several respects. For one thing, ideas in that paper are about inputs, which are not traded. But costless trade in final output allows for unbalanced royalty payments. For another, that paper allows for diminishing returns to research activity at the national level. Diminishing returns are needed to reconcile observations on the small share of workers doing research and their apparently large contribution to productivity growth. Since our purpose here is a better understanding of the properties of the basic model rather than a realistic application to data, we do not introduce this complication here. Finally, that model allows for imperfect protection of innovations, both at home and abroad.

The value of ideas (9) then becomes:

$$V_i = \frac{1}{\rho\theta - g_L}\frac{w_iL_i(1-r_i)}{T_i+T_C} + \left(\frac{1}{\rho - g_L\theta} - \frac{1}{(\rho+\epsilon)\theta - g_L}\right)\frac{w_nL_n(1-r_n)}{T_n+T_C} \tag{13}$$

for $i, n = N, S;\ i \neq n$. The first term on the right-hand side represents the value of the idea at home and the second its value abroad. Since goods aren't traded, diffusion into the common pool has no implication for the value at home, while any return from abroad must await diffusion.

In steady state, balanced trade in royalties implies that:

$$\frac{T_N}{T_N+T_S}\frac{T_C}{T_S+T_C}w_SL_S(1-r_S) = \frac{T_S}{T_N+T_S}\frac{T_C}{T_N+T_C}w_NL_N(1-r_N). \tag{14}$$

Substituting expression (14) into (13) and solving for steady-state values of T_N, T_S, and T_C gives conditions for research intensity in each country:

$$\Lambda = \frac{r_N}{1-r_N}\frac{Ar_N + Br_S}{DAr_N + \epsilon\theta r_S}$$
$$\Lambda = \frac{r_S}{1-r_S}\frac{r_S + BAr_N}{Dr_S + \epsilon\theta Ar_N}$$

where:

$$\Lambda = \frac{g_L}{(\rho\theta - g_L)D}$$
$$A = \frac{a_N\lambda}{\alpha_S}$$
$$B = \frac{\epsilon}{g_L+\epsilon}$$
$$D = (\rho+\epsilon)\theta - g_L.$$

There is no analytic solution for the general case, although with $\epsilon = 0$ or $\epsilon \to \infty$ we of course get back to $r_N = r_S = g_L/\rho\theta$. Imposing symmetry ($A = 1$) we get the following expression for the ratio of research workers to nonresearch workers:

$$\frac{r}{1-r} = \frac{g_L}{\rho\theta - g_L}G$$

where:

$$G = \frac{(\rho + 2\epsilon)\theta - g_L}{(\rho + \epsilon)\theta - g_L} \frac{g_L + \epsilon}{g_L + 2\epsilon}.$$

Note that G is the product of two fractions, the first exceeding one and the second less than one. If $G = 1$ we are back to $r = g_L/\rho\theta$. The first fraction reflects the added opportunities for earning royalties abroad that diffusion allows, which increases the incentive to do research. The second reflects the fact that, with diffusion, foreign ideas compete with domestic ones at home, reducing research incentives. Which effect dominates depends on particular parameter values. More diffusion means more research if $g_L/\rho\theta$ exceeds $1/(1 + \theta)$ and vice versa. Simulations suggest that deviations from $r = g_L/\rho\theta$ are small regardless.

What about the role of country size, as measured by A? Researchers in a larger country face less competition from foreign ideas, but have a smaller foreign market in which to earn royalties. In fact, our simulations reveal that the direction of the effect of country size on research intensity depends on parameter values.

We solve numerically for research intensity for the parameter values:

$$\begin{array}{cc} g_L & .01 \\ \rho & .02 \\ \theta & 8 \\ \epsilon & .02 \\ \alpha_N \lambda / \alpha_S & 1 \end{array}.$$

In the symmetric case research intensity in each country is .057 (compared with .063 with no diffusion). We find that increasing the relative size of the North by a factor of 10 leads research activity there to increase to a labor share of .062 while the share in the South falls to .051. Raising g_L to .02, however, reverses the effect of size on research activity (although deviations from symmetry are slight).

4.4.4 Costless trade

Say that trade is frictionless, meaning that $d = 1$. Case 3, with each country producing its own goods with the common technology, is, except by coincidence, eliminated as a possibility. If parameter values leave us in Case 2 above, then the wage in the two economies is identical, as are the value of ideas. If research productivity in the South is lower, only the North will undertake research. If the return is the same the location of research is indeterminate. In either case the world share of world labor engaged in research is the same as the closed economy value of $g_L/\rho\theta$.[8]

More interesting is a set of parameter values that leave us in Case 1 above, with the Northern wage above the South's. In this case the North uses only its own exclusive technologies, but earns royalties from technologies that have diffused into the common technology and are used in the South. The expression for the value of ideas, (9) above, simplifies by recognizing that spending on goods produced using Northern technologies is the same as spending on goods produced by Northern workers. Hence:

$$\pi_{NN}X_{Nt} + \pi_{SN}X_{St} = Y_{Nt} = \frac{1+\theta}{\theta}w_N L_{Nt}(1-r_N).$$

Only the South uses commonly available technologies, while it also uses its own exclusive technologies. Total spending on goods produced by Southern workers is thus:

$$(\pi_{NC} + \pi_{NS})X_{Nt} + (\pi_{SC} + \pi_{SS})X_{St} = Y_{St} = \frac{1+\theta}{\theta}w_S L_{St}(1-r_S).$$

Southern production using common technologies is

$$\pi_{NC}X_{Nt} + \pi_{SC}X_{St} = \frac{T_{Ct}}{T_{St}+T_{Ct}}Y_{St}$$

while Southern production using exclusively Southern technologies is

$$\pi_{NS}X_{Nt} + \pi_{SS}X_{St} = \frac{T_{St}}{T_{St}+T_{Ct}}Y_{St}.$$

Finally, the overall technology available to the South relative to their labor force is

$$\begin{aligned}
\frac{T^*_{St}}{L_{St}} &= \frac{T_{St}+T_{Ct}}{L_{St}} \\
&= \frac{\alpha_S r_S}{g_L+\epsilon} + \frac{\epsilon(\alpha_S r_S + \alpha_N r_N \lambda)}{g_L(g_L+\epsilon)} \\
&= \frac{\epsilon\alpha_N r_N\lambda + (g_L+\epsilon)\alpha_S r_S}{g_L(g_L+\epsilon)}.
\end{aligned}$$

[8] This outcome requires that the share of the world labor force in the North exceed $g_L/\rho\theta$. Otherwise the North will specialize completely in research, and its wage can be higher. Again, we leave this case as an exercise.

Substituting these expressions into the value of ideas (9) gives:

$$\begin{aligned}
V_S &= \frac{1}{\rho\theta - g_L}\frac{w_S(1-r_S)g_L(g_L+\epsilon)}{\epsilon\alpha_N r_N\lambda + (g_L+\epsilon)\alpha_S r_S} \\
V_N &= \frac{g_L+\epsilon}{(\rho+\epsilon)\theta - g_L}\frac{w_N(1-r_N)}{r_N} + \frac{\epsilon\theta}{\rho\theta - g_L}\frac{w_S(1-r_S)g_L}{\epsilon\alpha_N r_N\lambda + (g_L+\epsilon)\alpha_S r_S}.
\end{aligned}$$

Solving for the steady-state levels of r_N and r_S gives:

$$\begin{aligned}
r_N &= \frac{g_L+\epsilon}{\rho\theta + \epsilon\{1+\theta[1-(\alpha_N/\alpha_S)(w_S/w_N)]\}} \\
r_S &= \frac{g_L}{\rho\theta} - \frac{\epsilon}{g_L+\epsilon}(\alpha_N\lambda/\alpha_S)r_N\left(1-\frac{g_L}{\rho\theta}\right).
\end{aligned} \tag{15}$$

To solve for the relative wage we need to refer back to our solution (4) for the static case above, setting $d = 1$ and replacing L_i^P with $L_i(1-r_i)$. Solving out for r_S we are left with:

$$\frac{w_N}{w_S} = \left[\frac{r_N}{1-r_N}\frac{\alpha_N}{\alpha_S}\frac{\rho\theta - g_L}{g_L+\epsilon}\right]^{1/(1+\theta)}. \tag{16}$$

Case 1 requires, of course, that $w_N/w_S > 1$. This solution also requires that r_S exceed zero. For many parameter values, the South will end up doing no research at all. We don't explore this situation further, focusing on outcomes in which both countries continue to do research.

Note that r_N and the wage ratio w_N/w_S can be solved in terms of each other, with r_S determined as a function of r_N. Of course with no diffusion we are back to $r_N = r_S = g_L/\rho\theta$. With diffusion ($\epsilon > 0$) Northern research rises above this level while Southern research declines. More generally, greater diffusion shifts research in the direction of greater research productivity. Further analysis of equations (15) and (16) establishes that: (i) an increase in the relative research productivity of the North (α_N/α_S) raises the relative wage (w_N/w_S) there, but by a smaller percentage amount (so that the relative cost of doing research in the North falls); (ii) as a consequence, research shifts to the North; (iii) more diffusion (a higher ϵ) raises the relative wage of the North. While the first two results are predictable, the third contrasts with the outcome that would occur with exogenous research effort, such as in Krugman (1979). In that case more diffusion, by reducing the stock of exclusively Northern technologies, lowers the Northern wage. Two forces here work in the opposite direction. First, increased diffusion raises the demand for Northern workers as researchers. Second, the fact that the North is doing more research mitigates the effect of diffusion on the ratio of exclusive Northern technologies to those available in the South. In fact, as we discuss below, more diffusion can have the paradoxical effect of lowering the fraction of technologies available to the South as greater Northern research increases the pool of exclusively Northern technologies.

Solving the model numerically, a plausible base case emerges with the values:

g_L	.01
ρ	.02
θ	8
α_N/α_S	5
λ	.1

With no diffusion ($\epsilon = 0$) a fraction .0625 of workers in each country pursue research, and the relative wage is 1.20 times higher in the North. The ratio of Northern technologies to those available in the South is .50. Raising diffusion so that $\epsilon = .005$ raises the share of researchers in the North to .254 and lowers it in the South to .023. The Northern wage advantage rises to a factor of 1.37. Taking into account the higher productivity of researchers in the North, along with the smaller number of workers there, the effective level of research in the world rises by 60 percent. For the reason explained above, the ratio of exclusively Northern to technologies available in the South rises to 1.30.[9]

5 Conclusion

What does our analysis suggest about the implications of globalization, either in the form of greater diffusion of ideas or of lower trade barriers, for research incentives? And what role does country size play? In our base case with no diffusion, countries engage in the same amount of research regardless of their relative size and research productivity. Openness to trade doesn't alter research specialization. More research productive countries are richer, since the same research effort yields more new technology.

[9]The direction of the effect of greater diffusion on this last ratio depends on parameter values. Giving the North less of a research advantage ($\alpha_N/\alpha_S = 1.1$) while making it larger ($\lambda = 1$) means that more diffusion raises the share of technologies available in the South, but, as discussed above, lowers the relative wage in the South.

Jumping to a world with instantaneous diffusion can have a major effect on the allocation of research activity, or none at all, depending on the importance of trade barriers relative to differences in research productivity. When differences in research productivity are more pronounced, instantaneous diffusion leads to Ricardian specialization. But if trade barriers are more significant, countries continue to do the same amount of research as with no diffusion. Given the amount of diffusion, a lowering of trade barriers can lead to more specialization in research.

Intermediate levels of diffusion deliver less stark results. Under plausible parameter values we find a tendency for greater diffusion to shift research toward countries with greater research productivity.

While more trade and diffusion may cause research activity to shift across countries, our analysis provides little to suggest that greater openness of either form will increase research effort overall. Globalization, either in the form of lower trade barriers or more rapid diffusion, provides researchers larger markets, but also exposes them to more competition.

Even in our relatively simple model, intermediate levels of diffusion imply complex patterns of specialization in research. Size can matter, but the direction of the effect is ambiguous. It is not surprising, then, that we see some of the largest and smallest nations among the most active researchers. At the same time, there is reason to think that countries that do more research do so because they are better at it.

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TABLE 1

Business Sector Research Scientists
(per 1000 Industrial Workers)

COUNTRY	Scientists	Income	Population
Finland	12.2	69	5176
United States	10.2	100	275423
Japan	9.8	73	126919
Sweden	7.7	69	8871
Luxembourg	6.8	138	441
Russia	6.6	28	145555
Belgium	6.2	70	10254
Norway	6.0	90	4491
Canada	5.9	81	30750
Germany	5.5	67	82168
Singapore	5.3	80	4018
France	5.1	66	60431
Denmark	4.5	80	5338
Ireland	4.4	76	3787
Korea	4.2	42	47275
United Kingdom	4.2	68	59756
Taiwan	4.2	55	21777
Austria	3.9	70	8110
Netherlands	3.6	72	15920
Australia	2.4	76	19157
Slovenia	2.0	48	1988
Spain	1.8	53	39927
New Zealand	1.7	56	3831
Italy	1.6	64	57728
Slovak Republic	1.6	35	5401
Czech Republic	1.4	42	10272
Hungary	1.4	31	10024
Romania	1.4	14	22435
Poland	0.8	27	38646
Portugal	0.7	48	10005
China	0.7	11	1258821
Greece	0.5	44	10558
Turkey	0.2	21	66835
Mexico	0.1	27	97221

Data are for 2000 or the previous available year
Income is relative to the United States (100)
Population is in 1000's
Sources: OECD (2004) and Heston, Summers, and Aten (2002).