NBER WORKING PAPER SERIES

TRADE IN IDEAS:
PATENTING AND PRODUCTIVITY
IN THE OECD

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Working Paper No. 5049

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
March 1995

An earlier version of this paper was presented at the NBER-CEPR Conference on International Trade and Growth, Cambridge, MA, October 7-8, 1994. We thank participants for their comments. Poorti Srivastava and Akiko Tamura provided excellent research assistance, but we remain responsible for any errors. We benefitted from comments from Robert Baldwin, James Anderson, Ed Roman, and participants at the lunchtime workshop at the Board of Governors. This paper is part of NBER's research programs in Growth, International Trade and Investment, and Productivity. Any opinions expressed are those of the authors and not those of the Federal Reserve System, or the National Bureau of Economic Research.

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ABSTRACT

We develop and estimate a model of technological innovation and its contribution to growth at home and abroad. International patents indicate where innovations come from and where they are used. Countries grow at a common steady-state rate. A country's relative productivity depends upon its capacity to absorb technology. We estimate that, except for the United States, OECD countries derive almost all of their productivity growth from abroad.

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1 Introduction

Economists have devoted a lot of attention to the international movement of standard factors of production, such as capital and labor, and to what these movements imply for growth. The spread of technology among countries gets far less attention even though decompositions of the sources of growth show that technological innovation is a major contributor. A reason for this gap is the difficulty of observing either the creation or diffusion of inventions. While we can observe inputs into the inventive process, such as R&D expenditures or R&D scientists and engineers, we have no direct measure of the output.

Patents indicate research output, and where patent protection is sought reflects where inventors expect their ideas to be used. In order to isolate patterns of invention and technology diffusion from patent data we distinguish among various influences on the decision to patent. We relate the level of patenting by one country (the source) in another (the destination) to five factors: (1) the source's research effort; (2) the destination's market size, (3) how rigorously the destination protects intellectual property, (4) the cost of patenting in the destination, and (5) the likelihood that inventions from the source can be adopted into the destination's technologies.

We then apply the model to explain patenting and relative productivity among OECD countries. With the parameter estimates we obtain our model implies that all countries will eventually grow at a common steady-state rate, with each country's relative productivity determined by its ability to make use of technologies developed at home and abroad.

We find that international trade in ideas is a major factor in world growth. Our estimates imply that every OECD country other than the United States obtains more than half of its productivity growth from ideas that originated abroad. Moreover, we find that the return to innovation derives primarily from abroad, even though inventors from all but the smallest countries earn most of their income from patents at home.

Distance appears to inhibit the flow of ideas between countries while trade relationships enhance them. A critical factor determining a country's relative productivity level is its ability to adopt technology, whether the technology was developed abroad or at home. We find a country's level of education significant in explaining this ability.

The analysis here relates to other work on technology diffusion and patenting.[1] Coe and Helpman (1993) develop and estimate a model that relates technology diffusion to trade patterns. Their assumption is that technology diffuses as better inputs, developed and produced in the inventing country, are exported for use in production in other countries. To estimate the model, they create a foreign R&D stock for each country based on foreign research expenditures and the sources of the country's imports. They find that the growth of the foreign R&D stock contributes significantly to productivity growth. In smaller countries, the contribution of the foreign stock is even greater than the contribution of the domestic R&D stock.[2]

Eaton and Kortum (1994) also conclude that foreign research is a major contributor to productivity growth. They use patenting to infer the extent of tech-

[1]Both Caballero and Jaffe (1993) and Kortum (1994) use patent data to evaluate models of growth and technological change. They do not, however, consider the international diffusion of technology.

[2]Their specification of the contribution of R&D to growth differs substantially from ours. In particular they assume that productivity is a Cobb-Douglas function of foreign and domestic R&D. Strictly positive levels of both foreign and domestic R&D are essential for any output at all.

nology diffusion among the five leading research economies. Since they also model the decision to undertake research, their analysis is much more complicated, and limited in geographical scope, than ours. Moreover, they do not attempt to relate the rate of diffusion to other measures of economic interaction, as we do here.[3]

Our paper proceeds as follows. In the next section we review the international patent system. Section 3 presents a model of world innovation and patenting. We discuss our estimation procedures and results in section 4. Section 5 concludes.

2 The International Patenting System

While a single patent does not protect an invention worldwide, a single invention may be patented in any number of countries.[4] A patent in a specific country provides protection (subject to enforcement) in two ways: (i) the inventor is protected from imitators producing in that country and (ii) the inventor is protected from outside imitators selling in that country.

If patent protection were costless, an inventor might as well apply for patents in all countries offering patent protection. In fact, there are two types of costs associated with obtaining a patent. First, the specification of the invention is published in the local language in the country granting protection, thus divulging

[3]Our work here also relates to earlier "gravity models" of international patenting. Slama (1981) finds that the gravity specification does a good job of explaining patterns of international patenting. Bosworth (1984) argues for using international patent data as an indicator of technology transfer (noting the relatively sparse data on royalty payments). Supporting this view, he finds that patenting abroad by residents of the U.K. is influenced not only by the GDP of the foreign country but also by the extent of U.K. multinational interests there. Similarly, he finds that the sources of foreign patents in the U.K. reflect the sources of multinational interests in the U.K. Dosi et. al. (1990) estimate trade and patent flows among OECD countries. None of these papers relate patenting and technology flows to productivity. Nor do they explicitly model the patenting decision. Putnam (1995) does model this decision. Using data on individual inventions and where they are patented, he finds that international patent rights are quite valuable.

[4]Penrose (1951) provides a thorough discussion of the history and operation of the international patenting system. Evenson (1984) provides an overview of international patenting data.

information to potential imitators. Second, there are filing fees, agents fees and translation fees associated with obtaining a patent, on the order of \$1000-\$5000 in 1992 [Helfgott (1993)].

Since patenting is costly, an inventor should be careful in selecting where to seek protection. The head of General Electric's foreign patenting operations makes the following suggestions:

> By covering the competitor's home or major manufacturing country, the applicant has a better chance of preventing the competitor from entering into markets regardless of where such markets might develop.

But he continues:

> Where only a limited investment is needed to manufacture the product, greater focus should be given to covering the major market countries rather than the manufacturing countries, since it would be easy for competitors to shift manufacture in order to avoid a patent [Helfgott (1986, pg. 3)].

Here we model the market-covering justification for patenting. Hence, patent protection is sought in countries with large markets where competitors would be likely to imitate the technology if it were not protected.

Because patenting is costly inventions are typically protected in only a small fraction of the countries of the world. This is the case even among large and technologically advanced countries. Over 70% of patent families (the set of patents in different countries protecting the same invention) consist of only one patent while only 2% of patent families consist of 10 or more patents [Putnam (1993)].

From aggregate data on patents it is clear that most inventions are only protected at home. For example, in 1988 U.S. inventors applied for patent protection in the United States on 75 thousand inventions but applied for protection in France on only 15 thousand and in Ireland on only 12 hundred. Because foreign patenting is not undertaken carelessly, we believe that it may convey considerable information about patterns of technology diffusion.

3 A Model of International Patenting

Our model incorporates the patenting decision into the quality ladders model of innovation and diffusion developed by Grossman and Helpman (1991). Consider a world consisting of $n = 1, \ldots, N$ countries. Output in country n (Y_n) is produced by combining intermediate inputs subject to a constant-returns-to-scale Cobb-Douglas production function,

$$\ln(Y_{nt}/J) = J^{-1} \int_0^J \ln[Z_{nt}(j) X_{nt}(j)] dj, \tag{1}$$

where $X_{nt}(j)$ is the quantity of input j produced at time t in country n and $Z_{nt}(j)$ is the quality of that input. The range of inputs is fixed over time and the same across countries.[5] Output is homogeneous and tradable across countries, while inputs are nontraded.[6] We choose units so that to produce any input at rate x

[5]Grossman and Helpman (1991) assume that the range of inputs is the interval $[0, 1]$. Our slight generalization serves to parameterize the extent to which a given improvement in an individual input contributes to total output. A larger value of J means that a given improvement has less aggregate effect.

[6]By assuming a single, homogeneous tradable output we prevent inventions from having any effect on the terms of trade between countries. While it would be interesting to consider the implications of inventions for the terms of trade, we preclude the possibility here in order to focus purely on the implications of innovation for productivity.

requires local labor services at rate x.[7]

Output expands over time as the quality of inputs (Z) improve. To keep track of this process, we define an aggregate index of technology in country n as:

$$\ln A_{nt} = J^{-1} \int_0^J \ln Z_{nt}(j) dj. \tag{2}$$

We show below that this index of technology is closely related to labor productivity.

3.1 Inventions

The quality of inputs rises as a result of inventions. An invention, if adopted, improves the quality of a specific input by a percentage amount, the step size of the invention. We assume that the step size of an invention that is invented and adopted domestically is a random variable Q drawn from the exponential distribution, so that $\Pr[Q < q] = 1 - e^{-\theta q}$. The average inventive step of domestic inventions is therefore $\frac{1}{\theta}$. The type of input to which the invention applies is drawn from the uniform distribution on $[0, J]$. If adopted, an invention of size q applicable to input j raises the quality of that input from $Z(j)$ to $Z'(j) = e^q Z(j)$.

We make the size of an invention stochastic, rather than deterministic as in Grossman and Helpman (1991), to introduce heterogeneity in the patenting decision. Inventions that are large steps may be patented widely while small ones may not be worth protecting anywhere.

The same invention may be adopted in a wide set of countries. However, some

[7]The model could easily be modified to accommodate multiple factors. If capital is perfectly mobile between countries (which might be a reasonable approximation for the OECD) then its introduction has no implications for the analysis here. High productivity countries would have more capital seeking to exploit the higher return there, although these countries would not be more productive *because* they had more capital.

inventions will only be applicable to the technologies of one or two. We let ϵ_{nit} be the marginal probability that an invention that occurred in country i at time t is applicable in country n. In the empirical work we explore various parameterizations of these probabilities. We interpret these parameters as indicators of international technology diffusion.

Motivated by the theory of technological catch-up and results from Eaton and Kortum (1994), we assume that a given invention is generally a larger inventive step in a technologically less advanced country.[8] Furthermore, we expect that an invention from a technologically more advanced countries is, on average, bigger and better. To capture these effects in a simple way, we assume that the step size of an invention from country i, adopted in country n, is drawn from the exponential distribution with parameter $\theta \left(\frac{A_i}{A_n}\right)^{-\omega}$, where $\omega > 0$. One interpretation is that the step size is drawn from the exponential distribution in the home country and that the step is simply scaled up or down according to the relative productivity in the adopting country, $Q_{ni} = \left(\frac{A_i}{A_n}\right)^{\omega} Q$. Our theory does not require that we make any assumption about the cross-country correlation of the step size of a given invention.[9]

We assume that research workers are drawn from the same distribution of talent in each country. The most talented researchers engage in R&D activity. The distribution is such that if R_i workers are doing research out of a total workforce of L_i in country i then the country produces inventions at rate $\alpha R_i^{\beta} L_i^{1-\beta}$, where α and β are parameters. Ideas thus flow into country n from country i at time t

[8] The notion of technological catch-up plays an important role in economic history. Gerschenkron (1962) interprets the spread of the industrial revolution throughout Europe and Japan in this light. Fagerberg (1994) surveys analytic and empirical work on the topic.

[9] Putnam (1993) finds a large variance in the size of patent families. This is consistent with a high cross-country correlation of the inventive step of a given inventions.

at rate $\alpha\epsilon_{nit}R_{it}^{\beta}L_{it}^{1-\beta}$ where the mean step size of these inventions is $\frac{\left(\frac{A_i}{A_n}\right)^{\omega}}{\theta}$.

3.2 World Growth

Given the rates at which ideas from around the world bombard country n, and the average inventive step of these ideas, the country's growth rate g_{nt} is:

$$g_{nt} = \frac{\dot{A}_{nt}}{A_{nt}} = \frac{\alpha}{J\theta}\sum_{i=1}^{N}\epsilon_{nit}R_{it}^{\beta}L_{it}^{1-\beta}\left(\frac{A_{it}}{A_{nt}}\right)^{\omega}. \tag{3}$$

Consider a situation in which ϵ_{ni}, R_{it}, and L_{it} are constant over time for all countries. Defining the variable $\mu_{nt} = A_{nt}^{\omega}$, we can state the dynamics of productivity growth among the set of N countries in terms of the system of linear differential equations:

$$\dot{\mu} = \Delta\mu \tag{4}$$

where Δ has typical element:

$$\delta_{ni} = \frac{\omega\alpha}{J\theta}\epsilon_{ni}R_{i}^{\beta}L_{i}^{1-\beta}$$

If this system has a strictly positive eigenvalue λ with a corresponding positive eigenvector (defined up to a scalar multiple) μ then countries will converge to a steady state with a common productivity growth rate $g = \lambda/\omega$ with country n's productivity relative to county N given by $\left(\frac{\mu_n}{\mu_N}\right)^{\frac{1}{\omega}}$.[10]

[10]Frobenius' theorem ensures that, as long as Δ is indecomposable, meaning that there is no ordering of countries such that Δ can be written $\begin{pmatrix} \Delta_{11} & \Delta_{12} \\ 0 & \Delta_{22} \end{pmatrix}$, then there exists a unique strictly positive eigenvector that has a corresponding nonnegative eigenvector. See McKenzie (1960) or Takayama (1974, Theorem 4.B.1). Indecomposability here means that there is no isolated block of countries, i.e., countries not receiving ideas from outside the block, which on its own grows more slowly than countries outside the block.

Some characteristics of the steady state are as follows. First, more research in any particular country raises the world growth rate, rather than the growth rate of that country relative to others. Second, as long as more ideas are adopted locally than abroad then countries that do more research will have higher relative productivity. Third, greater flows of information, as reflected in higher values of the ϵ_{ni}'s, imply higher world growth.[11]

3.3 Market Structure

As in Grossman and Helpman (1991), Bertrand competition between the producers of inputs within a country allows the owner of an invention to charge the highest price at which production without that invention is unprofitable.[12] Let w_{nt} denote the wage in country n at time t, where we use the price of the final output as numeraire. A firm producing an input with an invention of size q in country n at time t will charge $p_{nt} = e^q w_{nt}$. Total purchases of the new input are $\frac{Y_{nt}}{J p_{nt}}$. Given the pricing equilibrium, the profit to the owner of the right to use an invention of size q in country n at time t is $\pi_{nt}(q) = (1 - e^{-q})\frac{Y_{nt}}{J}$.

3.3.1 Productivity

Since the markup differs across sectors, different sectors employ different quantities of labor. Hence our productivity index A_{nt} differs systematically from output per worker. Given the production function (1), cost minimization implies that the

[11]The first and third implications follow from the fact that if the conditions of Frobenius' Theorem are satisfied then λ is increasing in each element of Δ. See McKenzie (1960) or Takayama (1974, Theorem 4.B.1).

[12]The production technology implies a unit elastic demand for an individual input given the prices of all other inputs. Hence to maximize profit the owner of the invention charges the highest price at which it remains the only seller.

quantity produced of input j is $\frac{Y}{Je^{q(j)}w}$. Plugging this term and the definition of the technology index (2) into the production function and solving for the wage gives,

$$w_{nt} = A_{nt}e^{-E_n[Q]},$$

where $E_n[Q]$ is the expected step size of inventions that reach country n. Since output equals the sum of wage and profit income, $Y_{nt} = w_{nt}(L_n - R_n) + \int_0^J \pi_{nt}(q(j))dj = \frac{w_{nt}(L_n - R_n)}{E_n[e^{-Q}]}$. Combining this with the wage equation,

$$y_{nt} \equiv \frac{Y_{nt}}{L_n - R_n} = \frac{A_{nt}e^{-E_n[Q]}}{E_n[e^{-Q}]}.$$

This equation can be implemented using the results that, $E_n[Q] = \sum_{i=1}^N \phi_{ni}E_{ni}[Q]$ and $E_n[e^{-Q}] = \sum_{i=1}^N \phi_{ni}E_{ni}[e^{-Q}]$, where the representative weight, $\phi_{ni} \equiv \frac{\epsilon_{ni}R_i^\beta L_i^{1-\beta}}{\sum_{i=1}^N \epsilon_{ni}R_i^\beta L_i^{1-\beta}}$, is the fraction of usable ideas flowing into country n that originate in country i, $E_{ni}[Q] = \frac{\left(\frac{A_i}{A_n}\right)^\omega}{\theta}$ is the expected inventive step of ideas from country i used in country n, and $E_{ni}[e^{-Q}] = 1/\left(1 + \theta\left(\frac{A_i}{A_n}\right)^{-\omega}\right)$.

3.3.2 The Decision to Patent

An inventor earns the profit generated by his or her invention in a country as long as it is adopted there and has not been imitated or rendered obsolete by a more advanced technology. We assume that inventions are imitated at a rate that depends on whether or not the inventor has a patent in that country. The profits from an imitated invention pass to a local monopolist. We denote the hazard of imitation of an idea from country i in any country n as ι_{ni}^{pat} if it was patented there and as ι_{ni}^{not} if it was not.[13] For a patent in country n to have any value to an inventor from country i requires, of course, that $\iota_{ni}^{pat} < \iota_{ni}^{not}$.

The hazard of obsolescence depends on the rate at which ideas flow into a country and the probability with which they apply to a particular industry. The steady-state rate of obsolescence in country n is thus:

$$o_n = \frac{\alpha}{J}\sum_{i=1}^{N}\epsilon_{ni}R_i^{\beta}L_i^{1-\beta} = \theta g_n - \frac{\alpha}{J}\sum_{i=1}^{N}\epsilon_{ni}R_i^{\beta}L_i^{1-\beta}\left[\left(\frac{A_i}{A_n}\right)^{\omega} - 1\right].$$

In steady state, the hazard of obsolescence is lower in countries with a lower level of technology since these countries obtain fewer inventions. Countries with lower levels of technology still grow at the same rate since the inventions that flow to them come in bigger steps.

Consider, then, the expected value at time t of an invention from country i of size q that is applicable in country n, $V_{nit}(q)$. The probability of its not having become obsolete by time $s > t$ is $e^{-o_n(s-t)}$, while the probability of its not having been copied by then is $e^{-\iota_{ni}^{k}(s-t)}$, where $k \in \{pat, not\}$ depending upon whether or not the invention was patented. Therefore:

$$V_{nit}^{k}(q) = \int_0^{\infty}\pi_{nt+s}(q)e^{-(r+\iota_{ni}^{k})s}e^{-o_n(s-t)}ds = \frac{(1-e^{-q})Y_{nt}}{J(r+\iota_{ni}^{k}+o_n-g)}.$$

Here again $k = pat$ if the idea was patented and $k = not$ otherwise, and r is the discount rate, which we treat as constant over time.

We assume that an inventor chooses whether to seek patent protection in country n after learning both the size of her invention and whether it is applicable

[13]We allow imitation rates to vary depending upon whether or not the idea originated domestically.

in that country. A patent gives the inventor the incremental benefit of a lower hazard of imitation, so is worth $V_{nit}^{pat}(q) - V_{nit}^{not}(q)$. Hence, if it costs an inventor from country i c_{nit} to patent in country n then the inventor will seek patent protection in that country if $V_{nit}^{pat}(q) - V_{nit}^{not}(q)$ exceeds c_{nit} and not otherwise.[14] The return to patenting rises with the quality of the invention q. Hence the condition:

$$V_{nit}^{pat}(q) - V_{nit}^{not}(q) = c_{nit} \tag{5}$$

determines a threshold quality level $\bar{q}_{nit}$ such that inventions of higher quality are patented while those of lower quality are not. A possibility, of course, is that the cost of patenting would exceed the benefit for any invention regardless of its quality, in which case patenting would be zero, and $\bar{q}_{nit}$ infinite. Otherwise, with constant output growth and a constant rate of arrival of inventions, the equation for the quality threshold is,

$$\bar{q}_{nit} = -\ln\left(1 - \frac{J(r + \iota_{ni}^{pat} + o_n - g)(r + \iota_{ni}^{not} + o_n - g)}{\iota_{ni}^{not} - \iota_{ni}^{pat}}\left(\frac{c_{nit}}{Y_{nt}}\right)\right).$$

Note that the cost of patenting enters the problem scaled by the market size of the destination country.

Researchers in country i produce inventions at rate $\alpha R_i^{\beta} L_i^{1-\beta}$, a fraction ϵ_{ni} of which are applicable to country n. Given the quality threshold for patenting and the distribution function for the inventive step, inventors from country i choose to

[14]Since translating patent documents is costly, the cost of applying for a patent may depend on the source country as well as the destination country.

seek protection in country n on a fraction of these inventions given by,

$$f_{nit} \equiv e^{-\theta\left(\frac{A_i}{A_n}\right)^{-\omega}\bar{q}_{nit}} = \left(\max\left\{1 - \gamma_{ni}\frac{c_{nit}}{Y_{nt}}, 0\right\}\right)^{\theta\left(\frac{A_i}{A_n}\right)^{-\omega}}, \tag{6}$$

where $\gamma_{ni} \equiv \frac{J(r+\iota_{ni}^{pat}+o_n-g)(r+\iota_{ni}^{not}+o_n-g)}{(\iota_{ni}^{not}-\iota_{ni}^{pat})}$. Therefore, the number of patent applications from country i for protection in country n, P_{nit}, is:

$$P_{nit} = \alpha\epsilon_{ni}R_i^{\beta}L_i^{1-\beta}f_{nit}. \tag{7}$$

4 Estimation

We estimate the steady state productivity and patent equations using a cross-section of data from 19 OECD countries.[15] The patents variable is patent applications by reporting country and country of residence of the inventor in 1988 (WIPO, 1990). The productivity variable is real GDP per worker in 1988 from Summers and Heston (1991). The productivity variable is averaged over 1986-1988. The list of countries and tabulations of the data are in Table 1.

We begin with OLS estimates of the patent equation. We then present NLLS estimates of the complete system.

4.1 Estimates of the Patent Equation

We can estimate an approximation to the patent equation (7) without solving for the model's implications for growth and technology levels. The patent equation is of interest in its own right, and the parameter estimates can be used as starting

[15]We use this sample since data on research activity are available from them on a fairly uniform basis. Data limitations forced us to drop New Zealand and Switzerland, however.

values for estimation of the complete system.

In order to obtain an equation that is linear in logs, we take a first order approximation to $\ln f_{ni}$ around the points $\ln \frac{A_i}{A_n} = 0$ and $\frac{c_{ni}}{Y_n} = 0$. We obtain, $\ln f_{ni} \approx -\psi_{ni}\frac{c_{ni}}{Y_n}$, where $\psi_{ni} \equiv \gamma_{ni}\theta$. Applying the approximation to equation (7) and imposing constant returns to scale in the production of ideas,

$$\ln \frac{P_{ni}}{L_i} = \ln \alpha + \ln \epsilon_{ni} + \beta \ln \frac{R_i}{L_i} - \psi_{ni}\frac{c_{ni}}{Y_n} + \omega^* \ln \frac{y_i}{y_n} + u_{ni},$$

where we have added a term in relative productivity levels, $\frac{y_i}{y_n}$, as well as an iid error, u_{ni}.[16]

To estimate this equation we must specify the determinants of technology diffusion, ϵ_{ni}, i.e., the probability that an invention from country i will be adopted in country n. We let diffusion from country i to country n depend on: (1) whether n and i are the same country or not, (2) the distance between n and i, (3) the level of human capital in n (the adopting country), and (4) the level of country n's imports from i relative to n's GNP. The first factor allows ideas to flow more freely within than between countries [see Lichtenberg (1993)]. The second factor, distance, is a crude way of examining possible geographical impediments to the free flow of ideas. The third factor tests whether a country's level of human capital increases its ability to absorb ideas from either domestic or foreign sources. The fourth factor examines whether imported goods are a vehicle for the diffusion of

[16]In this equation P_{ni} is actual patent application plus 1. In this way we avoid the problem of zero patent applications (which occur between a few of our country pairs). Since most of the patent counts are quite large, we saw little gain in adopting a probability model that ensured integer valued realizations. For $\frac{c_{ni}}{Y_n}$ we use costs of applying for a patent, including agents fees and translation fees, from Helfgott (1986) scaled by the GNP (from the World Bank). The research variable is R&D scientists and engineers employed by businesses, averaged over 1986-1988 (OECD, 1991, with data interpolated for some countries).

technology [see Coe and Helpman (1994)]. Our specification of technology diffusion is thus,

$$\ln \epsilon_{ni} = \epsilon_{HOM} DH_{ni} + \epsilon_{KM} KM_{ni} + \epsilon_{KM^2} KM_{ni}^2 - \epsilon_{HK} \frac{1}{HK_n} + \epsilon_{IMP} \ln IM_{ni} \quad (8)$$

where DH_{ni} is a dummy variable that equals 1 if $n = i$ and zero otherwise, KM_{ni} is the distance from n to i, KM^2 is the square of distance, HK_n is the average years of schooling in country n, and IM_{ni} is n's imports from i relative to n's GDP (set equal to 1 if $n = i$). If ϵ_{HK} is positive, then our specification implies that the human capital effect has a theoretical maximum of 1 (in levels) corresponding to infinite years of schooling.[17]

Finally we specify how rates of imitation vary across countries, leading to variation in ψ_{ni}. We allow ι_{ni}^{pat} and ι_{ni}^{not} each to take on four values depending on whether $n = i$ or not and depending on whether country n provides strong intellectual property protection or not. This specification amounts to,

$$\psi_{ni} = \psi_{H5} DH_{ni} D5_n + \psi_{H4} DH_{ni}(1 - D5_n) + \psi_{F5}(1 - DH_{ni}) D5_n + \psi_{F4}(1 - DH_{ni})(1 - D5_n),$$

where $D5_n$ is a dummy variable that equals 1 if country n provides the highest level of intellectual property protection.[18] We implicitly assume that obsolescence rates do not vary across countries.

Table 2 reports the OLS estimate of the patent equation. The equation explains

[17]Our data on human capital are from Kyriacou (1991). We thank Mark Spiegel for providing them to us. Import data are from the IMF *Direction of Trade Statistics Yearbook*, various issues.

[18]We use Rapp and Rozek's (1990) index of the strength of intellectual property protection, as reported by Maskus and Penubarti (1994). This index rates countries according to the strength of protection that they provide on a scale from 1 to 5, with 5 serving as the highest level. The OECD countries all score 4 or 5, with the exception of Portugal, which scores 3. Hence we pool those scoring 3 and 4. We thank Keith Maskus for making these data available to us.

over 75% of the variation in foreign patenting across countries. The coefficient on the home dummy and the coefficient on the import variable should be interpreted together since the import variable is arbitrarily normalized to unity for home countries. These coefficients imply that imports are not an important vehicle for technology diffusion but that ideas diffuse more within countries than between them. More generally, technology diffusion between countries falls as the distance between them grows. The quadratic term in distance implies that diffusion attains a minimum at about 10,000 kilometers, at which point it is about one-fifth of the value at a zero distance. Diffusion between Japan or Australia and the rest of the world is somewhat greater, being on the upside of the diffusion-distance curve. It is somewhat surprising that the effect of distance dominates the effect of the import variable. Human capital has the predicted effect of raising the ability of a country to absorb technology. The magnitude of the coefficient implies that, due solely to its higher level of schooling, the U.S. absorbs about five times as much technology as does Portugal. The elasticity of idea production with respect to research employment is precisely estimated to be close to unity. The ψ parameters for foreign patenting are of the correct sign and precisely estimated. Furthermore, $\psi_{F5} < \psi_{F4}$ as theory predicts, i.e. countries providing strong protection are more attractive destinations for foreign patents. The ψ parameters for home patenting are insignificant and of the wrong sign. Finally, the productivity of the source country relative to the destination country does have a positive effect on patenting.

4.2 Simultaneous Estimation of the Patent and Productivity Equations

Our estimate of the patent equation suggests that our model captures some of the major determinants in the international patenting decision. There is a large role for factors that we interpret as determinants of diffusion between countries. These diffusion parameters should have important consequences for the behavior of productivity across countries. To examine these consequences and to sharpen our estimates of the diffusion parameters we now estimate the patent equation simultaneously with an equation for relative productivity levels based on the solution to equation (4).

Using the equations above, let Γy^* be the model's implication for productivity levels in the N countries, where Γ is an arbitrary constant since our model only has implications for relative productivity levels. As with the patent equation, we assume that there is a multiplicative error in measured productivity, i.e., $y_n = \Gamma y_n^* e^{v_n}$, where v_n, $n = 1, \ldots, N$ is iid with variance σ_v^2. Since Γ is unknown, we look at productivity levels relative to country N,

$$\tilde{y}_n \equiv \ln y_n - \ln y_N = \ln y_n^* - \ln y_N^* + \tilde{v}_n,$$

where $\tilde{v}_n \equiv v_n - v_N$ for $n = 1, \ldots, N-1$. The resulting variance-covariance matrix of the disturbance vector $\tilde{v}$ is $\sigma_v^2 \Omega_v$ where $\Omega_v \equiv [I_{N-1} + e_{N-1} e_{N-1}]'$ where I_{N-1} is the $N-1$ by $N-1$ identity matrix and e_{N-1} is an $N-1$ vector of ones.

4.2.1 Specification

All the parameters determining relative productivity levels in the model also determine international patenting, hence we stack the two equations,

$$\begin{bmatrix} \tilde{p} \\ \tilde{y} \end{bmatrix} = G(\Theta, x) + \varepsilon,$$

where $\tilde{p}$ is an N^2 matrix with elements $\tilde{p}_{N(i-1)+n} \equiv \ln \frac{P_{ni}}{L_{ni}}$, $\tilde{y}$ is an $N-1$ vector of relative productivity levels, Θ is a vector of parameters, x is a matrix of exogenous variables described below, and $\varepsilon \equiv [u, \tilde{v}]'$ is an $N^2 + N - 1$ vector of mean zero disturbances with variance covariance matrix, $\Omega = \begin{bmatrix} \sigma_u^2 I_{N^2} & 0 \\ 0 & \sigma_v^2 \Omega_v \end{bmatrix}$.

Since it requires solving an eigenvalue system, our productivity equation is inherently non-linear. We therefore also estimate the patenting equation in the non-linear form in which it appears in (7). We start with the specification of the parameters in f_{ni}: (1) $\iota_{ni}^{not} = \iota^{nf}(1 - DH_{ni}) + \iota^{nh} DH_{ni}$, where ι^{nf} is the rate of imitation of foreign non-patented ideas and ι^{nh} is the imitation rate for domestic non-patented ideas; (2) $\iota_{ni}^{pat} = \iota^{p5} D5_n + \iota^{p4}(1 - D5_n)$ where ι^{p5} is the rate of imitation for patented ideas in countries with the strongest patent protection and ι^{p4} is the imitation rate for patented ideas in other countries. Because of the difficulty of identifying the imitation rates, we set $\iota^{nf} = .25$ based on Mansfield and Romeo's (1980) estimate of the rate at which technology "leaks out" from U.S. firms to non-U.S. competitors. Furthermore, since estimates of ι^{nh} tend to be arbitrarily large (to explain the large amount of patenting at home), we simply fixed $\iota^{nh} = 1000$.

Other determinants of f_{ni} do not need to be estimated. Since the model predicts world growth, the parameter J can be calibrated, conditional on all the other parameters, to make the model predict a growth rate of g. We set $g = .02501$, the average rate of growth of GDP per worker in our countries during 1985-1990. The real interest rate is set at $r = .07$. Finally, the obsolescence rates for each country are calculated from the model. We make one alteration to the patent equation by assuming that with probability η an inventor will choose to patent an invention that is not worth patenting according to our model. This parameter is convenient because if $\eta > 0$ then the model never predicts zero patenting between a pair of countries.

The parameters α, β, ω, and θ enter the estimated model in exactly the way they enter the theory. The diffusion parameters are specified in the same way as in the patent equation estimated above. Thus, we estimate 12 parameters $\Theta = [\iota^{p5}, \iota^{p4}, \eta, \alpha, \beta, \omega, \theta, \epsilon_{HOM}, \epsilon_{KM}, \epsilon_{KM^2}, \epsilon_{HK}, \epsilon_{IMP}]'$ as they enter the three equations:

$$\begin{aligned} P_{ni} &= \alpha \epsilon_{ni} R_i^{\beta} L_i^{1-\beta} [f_{ni} + (1 - f_{ni})\eta], \\ g &= \frac{\alpha}{J\theta} \sum_{i=1}^{N} \epsilon_{ni} R_i^{\beta} L_i^{1-\beta} \left(\frac{A_i}{A_n} \right)^{\omega}, \\ \frac{y_i}{y_n} &= \frac{A_i}{A_n} \frac{E_n[e^{-Q}]}{E_i[e^{-Q}]} e^{(E_n[Q] - E_i[Q])}, \end{aligned}$$

where the second equation is solved for relative technology levels, with ϵ_{ni} defined as in (8) and f_{ni} as defined as in (6).

4.2.2 Estimation

We adopt a two-step feasible generalized non-linear least squares procedure. First, we impose the value of the ratio σ_u^2/σ_v^2, which allows us to construct $\hat{\Omega}$ up to a scalar multiple. We then use a numerical minimization routine to find the value of $\hat{\Theta}$ that minimizes,

$$\left[\begin{pmatrix} \tilde{p} \\ \tilde{y} \end{pmatrix} - G(\hat{\Theta}, x)\right]' \hat{\Omega}^{-1} \left[\begin{pmatrix} \tilde{p} \\ \tilde{y} \end{pmatrix} - G(\hat{\Theta}, x)\right]. \tag{9}$$

From the residuals $\hat{\varepsilon} \equiv [\hat{\varepsilon}_p, \hat{\varepsilon}_y]'$ we calculate $\hat{\sigma}_u^2 = \hat{\varepsilon}_p'\hat{\varepsilon}_p/N^2$ and $\hat{\sigma}_v^2 = \hat{\varepsilon}_y'\Omega_v^{-1}\hat{\varepsilon}_y/(N-1)$. From these estimates of the variances of the patent and productivity errors, we construct a new estimate of Ω and perform the minimization in (9) once again to obtain our parameter estimates. The estimates are shown in the first column of Table 3, based on $\hat{\sigma}_u^2/\hat{\sigma}_v^2 = 35.3$. In the second column we show the first-step estimates obtained by setting $\sigma_u^2/\sigma_v^2 = 100$. The last column shows estimates obtained by setting $\sigma_u^2/\sigma_v^2 = 10$, thus putting relatively more weight on the residuals from the patent equation.[19]

4.2.3 Results

The estimates of the diffusion parameters do not differ enormously from the OLS estimates. One difference, however, is that the coefficient on imports is now significant in the diffusion equation. A second difference is that the human capital parameter is smaller by a factor of 2. Nonetheless, the effect remains large: due to more schooling, the U.S. absorbs twice as much technology as does Portugal.

Most of the parameter estimates do not vary enormously as we change the weight that we place on fitting productivity relative to patenting. One important exception is the catch-up parameter ω which becomes quite large as we place

[19] We solve the model using a program written in GAUSS. The eigen system is solved first, from which we obtain the model's implication for relative productivity levels. Obsolescence rates for each country are then determined, which, along with relative technology levels, are used to obtain the model's implication for patenting. The solution requires less than a second on a Pentium PC with a corrected microprocessor.

great weight on fitting productivity. Surprisingly, given its major theoretical role in determining relative productivity levels, this parameter is poorly estimated in all cases.

Table 4 shows actual and fitted levels of productivity relative to the United States.

4.2.4 Implications for Diffusion

What do our estimates imply about the factors affecting where technologies flow?

Distance The estimates of distance and distance squared imply that ideas diffuse between the most distant countries in our sample at only about a third the rate as between countries that are touching, with the most dramatic decline occurring at small differences. Indeed, our estimates imply that flows between adjacent countries are slightly more intense than within countries.

Trade While imports do appear to be significant in explaining the flow of ideas in the estimation of the full system, the elasticity is only around .1.

Human Capital A country's level of education is significant in explaining a country's ability to make use of ideas regardless of whether they come from home or abroad. The GLS estimation implies that a country achieves 50 per cent of the theoretical maximum benefit from education (when average years of schooling is infinite) when the average level of education is between 13 and 14 years.

4.3 Implication for the Growth and the Distribution of Productivity

We use our estimates to make inferences about three aspects of the world diffusion of technology. One is the extent to which ideas diffuse between countries. A second is the extent to which productivity growth in different countries derives from ideas developed at home and abroad. A third is the extent to which inventors in different countries earn income from ideas at home and abroad. Based on the estimates from the GLS specification, we find the following.

4.3.1 Diffusion

Table 5 reports, for each pair of countries, the values of the diffusion rates ϵ_{ni} implied by our GLS parameter estimates and data on trade and distance. These estimates are normalized by the implied diffusion rate within a hypothetical home country with an infinite amount of human capital. Internal diffusion rates vary (depending on the country's level of human capital) from .23 (Portugal) to .45 (United States). Cross-border diffusion rates vary from .07 (Greece to Canada) to .48 (France to Belgium-Luxembourg).[20] The results suggest that, while there is a tendency for ideas to stay at home, the tendency is not overwhelming. International diffusion rates average roughly half those of domestic diffusion rates.

4.3.2 Growth

Combining our estimates of diffusion rates with our estimates of research output and relative productivity allows us to ascribe the share of each country's produc-

[20]The estimates of our nonlinear system (unlike our OLS estimates) can actually imply slightly higher rates of diffusion between bordering countries than within countries.

tivity growth emanating from each country. Specifically, our estimate of the share of productivity growth in country n that derives from ideas from country i is:

$$\frac{g_{ni}}{g} = \frac{\alpha \epsilon_{ni} R_i^{\beta} L_i^{1-\beta} \left(\frac{\dot{A}_i}{A_n}\right)^{\omega}}{g \theta J}$$

where relative technology levels $(\frac{\dot{A}_i}{A_n})$ are determined endogenously.

Our estimates imply that the United States, followed by Japan and Germany, are the major sources of growth in the world economy. The United States contributes more than half of the productivity growth in every country, while the fractions for Japan and Germany in other countries are around 10 per cent each. Because of its proximity and trade ties with other European countries, Germany's impact is primarily in Europe. We find that Japan contributes about 12 per cent of U.S. productivity growth with Germany contributing less than 2 per cent.

Table 6 reports the share of growth from domestic sources in each country in our sample. Only the United States derives more than half of its growth domestically, and only the United States, Japan and Germany derive more than 10 per cent of their growth from local R&D. Except for the United Kingdom and France, all remaining countries derive more that 95 per cent of their productivity growth from abroad.

The results suggest that the world is not far from one in which all (OECD) countries tap a common pool of knowledge, with a country's relative productivity depending on its ability to absorb that knowledge into its domestic technology.

4.4 The Value of Ideas

Our parameter estimates also allow us to infer how much inventors earn at home and abroad from both unpatented and patented inventions. We are much more uncertain about the implications for these magnitudes than for productivity and growth. They rest on our rather arbitrary assumption that the hazard of imitation abroad differs from that at home on unpatented ideas but not on patented ones. Ideally we would have allowed the imitation hazard to have varied for both types of ideas but our model would not have identified additional imitation parameters with any precision.

Since our model ascribes lower patenting abroad to the lower hazard of imitation of unpatented ideas rather than to a larger hazard of imitation of patented ideas, we are especially uncertain about the extent to which inventors reap the returns to unpatented ideas abroad. We are somewhat more confident that we capture (1) the returns that inventors attain through patenting, which is a lower bound on their total returns, and (2) the social returns to ideas, which has as its lower bound our estimate of the total that inventors capture.

Our estimates imply that the average value of a domestic patent (conditional on a patent having been taken out) varies roughly with market size, ranging from 18 thousand 1988 U.S. dollars for Portugal to $2.2 million for the United States. Our estimates also indicate that Portugal and Ireland have such small markets and poor protection of intellectual property that no foreign idea is worth patenting there.

Table 7 reports estimates of income from patents, total income from ideas (each in billions of 1988 U.S. dollars), along with the share earned at home from each country in our sample.[21] The value of all ideas from the United States appears somewhat large when compared to U.S. company funded R&D in 1988 of about 66 billion dollars. But, we could hardly expect these numbers to match up closely given that our model makes no attempt to explain research expenditures.

Note that only a handful of countries earn much income from patents. While all but the smallest countries earn most of their *patent* income at home, only the United States derives more than half of its total return to ideas at home. This last result also suggests a world in which ideas tend to flow into a common knowledge pool upon which all countries draw.

4.5 Counterfactuals

We can make use of our estimates to consider the consequences for world growth and relative productivity of varying any number of the exogenous variables. We report the results of two such experiments.

4.5.1 U.S. Researchers

What would happen if the United States were to double the number of its researchers? Since these represent a major share of researchers throughout the OECD the impact on steady-state growth is significant, rising from 2.5 per cent to 4.3 per cent. Moreover, it would increase estimated U.S. productivity relative to every country except Australia and Canada by about 10 per cent. For Australia the figure is closer to 5 per cent, while Canada actually gains slightly relative to the United States (see table 4).

[21]For reasons just discussed, we regard income from patenting as a plausible lower bound on what inventors earn from their ideas and total income as a plausible lower bound on the social return to ideas.

4.5.2 World Education

What would happen if every country brought its labor force up to an education level like that of the United States (12 years)? The effect on world growth is less dramatic, rising to 2.6 per cent. Countries with low levels of education would find their relative productivity much higher, however (see the last column in table 4). Our results imply, for example, that Portugal, whose labor force averages only 6.5 years of schooling, would find that its relative productivity level would rise from an initial estimate .47 of the U.S. level to .80 of the U.S. level. (Actually its productivity is only .36 of the U.S. level.)

5 Conclusion

We have developed a model technology diffusion and growth which we have applied to OECD data on patenting and productivity. A major finding is that ideas are very mobile internationally. Except for the United States, growth is largely determined by research done elsewhere.

These implications confirm what we found in our earlier examination of patenting, productivity, and research among the top 5 research economies [Eaton and Kortum, 1994]. A big difference, however, is that here we find a much larger elasticity of research output with respect to research intensity. Our estimate of this elasticity is near 1, as in the theoretical framework of Grossman and Helpman (1991), while in our previous work we found it to be close to zero, although significantly positive.

One explanation for this discrepancy is that our larger sample allows us to observe much more variation in research inputs, so that this parameter is identified more precisely. Another is that, in failing to take the endogeneity of R&D effort into account, we have overestimated the rewards to R&D. Indeed, the relative rewards to R&D implied by our model vary significantly across countries. A topic for future research is to endogenize the R&D process itself.

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Table 1: Selected Data

Country	GDP per Worker	Domestic Patents	Foreign Patents	Patents Abroad	Research S&E's	Research Intensity	Years of Schooling
Australia	30.61	6.57	14.49	8.66	9.86	0.13	8.7
Austria	25.50	2.23	27.90	5.79	3.47	0.10	8.6
Belgium	30.24	0.64	30.70	4.73	8.18	0.20	9.4
Canada	34.33	2.77	27.31	8.09	26.73	0.21	10.0
Denmark	24.56	1.33	9.13	5.06	3.90	0.14	6.9
Finland	26.30	2.04	6.79	5.38	13.51	0.53	10.8
France	29.14	12.44	49.65	42.36	48.80	0.19	9.5
Germany	28.02	31.98	47.79	103.25	107.11	0.36	10.3
Greece	16.83	0.37	12.34	0.17	0.63	0.02	8.4
Ireland	20.82	0.73	2.92	0.76	1.32	0.10	8.8
Italy	29.76	2.29	39.72	19.80	28.06	0.12	9.1
Japan	21.43	63.05	33.20	86.97	278.12	0.36	9.5
Netherlands	29.69	2.16	35.80	16.58	10.73	0.18	9.5
Norway	29.63	0.93	8.02	2.25	10.66	0.51	9.2
Portugal	13.26	0.05	2.19	0.09	0.63	0.01	6.5
Spain	24.45	1.82	22.57	2.21	6.50	0.05	9.7
Sweden	27.60	3.41	32.38	15.05	12.24	0.28	9.6
U.K.	25.51	20.90	55.34	41.18	87.33	0.31	8.5
U.S.	36.42	75.63	65.45	155.30	701.33	0.58	12.1

Sources: GDP per worker (averaged from 1986-1988) in $1000's is from Summers and Heston (1991). Patent applications by residents of each country (for 1988) in 1000's are from WIPO (1990). Foreign patents refer to applications from residents of one of the other 18 countries. Patents abroad is total applications by residents of the given country for patent protection in one of the other 18 countries. Business enterprise research scientists and engineers (averaged from 1986-1988) in 1000's is from OECD (1991). In some cases we interpolated to fill in missing years. Research intensity is researchers per worker in %, and years of schooling is from Kyriacou (1991).

Table 2: OLS Estimate of the Patent Equation

Dependent Variable: $\ln \frac{P_{ni}}{L_i}$

Independent Variable	Parameter	Estimate
Constant	$\ln \alpha$	6.4
		(.5)
DH_{ni}	ϵ_{HOM}	.73
		(.35)
KM_{ni}	ϵ_{KM}	-.31
		(.04)
KM_{ni}^2	ϵ_{KM^2}	.016
		(.002)
$\frac{-1}{HK_n}$	ϵ_{HK}	23
		(4)
$\ln IM_{ni}$	ϵ_{IMP}	.008
		(.041)
$\ln \frac{R_i}{L_i}$	β	.90
		(.06)
$-DH_{ni}D5_{ni}\frac{c_{ni}}{Y_n}$	ψ_{H5}	-.023
		(.021)
$-DH_{ni}(1 - D5_{ni})\frac{c_{ni}}{Y_n}$	ψ_{H4}	-.007
		(.010)
$-(1 - DH_{ni})D5_{ni}\frac{c_{ni}}{Y_n}$	ψ_{F5}	.020
		(.006)
$-(1 - DH_{ni})(1 - D5_{ni})\frac{c_{ni}}{Y_n}$	ψ_{F4}	.035
		(.002)
$\ln \frac{y_i}{y_n}$	ω^*	1.2
		(.22)
Total Sum of Squares		1131
Residual Sum of Squares		250
Number of Observations		361

Estimated standard errors are in parentheses. The estimates of the ψ parameters should be multiplied by one million.

Table 3: NLLS Estimates of the Patent and Productivity Equations

Parameter	Feasible GLS $\hat{\sigma}_u^2/\hat{\sigma}_v^2 = 35.3$	$\sigma_u^2/\sigma_v^2 = 100$	$\sigma_u^2/\sigma_v^2 = 10$
$\ln \alpha$	5.9	6.2	5.8
	(.3)	(.3)	(.3)
ϵ_{HOM}	-.6	-.5	-.3
	(.2)	(.1)	(.2)
ϵ_{KM}	-.27	-.32	-.27
	(.04)	(.03)	(.04)
ϵ_{KM^2}	.015	.018	.015
	(.002)	(.002)	(.002)
ϵ_{HK}	9.5	13	8.7
	(2.1)	(1)	(1.9)
ϵ_{IMP}	.13	.10	.10
	(.04)	(.03)	(.04)
β	.93	.95	.96
	(.05)	(.05)	(.05)
ω	3.6	71	6.9
	(2.2)	(437)	(11)
θ	1.9	1.8	1.8
	(.2)	(.2)	(.2)
ι^{p5}	.240	.239	.239
	(.001)	(.001)	(.001)
ι^{p4}	.238	.238	.237
	(.001)	(.001)	(.001)
η	.047	.055	.054
	(.008)	(.009)	(.010)
$\hat{\epsilon}_p'\hat{\epsilon}_p$	267	268	266
$\hat{\epsilon}_y'\Omega_v^{-1}\hat{\epsilon}_y$	.47	.40	.49
Number of Observations	380	380	380

Estimated standard errors are in parentheses.

Table 4: Productivity Levels Relative to the United States

	Source Country			
Country	Actual	Fitted	Simulated (double U.S. RSE's)	Simulated (12 years of school)
Australia	0.84	0.70	0.65	0.85
Austria	0.70	0.58	0.46	0.74
Belgium	0.83	0.71	0.60	0.82
Canada	0.94	0.99	0.99	1.06
Denmark	0.67	0.49	0.38	0.78
Finland	0.72	0.67	0.57	0.73
France	0.80	0.65	0.54	0.76
Germany	0.77	0.69	0.59	0.77
Greece	0.46	0.50	0.40	0.68
Ireland	0.57	0.69	0.60	0.84
Italy	0.82	0.59	0.49	0.72
Japan	0.59	0.64	0.55	0.75
Netherlands	0.82	0.69	0.59	0.81
Norway	0.81	0.65	0.54	0.78
Portugal	0.36	0.47	0.36	0.80
Spain	0.67	0.67	0.56	0.77
Sweden	0.76	0.66	0.57	0.77
U.K.	0.70	0.61	0.51	0.78
U.S.	1.00	1.00	1.00	1.00

Table 5: Percentage of Ideas Diffusing Between Countries

	Source Country																		
Country of Destination	AL	AU	BE	CA	DK	FI	FR	GE	GR	IR	IT	JA	NE	NO	PT	SP	SW	UK	US
Australia	33	12	20	18	13	12	24	20	10	15	21	12	19	14	22	23	14	25	19
Austria	15	33	25	08	23	19	27	39	19	15	31	08	26	21	14	19	23	26	10
Belgium	21	28	36	11	28	22	47	43	19	25	34	10	48	27	22	28	27	43	14
Canada	20	08	10	38	08	08	12	12	06	09	10	33	11	10	09	09	09	14	44
Denmark	12	17	19	07	25	19	21	29	12	14	18	07	22	26	11	14	26	24	08
Finland	19	25	26	12	33	41	28	37	18	20	24	11	29	33	15	19	45	32	14
France	21	23	37	11	22	17	36	35	17	21	31	10	33	21	21	28	21	37	12
Germany	21	37	37	11	34	26	38	39	21	22	34	11	39	30	19	25	32	37	14
Greece	12	20	18	07	15	14	21	25	32	11	28	08	18	17	12	16	15	19	10
Ireland	26	20	32	12	23	18	35	32	15	33	25	11	33	25	18	25	23	46	14
Italy	18	26	24	09	18	16	31	31	23	15	35	09	23	17	18	24	18	26	11
Japan	09	08	08	09	07	08	09	10	07	07	08	36	08	07	07	09	08	10	13
Netherlands	22	27	47	11	31	22	40	45	20	26	32	10	36	28	21	26	28	44	13
Norway	18	22	28	11	36	27	31	38	14	19	22	10	32	35	16	18	37	36	12
Portugal	18	12	15	07	12	10	20	16	08	12	15	15	16	12	23	24	12	19	08
Spain	23	18	25	10	17	14	33	26	16	18	27	24	24	17	32	37	16	29	12
Sweden	19	25	28	11	36	37	28	36	16	20	24	10	29	37	15	20	37	31	14
U.K.	22	18	30	11	22	17	33	29	14	29	23	09	30	22	18	22	21	32	12
U.S.	19	09	10	37	09	09	12	12	07	11	11	35	11	09	09	11	10	13	45

Diffusion percentages are based on estimates of $100\epsilon_{ni}/\exp(\epsilon_{HOM})$.

Table 6: Growth from Domestic Research

Country	Percentage Domestic
Australia	0.94
Austria	0.33
Belgium	0.82
Canada	2.83
Denmark	0.28
Finland	1.44
France	4.95
Germany	11.25
Greece	0.07
Ireland	0.13
Italy	2.81
Japan	27.02
Netherlands	1.09
Norway	0.98
Portugal	0.05
Spain	0.74
Sweden	1.22
U.K.	7.62
U.S.	81.86

Based on the following expression, for country n,

$$\frac{\alpha}{gJ\theta}\sum_{i\neq n}\epsilon_{nit}R_{it}^{\beta}L_{it}^{1-\beta}\left(\frac{A_{it}}{A_{nt}}\right)^{\omega},$$

and estimated parameters.

Table 7: The Private Value of Ideas

Country	Value of Patented Ideas (in $ billions)	Percentage of Patent Value from Domestic Patents	Value of All Ideas (in $ billions)	Percentage of Total Value from Domestic Market
Australia	0.19	53	2.99	3
Austria	0.04	46	0.81	3
Belgium	0.14	43	2.65	2
Canada	0.96	62	12.14	5
Denmark	0.04	38	0.76	2
Finland	0.15	45	2.76	2
France	2.73	85	15.97	14
Germany	7.51	88	36.67	18
Greece	0.01	33	0.11	1
Ireland	0.01	15	0.33	1
Italy	1.33	85	7.76	15
Japan	38.05	96	91.41	40
Netherlands	0.22	54	3.46	3
Norway	0.11	38	2.34	2
Portugal	0.00	21	0.12	1
Spain	0.17	68	1.88	6
Sweden	0.19	54	3.05	3
U.K.	3.64	81	26.52	11
U.S.	197.17	97	366.05	52

Based on estimated parameters.