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ABSTRACT

European countries do less research than Japan and the United States. We use a quantitative multi-country growth model to ask: (i) Why is this so? (ii) Would there be any benefit to expanding research in Europe? (iii) What would various European research promotion policies do? We find that (i) Europe's lower research effort has more to do with the smaller markets facing European inventors than with lower research productivity. (ii) Europe has substantial research potential in that increased research effort in most European countries generates bigger income benefits there than increased effort in the United States and Japan of equivalent amounts. (iii) Policies to stimulate research in Europe raise productivity not only there but elsewhere. But a problem with pursuing these policies at the national level is the potential for free riding. A second possible problem with promoting research is distributional: While all countries within the European Union benefit, the countries that are already best at doing research, which tend to be the richer members, fare best. The benefits of policies that facilitate the adoption of innovations are more evenly spread.

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1 Introduction

By a number of measures the recent economic performance of Europe has been sluggish. Average GDP per capita in the European Union (EU) is only about two-thirds that in the United States, and is below that in Japan, as shown in Table 1. The generally lower level of per capita employment in Europe explains some of the problem, but output per active worker in the EU is still only 83 per cent of the U.S. level and just higher than Japan's. While productivity in some individual EU members is impressive, a perception remains that Europe has been falling behind. Associated with the sense of relatively poor aggregate performance is Europe's apparent failure to be a player in such burgeoning "high-tech" industries as electronics, computer software, and biotechnology.[1]

A possible culprit is Europe's research performance. European firms, on average, employ a substantially smaller fraction of their workers as researchers, as Table 1 reports. Measures of research output are also not flattering to Europe. In 1993, the average worker in Japan applied for over twice as many U.S. patents as the average worker in the EU. Even on its home turf European patent activity has not been impressive. The average U.S. and Japanese worker sought more German patents than the average non-German worker in the EU.

As Table 1 also indicates, the figures for the EU overall mask considerable variability within its membership. Some European countries, such as Germany and Sweden, appear to be leading innovators as measured by either research intensity or patenting intensity. But the question remains as to how innovative effort translates

[1]See, e.g., the European Commission's "Green Paper on Innovation" (1995). Henceforth EC 1995. On the last point, Zucker and Darby (1995) document that star U.S. bioscientists are much more likely to have a tie with a business enterprise than are their European counterparts.

into productivity advantage.[2]

For Europe's low research output to explain poor performance in other arenas implies that impediments exist to the flow of ideas from the rest of the world. If Europe could exploit inventions from the United States and Japan as readily as the innovators themselves then its own lack of inventiveness would convey no overall productivity disadvantage. To the extent that barriers to diffusion do limit the amount of productive knowledge that flows between countries, however, then innovative lethargy can explain economic doldrums.

If a stagnant research sector is the problem, then why has Europe been less innovative than the United States and Japan? There are two possible answers. One is that research is not rewarded in Europe to the extent that it is elsewhere. Low rewards could be the consequence of fragmented markets, weak patent protection, or the absence of subsidies. Another answer is that Europe is just not very good at doing research, either because it has fallen too far behind the technological frontier, or because it lacks the necessary research infrastructure.[3]

The two explanations suggest different policy responses. Market integration,

[2] Concern about Europe's "research gap" with the United States and Japan is not new. Citing work from the 1960s lamenting Europe's technological backwardness, Patel and Pavitt (1987) provide a detailed comparison of the research achievements of Japan, the United States, and Europe during the period between 1963 and 1983. They conclude that concern about Europe's research situation was overblown. What we find here is that, while a few European countries are rather uncompetitive as research centers, others are very innovative. But the smaller market size facing their inventors keeps them from fully exploiting their research potential.

[3] Schmookler (1966) emphasizes the importance of market size, in contrast to research productivity, as a determinant of innovative activity. Konig and Zimmermann (1986) in examining firm level data on innovation, find an important role for the size a firm's market in influencing its research effort.

more effective and cheaper patent protection, and government subsidies increase the rewards to innovative activity, while enhanced access to foreign technology and improved infrastructure increase research productivity. In fact, as a visit to the webpage of the European Union (`http://europa.eu.int`) reveals, proposals along all of these lines are under discussion.

Missing from the discussion is any assessment of the role of incentives vs. productivity in determining why Europe is not more innovative, or any quantification of how much various policies would help. Two questions need to be answered in assessing benefits relative to costs. First, how effective is a policy in stimulating research effort and, more importantly, innovative output? Second, which countries, if any, are the ultimate winners in terms of productivity and income? Increased innovation might improve Europe's economic performance relative to countries elsewhere, confer improvements globally, or achieve some combination of the two. Alternatively, increased innovation might have no discernible effect, either because Europe's potential contribution is so small or because it displaces innovation elsewhere.

A further set of questions concern the implications of various policies for the individual European states. What are the gains, if any, from coordinating or centralizing policy? Are some countries much better at research than others? How might research be reallocated within Europe? What is the impact on the distribution of income in Europe?

Different approaches to promoting innovation have very different impacts, especially in an international context. Government subsidies typically support activities carried out domestically, regardless of where the results get used, while patents reward research that ends up being used domestically, regardless of where it took place. A government research lab may promote innovation locally, or may spur inventive activity worldwide. On the cost side, government subsidies and spending on infrastructure use up tax revenue, while tougher patent protection inhibits competition.

Eaton and Kortum (1996, 1998) model the determinants of productivity, research activity, and innovation in a world economy in which ideas diffuse imperfectly across borders. Eaton, Gutierrez, and Kortum (1998) extend the model and estimate it using data on productivity, research effort, and patenting from 21 OECD countries in the period 1988-1990. What we do here is to use this framework and the parameter estimates to provide some quantitative insight into the European situation and to examine what various alternative policies might do.[4]

What we find is that Europe does indeed suffer relative to the United States from having smaller and more fragmented markets for its innovations. With a few exceptions, however, we do not find European countries as a whole lacking in intrinsic capacity to do research or in research infrastructure, although our model suggests that Europe might suffer from a lower knowledge base. When we ask, for example, where would more research effort do Europe the most good (in terms of raising EU average income), our answer is in Germany, followed by the low countries. Moreover, more research anywhere in Europe would make a larger contribution to average European income than more research in the United States

[4]To justify our reliance on this framework, we quote two experts on the European research scene: "In principle, any discussion of the policy implications of technology should be based on a fully worked out theory of the role of technology in international trade, investment, growth, and welfare; and of the role of government in dealing with 'market imperfections'." (Patel and Pavitt, 1987).

or Japan.

In terms of various policies, the basic picture that emerges is that research in Europe is very responsive to various types of research policies. Direct research subsidies have a substantial effect on research inputs, with an elasticity of about 4, although our framework does not incorporate the many problems with implementing such policies. But we also find that improved patent protection, if pursued at a continental level, also raises research effort substantially.

Moreover, increasing research effort yields a payoff. It takes less than a 5 per cent research subsidy to raise average per capita income levels in the European Union to a higher steady-state level of 10 per cent. But the benefits are not contained only within the EU. Non EU members in Europe benefit by about as much, while Australia, Canada, Japan, and the United States benefit to a lesser extent. Stronger patent protection in the EU provides another means of achieving higher productivity levels, but here the spillover effects are even greater.

Hence a potential problem is that, since the benefits of such research promotion policies are largely shared, only the largest European economies, such as Germany, have much incentive to pursue them on their own. The rest have little incentive to engage in these policies unilaterally. Our results therefore suggest a role for a coordinated technology policy in Europe.

In section 2, we take a look at some measures of productivity performance, national research activity, and innovation. We then, in section 3, describe our methodology. In section 4 we discuss what our model says about why the situation in Europe is as it is. Finally, in section 5, we examine some implications of various policy alternatives.

2 Research in Europe: A Closer Look

What do the data tell us about research in Europe? In this section we give a statistical overview of research effort at the national level, the sectoral composition of research, and patenting activity in Europe and in other developed countries.

2.1 Aggregate Research Effort

The OECD reports expenditure on R&D by country broken down by sector of performance and by source of funding. Of particular relevance are: (1) R&D performed and funded by business enterprises, (2) R&D performed by business enterprises but not necessarily funded by them, and (3) total R&D spending. The first measure might be called private-sector research while the latter two include a narrow and a broad measure, respectively, of government research support.

The OECD also reports employment of R&D Scientists and Engineers by sector of employment. To obtain a measure of researchers analogous to private-sector research expenditure, we multiply research employment in the business sector by the fraction of business sector R&D that is financed by the business sector.

The scale of a region's research effort is relevant to gauge its influence on technological change. For example, the third column of Table 1 shows that the EU is between Japan and the United States in terms of its overall number of researchers.

More telling about research effort, however, is a measure that corrects for size. Hence in column 3 of Table 1 we report as a measure of research intensity employment of researchers divided by total employment. Here the EU comes in third.

Europe's third-place ranking is not a consequence of this particular definition. Figure 1 presents four different measures of research intensity for Europe, Japan, and the United States during 1988-1990. For both the expenditure-based and the employment-based measures one version incorporates research in all sectors and one includes only private-sector research. While Japan is actually ahead of the U.S. according to the expenditure based measures, Europe is consistently third.

Figure 2 focuses on the employment-based measures of research intensity across all of the 21 countries. The shaded bars portray total research scientists and engineers as a fraction of the labor force, while the lighter bars represent only those who both work in and are funded by the business sector. The picture is one of a Europe that on average devotes a smaller share of its resources to R&D than does the United States and Japan. But note also the tremendous variation in research effort within Europe, especially in the private sector. Some individual European countries, such as Germany, Sweden, and Switzerland, are highly research intensive. On the other hand, Greece and Portugal devote only a tiny fraction of their resources to research. The disparity in the absolute scale of research between the large and small countries of Europe is even greater.

2.2 Industry Composition

One possible reason for cross-country variation in research effort is cross-country variation in industry composition. Industries vary widely in their reliance on research, and research may occur close to production. A country's high research intensity might thus reflect its specialization in research-intensive industries. Alternatively, research intensive countries may have roughly the same industry composition as others but simply do more research overall.

To get a handle on the role of overall level effects vs. industry-composition effects we decompose total research intensity (business enterprise research scientists and engineers as a fraction of employment) in country c, denoted r_c, as:

$$r_c - r_W = \sum_{i=1}^{I}(s_{ic} - s_{iW})r_{iW} + \sum_{i=1}^{I}(r_{ic} - r_{iW})s_{iW} + \sum_{i=1}^{I}(r_{ic} - r_{iW})(s_{ic} - s_{iW}) \quad (1)$$

where r_W is research intensity across all countries, s_{ic} is the employment share of industry i in country c, s_{iW} is the share of industry i in the employment of all countries, r_{ic} is research intensity in industry i in country c, and r_{iW} is research intensity in industry i over all countries. (I is the number of industries.) We thus divide the difference between country c research intensity and the world average into three components: (i) the composition effect, how much employment in country c is weighted toward research-intensive activities, (ii) the intensity effect, how much country c is relatively research intensive across all industries, and (iii) the interaction effect, measuring how much c's industry composition is tilted toward industries in which it is unusually research intensive.

Figure 3 reports this decomposition for 15 countries across 7 industries in the period 1988-1990.[5] Each country has 4 bars. On the left is the country's overall research intensity relative to the average. Following (from left to right) are the contributions of (i) composition, (ii) intensity, and (iii) interaction, respectively, to the total. In general, the cross-country pattern of overall research intensity is explained by the intensity effect: Major research economies tend to do more

[5]Data limitations forced us to reduce the number of countries from 21 to 15. (Switzerland, for example, does not provide any industry breakdown of research activity). The 7 industries are Chemical-linked (food, textiles, and plasics), Earth-linked (wood and furniture, paper and printing, non-metallic minerals, and miscellaneous), Chemicals, Metals, Machinery, Electrical, and Transportation.

research across industries. The composition and interaction effect explain very little of the variation in research intensity. Thus understanding why some countries emerge as research centers requires knowing why they do more research overall, not why they are attractive to high-tech sectors.

2.3 Research and Patenting

Patenting in the United States provides a measure of the effectiveness of research performed in different countries. If patents reflect research output while expenditure or personnel data reflect inputs, we should see a tight relationship between the two. The expected relationship between research effort and patenting in the United States comes through clearly in the numbers in Table 1. The relationship is not simply driven by variation in country scale since we have divided both patenting and private-sector R&D by each countries' work force. Note that Switzerland, Japan, Finland, and Sweden are the leaders in terms of patenting per worker, with Portugal, Greece, and Spain at the other extreme. Although Japan is known to be aggressive in seeking U.S. patent protection, the top European countries do not look too bad in comparison.

3 A Framework for Assessing International Technology Policy

We now turn to an analytic framework that can account for these various figures. It needs to explain: (i) how domestic and foreign markets provide incentives to do research, (ii) how this research generates ideas that advance technology, and (iii) how these ideas are reflected in productivity around the world. Eaton, Gutierrez, and Kortum (1998) provide a framework that integrates these three relationships into a general equilibrium model of growth in the world economy. In the sections that follow we examine Europe's current situation, and assess the implications of various European technology policies, using an estimated version of this model. But first we describe the bare bones of how the model incorporates the three key ingredients, taking them in reverse order.[6]

3.1 Productivity and Ideas

Nontradable intermediate inputs, combine to produce tradable output Y through the production function:

$$\ln(Y/J) = J^{-1} \int_0^J \ln[Z(j)K(j)^{\phi}L(j)^{1-\phi}]dj. \tag{2}$$

Here $K(j)$ is the amount of capital used in making input j, $L(j)$ the amount of labor, and ϕ the capital elasticity. The term $Z(j)$ represents productivity in making input j (or, equivalently for our purposes, the quality of that input in producing output). The range of inputs and, except for $Z(j)$, the technologies for producing them are the same across inputs, countries, and time.

The average quality of inputs will generally differ across countries and over time depending on patterns of innovation and adoption. A natural measure of the average level of technology at any place and time is simply the geometric average of the $Z(j)'s$, which we call A. Indeed, if factors were allocated efficiently

[6]This theoretical framework extends the quality ladders model of Grossman and Helpman (1991) and Aghion and Howitt (1992) to a setting in which multiple countries are innovating and making use of each others innovations. Aghion and Howitt (1997) provide a recent survey of the closed-economy endogenous growth literature, which was pioneered by Phelps (1966), Shell (1966), and Nordhaus (1969).

across sectors then A would correspond to total factor productivity. As discussed below, however, associated with innovation are monopoly markups which lead to an inefficient allocation of labor

An invention is an idea for making a particular input more cheaply, or for improving its quality: If adopted at home, an invention of size q makes the quality of a specific input e^q times better. We interpret q as the inventive step and assume that for each invention it is drawn from an exponential distribution with parameter θ. The average inventive step of a domestic invention is thus $1/\theta$, but ideas can differ in size.

Since a given idea might provide a larger percentage contribution in a more backward country, we allow an idea from country i that constitutes an improvement q at home to provide country n with an improvement of $q(A_i/A_n)^{\omega}$, where ω relates the step size of inventions to the technology gap between source and destination.

Ideas differ in their universality as well as in their size. Some inventions might be adopted widely while others may only find use in a small number of countries. Important for our analysis are the fractions of inventions from each country that are used in each country. We use ϵ_{ni} to denote the fraction of ideas from country i that are used in country n. If some country n is particularly good at adopting ideas, then its ϵ_{ni}'s will be high compared with other countries as destinations. If ideas are more likely to be used at home than abroad then we would expect the ϵ_{ii}'s to exceed the ϵ_{ni}'s for which $n \neq i$..

Countries differ in their ability to generate ideas. We use the parameter α_i to represent the flow of ideas generated in country i.

Putting these concepts together gives us a fundamental relationship between the growth of technology g_n in each country n and the generation of ideas around the world:

$$g_n = \frac{1}{J\theta} \sum_{i=1}^{N} \epsilon_{ni} \alpha_i \left(\frac{A_i}{A_n}\right)^{\omega}. \quad n = 1, ..., N \tag{3}$$

Here N is the number of countries.

Note that as a destination country gets farther behind, ideas that arrive have a larger percentage effect on productivity (as long as $\omega > 0$). This force eventually brings countries to a common steady-state growth rate, although their relative productivity levels may remain permanently different, depending on their abilities to adopt inventions.[7] In the steady state of the model, the α's and ϵ's are constant, technology grows at the same rate in all countries, and the system of equations (3) determines levels of technology in each country relative to country N as well as a common technology growth rate g.

This relationship points to how a country's productivity depends both on the flow of ideas generated around the world and on its ability to make use of those ideas. National policies to promote technology include: (i) measures to stimulate innovative output at home, (ii) measures to stimulate innovative output in other countries whose ideas feed domestic technology, and (iii) measures to enhance the adoption of ideas.

We relate ϵ_{ni} to the distance between i and n, imports of n from i, the level of education in country n, and to whether n and i are the same country. In particular:

$$\ln \epsilon_{ni} = \epsilon_D DH_{ni} + \epsilon_{KM} KM_{ni} + \epsilon_{KM^2} (KM_{ni})^2 - \epsilon_{HK} \frac{1}{HK_n} + \epsilon_{IMP} \ln IM_{ni}, \tag{4}$$

where DH_{ni} is a dummy variable that equals 1 if $n = i$ and zero otherwise, KM_{ni}

[7] This force can be interpreted as Gerschenkron's (1962) "advantages of backwardness". See Eaton and Kortum (1996).

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 i's GDP (set equal to 1 if $n = i$). We turn next to the determinants of the α's.

3.2 Generating Ideas

We relate a country's inventiveness to its research effort, which involves scientists, other workers, and materials.[8] Since increasing research effort may force a country to use less talented researchers, we assume that the productivity of additional researchers declines as the fraction of researchers employed relative to the total labor force rises. We also allow countries to differ fundamentally in the environments that they provide for research activity. Finally, we allow for the possibility that, as technology progresses, coming up with new ideas may become harder and harder.

Combining these effects we specify a country's inventive output as:

$$\alpha_i = a_i (r_i^{\beta} L_i)^{\beta_L} M_i^{1-\beta_L} \overline{A}^{-\gamma}. \tag{5}$$

Here L_i is country i's total labor force and r_i the fraction engaged in research, with β reflecting the rate at which research productivity declines as more people do research; β_L is the labor share in the innovative process; and M_i denotes materials used in innovation. The parameter a_i captures the country's research productivity or ability to provide an environment conducive to research. Finally, $\overline{A}$ is the average state of technology in the *world*, reflecting the state of world

[8]We estimate the share of labor as an input in innovation by its percentage of total R&D cost. Based on OECD data, for the countries in our sample, labor, capital, and materials account respectively for 48%, 18%, and 34% of R&D costs. We simplify by combining capital with materials used in research.

knowledge. As world technology advances coming up with better ideas becomes harder, as governed by the parameter γ.[9] We assume that each scientist employed in innovation requires b additional workers.

We assume that the labor force of each country grows at a common rate g_L. We consider a steady state in which inventive output nonetheless remains constant as the growth of human and materials inputs in research is just offset by the "research drag" from rising world technology.

Policies affect inventive output in two ways. One is by increasing resources devoted to R&D activities, i.e. r or M. The other is by increasing research productivity a.

3.3 Research Incentives and Patenting

The rewards to employing people or materials in research depend both on their marginal product in coming up with ideas and the value of those ideas to the inventor. We use V_i to denote the average value of an idea to an inventor in country i (which will not, in general, correspond to its social value).

We use aggregate output as numeraire. Hence output will be devoted to research (in the form of R&D materials) up to the point at which its marginal value product equals $1/(1+s_i)$, where s_i represents the R&D subsidy in country i. Similarly, labor will be devoted to research until $(\partial\alpha_i/\partial r_i)(V_i/L_i)$ is equal to $w_i/(1+s_i)$, where w_i is the production wage.

[9] A strictly positive γ yields Jones's (1995) explanation for the slowdown in U.S. research productivity. For $\gamma = 0$ growth is endogenous while if $\gamma > 1$ it is only "semi-endogenous."

Solving the labor market equilibrium condition for r gives, in logarithms:

$$\ln r_i = k^r + \frac{1}{\beta_L(1-\beta)}\left[\ln(1+s_i) + \ln a_i + \ln\left(\frac{V_i}{w_i^{\beta_L}}\right)\right] + u_i^r. \qquad (6)$$

Here k^r is a constant common to all countries which incorporates, among other things, the "research drag" imposed by the existing world stock of ideas $\overline{A}$ on research productivity and u_i^r is a multiplicative error in our measure of research intensity. (As noted in Section 2, there are many alternative measures which give somewhat different readings on countries' research efforts.)

Our policy discussion considers a government's influence on three key terms entering equation (6). A government can set subsidies directly, as they often do through the tax treatment of R&D expenditure and income.[10] A government might also enhance the productivity of private research through education and public sector research. Finally, patent policy affects the value of ideas. But lacking any comprehensive data, in fitting equation (6) to the cross-country data on research effort appearing in column 1 of Table 4, we set research subsidies to zero.

The estimating equation highlights the two systematic sources of variation in research activity posed by Schmookler (1966): (1) differences in research productivity a_i and (2) differences in the value of inventions relative to the wage $(V_i/w_i^{\beta_L})$.

To give the equation substance it remains to determine V_i and w_i. We assume that, as long as an idea has not been imitated or rendered obsolete by further invention, its inventor can charge a markup over cost equal to the inventive step of the idea over the previous state of the art.

Imitation depends on: (1) whether the innovation is patented, (2) whether the

[10] Bloom et al. (1998) discuss differences in the tax treatment of R&D across 8 of our 21 countries.

innovation is from a local or foreign inventor, and (3) the level of intellectual property protection provided by the destination country. For unpatented inventions the third factor is irrelevant. Hence an unpatented invention from country i in country n faces an imitation hazard ι_{ni}^{not} given by:

$$\iota_{ni}^{not} = \begin{cases} \iota_D^{not}, & n = i \\ \iota_F^{not}, & n \neq i. \end{cases} . \tag{7}$$

For an inventions that is patented, the hazard is ι_{ni}^{pat} is:

$$\iota_{ni}^{pat} = \begin{cases} \iota_D^{not}(IP_n)^{\gamma_{IP}}, & n = i \\ \iota_F^{not}(IP_n)^{\gamma_{IP}}, & n \neq i, \end{cases} , \tag{8}$$

where IP_n is an index of the strength of intellectual property protection in country n. Once an innovation is imitated it is generally available, so the mark-up falls to zero.

While imitation rates appear in the model as parameters, the hazard o_n of obsolescence in country n depends endogenously on the flow of ideas arriving there.

Let $\pi_{nu}(q)$ denote the profit generated by an invention of size q in country n at time u, and ρ the discount rate (treated as an exogenous constant). Given a patent duration of T_n years in country n, then, the value there at time t of an invention of quality q from country i, if it is patented, is:

$$V_{nit}^{pat}(q) = \int_0^{T_n} \pi_{nt+s}(q)e^{-(\rho+\iota_{ni}^{pat}+o_n)s}ds + \int_{T_n}^{\infty} \pi_{nt+s}(q)e^{-(\rho+\iota_{ni}^{not}+o_n)s}ds. \tag{9}$$

If it is not patented the value is:

$$V_{nit}^{not}(q) = \int_0^{\infty} \pi_{nt+s}(q)e^{-(\rho+\iota_{ni}^{not}+o_n)s}ds. \tag{10}$$

An inventor from i decides whether to apply for a patent in country n after learning the size of her invention and whether it is applicable in that country. A patent gives the inventor the incremental benefit of a lower hazard of imitation in n, so is worth $V_{ni}^{pat}(q) - V_{ni}^{not}(q)$. Hence, if it costs the inventor C_{ni} to patent there then an application is worthwhile if $V_{ni}^{pat}(q) - V_{ni}^{not}(q)$ exceeds C_{ni}. This condition determines a threshold quality level $\bar{q}_{ni}$ such that inventions of higher quality are patented while those of lower quality are not. The fraction of diffused ideas that are worth patenting is thus $f_{ni} \equiv \exp(-\theta_{ni}\bar{q}_{ni})$. We assume, however, that patent applications are subject to an additive error η and multiplicative error u_{ni}^P.

Putting these things together, and taking logarithms, our patent equation is:

$$\ln P_{ni} = \ln \alpha_i + \ln \epsilon_{ni} + \ln[f_{ni} + \eta(1 - f_{ni})] + u_{ni}^P. \tag{11}$$

We use this equation to estimate cross-country patterns of patenting.

To ascertain the expected returns to research, we first note that an invention from country i of size q has value in country n, conditional on making it there, of:

$$V_{ni}(q) = \begin{cases} V_{ni}^{pat}(q) - C_{ni}, & q \geq \bar{q}_{ni} \\ (1-\eta)V_{ni}^{not}(q) + \eta(V^{pat}(q) - C_{ni}), & q < \bar{q}_{ni} \end{cases} \tag{12}$$

When deciding to do research, however, an inventor does not know how large her invention will be or how widely it will be used. Unconditional on quality or diffusion, then, the expected value of an idea is:

$$V_i = \sum_{n=1}^{N} \epsilon_{ni} \int_0^\infty V_{ni}(q)\theta_{ni}e^{-\theta_{ni}q}dq, \tag{13}$$

which is what matters for labor market equilibrium, condition (6).

A major policy influencing the value of an idea is thus the strength of patent protection. Tougher patent protection, by reducing the hazard of imitation, increases the value of ideas not only for a local inventor but for any foreign inventor whose idea might be used in the country. Hence tougher patent protection raises the reward to research not only at home but in foreign countries whose ideas the domestic market draws upon. Strengthened protection comes at the cost of higher markups in local markets and, when inventors are foreign, in greater royalty payments abroad.

The production wage w_i depends on the level of technology A_i and the extent of monopoly distortion. Our model implies that markups in country i are a random variable U_i with a complicated distribution which depends, among other things, on the nature of i's patent protection and its ability to absorb ideas.[11] Our assumptions here imply that:

$$w_i = (1-\phi)\left(\frac{\phi}{\rho}\right)^{\phi/(1-\phi)} A_i^{1/(1-\phi)} \left\{e^{-E[U_i]}\right\}^{1/(1-\phi)} \tag{14}$$

Note that the wage is higher when technology A_i is more advanced, but lower when the average monopoly markup $E[U_i]$ is greater.

Finally, we relate countries' observed labor productivities to their technology levels. Three issues arise in this connection. First, since production uses capital, we make an adjustment to move from total factor productivity to labor productivity, assuming perfect capital mobility. Second, we need to account for the role of markups in lowering the efficiency of labor allocation in the economy. Third, some workers do research so do not produce measured output.

In fitting our model to data on labor productivity y_n we assume that it is observed with error u_n^y, and normalize by productivity in one country (N). Putting

[11] We spare the reader its derivation here, referring the curious to Eaton, Gutierrez, and Kortum (1998).

all this together, our estimated productivity equation is:

$$\ln(y_n/y_N) = \ln(\Gamma_n/\Gamma_N) + \frac{1}{1-\phi}\ln(A_n/A_N) + \ln\frac{1-(1+b)r_n}{1-(1+b)r_N} + u_n^y - u_N^y, \quad (15)$$

where Γ_n reflects the extent to which monopoly mark-ups reduce labor productivity.

3.4 Combining the Ingredients

Given a set of parameters, we can solve for the steady-state levels of research intensity, international patenting, and labor productivity given by equations (6), (11), and (15). Equation (3) determines the relative technology levels which enter equation (15) and, if J is appropriately calibrated, it will predict actual world TFP growth. Where possible, we used previous studies to set parameter values, as reported in Table 2. The remaining parameters were estimated to fit data on research intensity, patenting, and productivity. The data are described in the appendix. We report our estimates and their standard errors in Table 3.

Assessing the general equilibrium implications of a research policy in a global context requires tracking its impact on research activity and productivity around the world. Hence numbers must be put on a large number of parameters. Any quantitative answers we provide about the effects of policy depend, of course, on the parameter values we use. A particularly critical parameter is β, the elasticity of research output with respect to research activity. We estimate it to be .19, suggesting that returns to research effort diminish quite rapidly. This low estimate is the model's way of reconciling the rather low variation in research effort in the face of big differences in research output and productivity. Also critical is β_L, the share of labor in research effort. As this share falls, the productivity of doing research becomes more sensitive to productivity overall, multiplying the effect of research on productivity by a greater amount. Based on research costs from our countries we set β_L at .5, but our results are very sensitive to the particular value we impose. Since these parameters are key, a particular goal of future work is to bring additional evidence to bear on their magnitudes.

Note also that our parameter estimates imply that patenting abroad diminishes the hazard of imitation only modestly. While this is consistent with other evidence, we are somewhat wary of these particular magnitudes. An item for future research is obtaining alternative estimates, and examining the sensitivity of the results to these particular magnitudes.

4 Understanding Europe's Situation

Before turning to analyzing specific policies, we first ask how are model explains why Europe isn't more active in research, and what is says about whether it should be.

4.1 Why Doesn't Europe Do More Research?

Recall that equation (6) allows us to decompose the sources of variation in research intensity into market return effects (the expected value of an invention to an inventor relative to the wage, V/w^{β_L}) and research productivity effects (a). The first column of numbers in Table 4 presents, for the countries of our sample, the fraction of the labor force engaged as private researchers. Note, as we discussed above, that despite concern about Europe's lack of inventiveness, three European countries are more research oriented than Japan. While the United States allocates the largest fraction toward research, Germany is close behind.

The second column reports what our model *predicts* about research intensity. We capture the Italian, Japanese, U.K. and U.S. figures quite closely but we substantially overpredict research in some of the smaller European countries (which patent a lot given their research effort, suggesting that their research productivity is high). On the other hand, our predictions for New Zealand, Ireland, and Greece are on the low side. Overall, our model explains about 80 per cent of the variation in research intensity across countries.

How does our model divide its explanation of its predictions about research intensity between research productivity and incentives? The third column of numbers presents our estimates of research productivity (a), normalized with the United States at one. We find the United States actually below average, ranking only above Portugal. Among most of the other larger countries research productivity is around double the U.S. level, while for some of the smaller and more distant countries we estimate it to be substantially higher.

So why don't these countries do more research? The fourth column of numbers reports our estimates of the value of invention relative to the wage (V/w^{β_L}), again normalized by the United States. Note that these magnitudes are by far the largest for the United States and Japan. An implication is that access to a large home market for inventions, rather than research prowess *per se*, explains the extent of U.S. and Japanese research activity.

4.2 Should Europe Do More Research?

Do these estimates imply, then, that Europe as a whole would benefit by shifting research activity toward countries where research productivity is higher? Not necessarily, since countries with high research productivity might not be good at transmitting innovations elsewhere. Table 5 reports the implications for total income in the EU and (for purposes of comparison) in the United States of adding one private researcher to each country. Since absolute magnitudes are arbitrary, for each case we normalize by the effect of increasing research activity in the United States.

Note that an additional researcher in any of the European countries has more impact on overall EU production than an additional researcher in the United States. Additional research in Germany, followed by the Netherlands and Belgium, deliver the biggest bang to EU income. While these countries are not as productive in research as Switzerland and the Scandinavians, their innovations disseminate more broadly. At the other extreme, within Europe more research in Portugal and Greece delivers the least.

Not only is German research, on the margin, most potent in Europe, it ranks third in the United States (after the U.S.'s own and Canada's). Even though, in related work, Eaton and Kortum (1996) find Japanese innovation the second largest source of U.S. productivity growth (after that of the United States itself) in terms of its total contribution, here we find that increased Japanese research, at the margin, makes a relatively small contribution (behind most European countries). This finding follows from the relatively large amount of research that Japan is already doing, relative to its size, and its modest research productivity.

In summary, these results portray a Europe with unfulfilled research potential. We now ask how successful alternative policies could be in exploiting it.

5 Alternative Scenarios for Europe

We examine four alternative policies that might invigorate the European research scene. The first three affect research output directly: research subsidies, strengthened patent protection, and enhanced research productivity. We then compare the effects of increasing European research output with the effects of increasing Europe's ability to *adopt* technology, including technology from abroad. The absolute magnitude of intervention is in each case arbitrary. For purposes of comparison we consider, in each case, a level of intervention sufficient to increase the average steady state level of income among the members of the European Union by 10 per cent.

While the policy interventions required to subsidize research and strengthen patent protection are straightforward, it is less clear what governments can do to improve research productivity and absorptive capacity. To shed some light on the first issue we relate our estimates of the productivity of private research to measures of public research support. We find a strong positive association between government supported research and private research productivity. We are hesitant to attribute all of the relationship to causality from public support to research productivity, however. Regarding the second issue, our estimates point to education and imports as determinants of international diffusion, suggesting how Europe might enhance its ability to adopt innovations by raising educational levels and opening markets.

An important distinction is between policies pursued collectively and by individual countries. We report the effects of changing these various features of the research environment in the EU as a whole, but have also considered what happens when individual members implement the policy changes. In many cases the country implementing the policy benefits less than the other members of the Community, pointing to the benefits of collective action.

The changes we consider have implications for a number of magnitudes of interest. As a country absorbs more inventions, the average efficiency of its production sector, i.e. its technology level, rises. But advances in technology do not raise income one-for-one. Policies (in particular patent policy) can alter the allocative efficiency of the economy and therefore change the wedge between the state of technology and output per worker. Furthermore, different policies affect what a country pays to foreigners and earns from foreigners in the form of patent royalties. For purposes of brevity we report the effects of the changes we consider on labor productivity and on income, as well as what their imply for private research activity.

5.1 Subsidizing Research

We estimate that achieving a 10 per cent rise in the average level of EU income would require a permanent research subsidy of around 4.9 per cent. Table 6 presents the results. We find that research intensity rises within the EU by about 20 per cent more or less across the board.[12] The effect on research elsewhere varies. Research also rises, but by lesser amounts, in countries near the EU, but falls in countries farther away. The effect on nearby countries seems to be dominated by

[12] Bloom, Griffith, and Van Reenen (1997) find that R&D is stimulated by favorable tax treatment, although their estimated long-run elasticity is considerably lower than that implied by our simulations. They also find a substantial amount of relocation of R&D relocates in response to changes in its tax treatment, a result that is reflected somewhat in our simulations.

the larger European market while the more rapid obsolescence resulting from more European innovation is the dominant effect farther away.

Since there are diminishing returns to research, the effects on EU income and productivity are, of course, more modest. Evidence of the importance of diffusion is that these magnitudes outside the EU rise by 2 per cent or more, and approach those within the EU for countries nearby, illustrating the potential for free-riding.[13]

These results suggest that encouraging research is very much a world public good. In principle one country's research subsidy could largely crowd out another's, leading to little increase in overall research activity but simply a reallocation of the productivity benefits. We find the potential for such crowding out to be small, however, in that the decline in research elsewhere is fairly small. Moreover, the productivity benefits abroad can approach or exceed those in the subsidizing country.

It is important to point out that our model does not take into account many of the problems associated with research subsidies. We do not, for example, take into account the excess burden of the taxes that finance the subsidies. Nor do we ask how the government overcomes the adverse selection problem of targeting the most productive researchers or the moral hazard problem of eliciting serious research effort. The microeconomic literature on research incentives suggests how a patent system, despite the monopoly distortions it imposes, can overcome some of these problems.

[13]Our experiment allows inventors to charge distortionary markups over the cost of production (until imitation or obscolescence) even though they are also receiving a government subsidy. Hence we are not considering the effect of *replacing* monopoly rights with government subsidies as a means to encourage research.

5.2 Strengthening European Patent Protection

We estimate that achieving the same overall EU income objective through strengthened patent protection would require reducing the hazard of imitation of inventions patented within the EU by slightly more than 15 per cent (thus leaving the imitation rates at 85 per cent of their current levels). Table 7 reports the consequences.

Research effort rises by slightly more, both within and outside of the EU, than with a subsidy. In terms of income the spillover effects are even larger in that countries outside the Union benefit by more than they did with a subsidy. Indeed the biggest beneficiary is Switzerland, which does not increase its own level of patent protection in this simulation.

Note also that, compared with a research subsidy, improved patent protection has a more uneven effect on incomes within the EU, with the richer, already more research-intensive economies faring the best.

5.3 Enhancing Research Productivity

Another form of policy intervention might aim directly at improving research productivity. Our estimates imply that achieving a permanent 10 per cent income gain across the EU would require a rise in research productivity of just under 3 per cent. Table 8 reports what would happen to individual countries. The income effects are very similar to those of a research subsidy: Non-EU European countries gain about as much as their EU neighbors, while the effect in the U.S. is a little less than a quarter of that in Europe. Germany is the biggest gainer, while, as with stronger patent protection, poorer EU members gain less. Research activity rises everywhere, but not as much as with a subsidy, except in North America and in Japan (where it barely changes).

But what sort of specific policy interventions might increase private research productivity? A possibility might be government-supported research (either in the private sector or in government laboratories or universities). Of course any connection drawn between such public activities and the efficacy of private research are highly speculative. But to provide some idea of the possible connection regressed the log of our estimate of private research productivity on the log of the share of *public* research scientists and engineers in the total labor force. The results imply that a one per cent increase in public researchers raises private research productivity by 0.72 per cent. This estimate probably overstates the effect, however, since, factors that make a country a good place to do private research probably also lead the government to do more public research. Nevertheless, the result leaves open the possibility of high returns to public research efforts.[14] Taking seriously, for a moment, this relationship, public research effort would have to go up by 4.1 per cent to achieve the 10 per cent income gain in the EU.

5.4 Facilitating Adoption

Finally, what would happen if Europe sought to increase income with measures to increase its ability to adopt innovations, rather than to innovate? Our model points to two channels that might facilitate adoption: raising levels of education

[14]To what extent do the benefits of publicly supported research spill across borders? We related our estimates of research productivity to public research scientists and engineers in other countries, weighted by our estimates of diffusion based on patenting. We did not find a significant relationship. We also asked whether being a major destination for patenting enhances research productivity (using distance as an instrument for patenting from other countries). The relationship was positive, but not significant.

and increasing trade among EU members.

We estimate that the EU could attain a 10 per cent permanent increase in its average income level by raising the average level of schooling among its members by a little over half a year. Table 9 reports. The effects are very similar to those of subsidizing research or raising research productivity except that the benefits are spread more equally among the EU membership, with poorer countries such as Portugal sharing more of the gains. Research effort rises everywhere except in North America.[15]

Increased trade provides another means of encouraging diffusion. Table 10 reports the effects of achieving a permanent 10 per cent average income gain through increased trade within the EU. We estimate that achieving this goal would require increasing intra EU trade volumes by about 70 per cent. The effects are roughly similar as with increased schooling, except that the effects outside the EU are more muted, since this policy does not have a direct impact on the absorption of technology from outside the EU.[16]

6 Conclusion

Our analysis points to several broad conclusions:

[15] Hence our results suggest that the returns to improving education in Europe are potentially high. This impression should be tempered by three caveats: (1) cross country comparisons of educational attainment are notoriously problematic; (2) our estimates of the impact of educational attainment on absorbtion are imprecise; (3) our calculations do not take into account the cost of education.

[16] A caveat here is that we have not modelled the determinants of trade itself in order to indicate what specific policies might lead to increased trade flows. Moreover, we have not established that causality runs from trade to diffusion and not the other way around.

1. For the most part research productivity in Europe is as high or higher than in the United States or Japan. Smaller market size, rather than lower research productivity, explains Europe's lower rate of private research effort.

2. Increasing research activity in most European countries, in particular in Germany, could make a substantial contribution to productivity levels not only in the EU but throughout the OECD.

3. EU policy measures to increase research output (subsidies, stronger patent protection, or enhanced research productivity) can raise productivity not only in the EU but throughout the OECD. While policies that increase research activity within the EU raise productivity both there and elsewhere, they tend to reduce research effort in countries farther away.

4. A problem in implementing research policy at the national level is the enormous potential for free riding. This potential is somewhat greater with respect to patent protection than the other policies we consider.

5. While policies to stimulate research can benefit countries throughout the EU, the wealthiest countries tend to benefit slightly more. Policies aimed at improving the ability to adopt innovations, however, tend to favor poorer countries.

All these conclusions are, of course, drawn from a particular parameterization of a particular framework, as any such conclusions must be, and at this point they must be regarded as tentative. Any theoretical framework ignores aspects of the world that are potentially important. As just one example here, lack of comprehensive data prevented us from looking at the relationship between foreign direct investment and technology flows.[17] Even in terms of the model itself, our analysis is incomplete. We have not taken into account all of the costs of some of the policies we examine, such as increasing education levels and increasing public research effort. Moreover, we only look at the effect of different policies in the long run, ignoring what happens during the transition. Confronting these issues will be difficult, but taking them into account remain important topics for future research.

What we hope we have done is: (i) to provide a basic framework for thinking about the fundamental issues involved in European technology policy, (ii) more speculatively, to combine this framework with available data to provide an answer as to why the countries of Europe specialize in research as they do, and (iii) more speculatively still, to see what various European policies toward research might achieve.

[17] Among the evidence that this connection might be important is Bosworth's (1984) finding of a relationship between patent flows to and from the United Kingdom and foreign direct investment positions.

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A *Appendix A: The Data*

Our sample is a cross section of 21 OECD countries.[18] Our data are chosen to reflect the situation in the period 1988-1990 as closely as possible.

Our endogenous variables are as follows:

- Patents P_{ni} are patent applications by reporting country n and country of residence of inventor i averaged over 1988-1990 (OECD, 1995).[19]

- Productivity y_n is real GDP per active worker in country n, relative to the United States, averaged over 1988-1990 (OECD, 1997).

- Our measure of research effort starts with business enterprise research scientists and engineers, relative to total employment, from OECD (1995). To obtain our measure of research intensity in country i, r_i we multiply this figure by the fraction of business enterprise R&D expenditure that is privately financed (averaged 1988-1990). In some cases we interpolated to fill in missing years.

[18]The countries are listed in Table 1. Data on research activity from them are available on a fairly uniform basis. The sample includes the major research economies of the world (based on international patenting activity, for instance) and it covers a overwhelming preponderance of world GDP.

[19]During this period Japanese inventors applied for over 300,000 patents per year domestically. This figure compares, for example, with only around 75,000 applications by U.S. inventors in the United States. Okada (1992) finds that Japanese patents granted to foreigners contained on average 4.9 times as many inventive claims as patents granted to domestic inventors. To account for this discrepancy we translate 4.9 Japanese patents sought domestically to the equivalent of one application by a foreign inventor in Japan or by any inventor elsewhere. There is no evidence of any other significant international differences in the claim content of patents.

Our explanatory variables are as follows:

- Our labor variable L_i is total employment in country i relative to the United States (OECD, 1997).

- We measure human capital HK as average years of schooling of the labor force in 1985 (1980 for Switzerland), as reported by Kyriacou (1991).

- Import data IM are from the IMF *Direction of Trade Statistics Yearbook*, various issues.

- Distance KM is between major cities (reported in Eaton and Tamura, 1994) from Software Toolworks, version 5.0.

- We measure patenting costs $c_{ni} = \frac{C_{ni}}{Y_n}$ as the cost of applying for a patent, including agents fees and translation fees, constructed from Helfgott (1986), scaled by GNP (from the World Bank).[20]

- To measure the strength of intellectual property protection in country n we take the arithmetic average of four of the five sub-indices entering Ginarte and Park's (1997) overall index of the strength of patent rights by country, which we label GP_n. The four sub-indices are the coverage given to patent holders, the enforcement of patents, membership in international agreements, and possibilities for losing protection (we exclude their index of patent duration since it enters our model directly). Our final index is

[20]We ignore the more complicated fee structure applying to patents through the European Patent Office, except to the extent that it reduces translation costs. We also ignore complications introduced by patent renewal fees. Pursuant to our discussion of Japanese patents in the footnote above, we scale up the cost of an application for a Japanese inventor in Japan by a factor of 4.9.

$IP_n = (1 - GP_n)/\max\{1 - GP_j\}$ which is decreasing in the strength of intellectual property protection and is bounded between 0 and 1.

- We use Ginarte and Park's data on patent duration T_n by country.

Table 1: Is the European Union Technologically Backward?

Country	GDP per Capita	GDP per Worker	Researchers in Business	Research Intensity	Patenting Intensity in Germany	Patenting Intensity in the U.S.
	dollars	dollars	persons	per cent	per thous.	per thous.
U.S.A.	27,821	58,329	764,500	0.635	0.197	——
Japan	23,235	45,049	257,094	0.398	0.204	0.567
EU	19,318	48,958	375,775	0.257	0.177	0.250
Austria	21,395	50,496	4,010	0.122	0.295	0.225
Belgium	21,856	60,031	8,750	0.232	0.200	0.220
Denmark	22,418	46,303	5,883	0.237	0.250	0.320
Finland	18,871	46,102	5,453	0.267	0.405	0.534
France	20,533	53,508	66,455	0.299	0.237	0.256
Germany, W.	21,200	50,376	128,956	0.366	——	0.387
Greece	12,743	34,462	1,319	0.035	0.011	0.011
Ireland	18,988	51,799	2,576	0.218	0.101	0.143
Italy	19,974	57,173	27,932	0.136	0.115	0.110
Netherlands	20,905	52,479	11,370	0.192	0.384	0.312
Portugal	13,100	30,868	481	0.011	0.004	0.004
Spain	14,954	47,302	11,256	0.092	0.032	0.031
Sweden	19,258	43,327	15,334	0.386	0.365	0.527
U.K.	18,636	41,416	86,000	0.336	0.179	0.272
Australia	20,376	44,472	13,976	0.188	0.094	0.191
Canada	21,529	47,159	35,484	0.273	0.061	0.320
New Zealand	17,473	37,682	1,508	0.101	0.095	0.143
Norway	24,364	50,077	7,141	0.356	0.125	0.182
Switzerland	25,402	47,537	8,600	0.225	0.808	0.580

Notes: The two columns with GDP figures are for 1996 while the rest of the data are for 1993. GDP is translated to current dollars by the OECD using their PPP's. The number of workers is OECD employment. Researchers are R&D Research Scientists and Engineers employed in Business Enterprises. Missing observations for 1993 were filled in with the latest year available. Research Intensity is the researchers expressed as a per cent of total employment. Patenting intensity is the number of patent applications in either Germany or the United States per thousand workers in the inventor's country. We do not report domestic patent applications since they are not comparable due to the large home bias in patenting.

Table 2: Calibrated Parameters

Description	Symbol	Value	Source
Real interest rate	ρ	0.07	Stock Returns
Capital Elasticity	ϕ	0.3	Capital's Share
Labor Share in Research	β_L	0.478	OECD average, 1989-1991
Employment Growth	g_L	0.0097	OECD average, 1986-1996
Labor Productivity Growth	g_y	0.0136	OECD average, 1986-1996
Total Factor Productivity Growth	g	0.0952	$(1-\phi)g_y$
Research Drag	γ	0.71	$\gamma = g_L/g + (1-\beta_L)/(1-\phi)$
Markets per Country	J	1.5 (million)	Calibrated to fit $g_y = .0136$
Staff per Researcher	b	1.43	OECD average, 1988-1990
Domestic Nonpatent Imitation	ι_D^{not}	0.41	Mansfield
Foreign Nonpatent Imitation	ι_F^{not}	0.25	Mansfield

Table 3: Estimated Parameters

Description	Symbol	Value	Std. Error
Domestic Patent Imitation	ι_D^{pat}	0.046	(0.111)
Foreign Patent Imitation	ι_F^{pat}	0.237	(0.001)
Stronger IP Protection	γ_{IP}	0.023	(0.006)
Fraction of Mistaken Patents	η	0.055	(0.007)
Home-bias of Diffusion	ϵ_D	0.28	(0.16)
Distance effect on Diffusion	ϵ_{KM}	-0.14	(0.02)
Squared Distance Effect	ϵ_{KM^2}	0.0054	(0.0012)
Human Capital Effect	ϵ_{HK}	4.5	(2.3)
Import Effect on Diffusion	ϵ_{IMP}	0.11	(0.03)
Technological Catch-up	ω	3.3	(1.0)
Size Distribution Parameter	θ	5.4	(0.9)
Research Skill Elasticity	β	0.19	(0.04)
Research Productivity, Australia	a_1	72.2	(27.6)
Research Productivity, Austria	a_2	48.8	(17.1)
Research Productivity, Belgium	a_3	36.0	(11.9)
Research Productivity, Canada	a_4	23.3	(8.2)
Research Productivity, Denmark	a_5	59.4	(22.6)
Research Productivity, Finland	a_6	57.4	(18.2)
Research Productivity, France	a_7	34.1	(13.0)
Research Productivity, Germany	a_8	36.1	(13.4)
Research Productivity, Greece	a_9	18.6	(7.5)
Research Productivity, Ireland	a_{10}	31.7	(10.9)
Research Productivity, Italy	a_{11}	28.1	(11.5)
Research Productivity, Japan	a_{12}	25.0	(11.1)
Research Productivity, Netherlands	a_{13}	47.1	(15.3)
Research Productivity, New Zealand	a_{14}	53.2	(19.3)
Research Productivity, Norway	a_{15}	43.3	(14.6)
Research Productivity, Portugal	a_{16}	9.6	(4.5)
Research Productivity, Spain	a_{17}	19.3	(7.7)
Research Productivity, Sweden	a_{18}	56.2	(18.3)
Research Productivity, Switzerland	a_{19}	70.4	(23.4)
Research Productivity, U.K.	a_{20}	31.3	(12.7)
Research Productivity, U.S.	a_{21}	15.8	(6.8)

Table 4: What Determines Research Intensity?

Country	Research Intensity Actual (per cent)	Research Intensity Estimated (per cent)	Research Productivity Estimated (US = 1)	Research Incentive Estimated (US = 1)
Australia	0.155	0.198	4.568	0.144
Austria	0.109	0.184	3.083	0.207
Belgium	0.212	0.165	2.277	0.269
Canada	0.161	0.094	1.473	0.335
Denmark	0.145	0.256	3.756	0.193
Finland	0.200	0.260	3.630	0.201
France	0.169	0.302	2.158	0.359
Germany	0.358	0.511	2.280	0.416
Greece	0.015	0.008	1.176	0.163
Ireland	0.120	0.070	2.006	0.219
Italy	0.110	0.125	1.775	0.311
Japan	0.351	0.324	1.578	0.504
Netherlands	0.165	0.354	2.975	0.277
New Zealand	0.090	0.045	3.367	0.111
Norway	0.227	0.140	2.736	0.210
Portugal	0.009	0.002	0.608	0.178
Spain	0.061	0.032	1.222	0.266
Sweden	0.236	0.371	3.552	0.236
Switzerland	0.242	0.692	4.451	0.240
U.K.	0.222	0.265	1.977	0.372
U.S.	0.450	0.583	1.000	1.000

Notes: The research incentive, relative to the reward for production work, is defined as V/w^{β_L}.

Table 5: Where Would Another Researcher Do the Most Good?

Another Research in:	Effect on EU Income	Effect on US Income
Australia	1.749	0.316
Austria	4.451	0.386
Belgium	5.019	0.433
Canada	1.641	0.571
Denmark	4.240	0.389
Finland	4.326	0.416
France	4.709	0.387
Germany	5.585	0.456
Greece	2.762	0.234
Ireland	3.872	0.400
Italy	4.044	0.323
Japan	0.912	0.316
Netherlands	5.025	0.450
New Zealand	1.849	0.316
Norway	3.823	0.409
Portugal	1.746	0.139
Spain	3.602	0.313
Sweden	4.647	0.436
Switzerland	4.422	0.436
U.K.	4.301	0.364
U.S.	1.000	1.000

Notes: The figures are normalized relative to the effect on income of one more researcher in the United States.

Table 6: A Research Subsidy in the European Union

Country	Income	Productivity	Research
Australia	6.63	6.70	-0.01
*Austria	10.18	9.96	23.12
*Belgium	9.93	9.74	22.00
Canada	3.92	3.97	-5.52
*Denmark	9.82	9.51	22.03
*Finland	9.52	9.21	21.15
*France	10.20	9.89	20.36
*Germany	11.19	10.57	22.14
*Greece	9.26	9.33	20.40
*Ireland	8.98	8.95	20.37
*Italy	9.61	9.54	18.85
Japan	6.19	6.21	-0.11
*Netherlands	10.29	9.80	22.87
New Zealand	6.95	7.02	0.69
Norway	9.49	9.48	7.54
*Portugal	8.66	8.74	18.45
*Spain	8.79	8.82	17.68
*Sweden	9.55	9.10	20.52
Switzerland	9.77	9.49	7.23
*U.K.	9.64	9.41	18.87
U.S.	2.39	2.48	-6.20

Notes: The numbers represent the per cent change in the steady-state paths of endogenous variables caused by a research subsidy in the EU of $s = 0.0488$. Current members of the EU are identified with a $*$.

Table 7: Stronger Patent Protection in the European Union

Country	Income	Productivity	Research
Australia	7.70	7.68	6.83
*Austria	10.15	10.36	26.67
*Belgium	9.94	10.17	25.95
Canada	4.97	4.99	-0.13
*Denmark	9.74	9.85	25.36
*Finland	9.49	9.62	23.46
*France	10.22	10.35	20.52
*Germany	11.17	10.99	21.34
*Greece	9.15	9.68	23.03
*Ireland	9.15	9.44	22.91
*Italy	9.63	10.01	19.10
Japan	7.17	7.16	1.22
*Netherlands	10.33	10.23	25.84
New Zealand	7.92	7.96	10.05
Norway	10.42	10.25	23.02
*Portugal	8.55	9.08	21.47
*Spain	8.80	9.29	18.81
*Sweden	9.58	9.55	22.78
Switzerland	11.32	10.20	24.44
*U.K.	9.64	9.87	18.25
U.S.	3.48	3.52	-4.79

Notes: The numbers represent the per cent change in the steady-state paths of endogenous variables from reducing imitation rates for inventions patented in the EU by 15.03 per cent. Current members of the EU are identified with a *.

Table 8: More Productive Research in the European Union

Country	Income	Productivity	Research
Australia	6.68	6.74	0.02
*Austria	10.20	10.05	17.50
*Belgium	9.95	9.83	16.42
Canada	3.95	4.00	-5.54
*Denmark	9.82	9.61	16.45
*Finland	9.52	9.31	15.60
*France	10.19	10.00	14.86
*Germany	11.14	10.72	16.60
*Greece	9.32	9.39	14.88
*Ireland	9.02	9.02	14.85
*Italy	9.64	9.62	13.39
Japan	6.23	6.25	-0.11
*Netherlands	10.27	9.92	17.26
New Zealand	7.00	7.07	0.73
Norway	9.55	9.54	7.63
*Portugal	8.72	8.80	13.00
*Spain	8.84	8.88	12.26
*Sweden	9.52	9.22	15.00
Switzerland	9.84	9.55	7.32
*U.K.	9.64	9.52	13.42
U.S.	2.41	2.50	-6.23

Notes: The numbers represent the per cent change in the steady-state paths of endogenous variables from raising research productivity in the EU by 2.96 per cent. Current members of the EU are identified with a *.

Table 9: More Technology Absorption via Schooling in the European Union

Country	Income	Productivity	Research
Australia	5.92	5.97	0.68
*Austria	10.35	10.23	15.58
*Belgium	9.92	9.82	13.71
Canada	3.61	3.65	-4.07
*Denmark	10.88	10.64	18.26
*Finland	9.21	9.06	11.51
*France	10.08	9.93	12.31
*Germany	10.59	10.28	12.62
*Greece	9.65	9.73	13.75
*Ireland	9.30	9.31	12.98
*Italy	9.72	9.71	11.58
Japan	5.51	5.52	0.09
*Netherlands	10.15	9.88	14.23
New Zealand	6.20	6.25	1.55
Norway	8.35	8.32	8.19
*Portugal	10.14	10.23	16.63
*Spain	8.89	8.93	9.93
*Sweden	9.47	9.23	12.10
Switzerland	8.64	8.32	8.10
*U.K.	10.00	9.90	12.68
U.S.	2.31	2.38	-4.90

Notes: The numbers represent the per cent change in the steady-state paths of endogenous variables from more technology absorption as predicted by raising the level of schooling by 0.5357 years throughout the EU. Current members of the EU are identified with a *.

Table 10: More Technology Absorption via Trade Within the European Union

Country	Income	Productivity	Research
Australia	5.86	5.92	-0.90
*Austria	10.59	10.39	21.59
*Belgium	10.41	10.23	20.83
Canada	3.46	3.51	-5.46
*Denmark	10.26	9.97	20.81
*Finland	9.95	9.68	19.24
*France	10.19	10.00	13.63
*Germany	10.48	10.11	13.07
*Greece	9.71	9.80	18.63
*Ireland	9.45	9.44	19.26
*Italy	9.89	9.86	12.74
Japan	5.45	5.47	-0.26
*Netherlands	10.66	10.22	20.55
New Zealand	6.16	6.22	-0.63
Norway	8.40	8.41	5.01
*Portugal	9.07	9.16	16.56
*Spain	9.16	9.20	13.10
*Sweden	9.89	9.51	17.93
Switzerland	8.56	8.40	4.57
*U.K.	9.66	9.54	11.67
U.S.	2.11	2.20	-5.44

Notes: The numbers represent the per cent change in the steady-state paths of endogenous variables from more technology absorption as predicted by increasing trade within the EU by 69.57 per cent. Current members of the EU are identified with a $*$.

Figure 1: Research Intensity Indicators

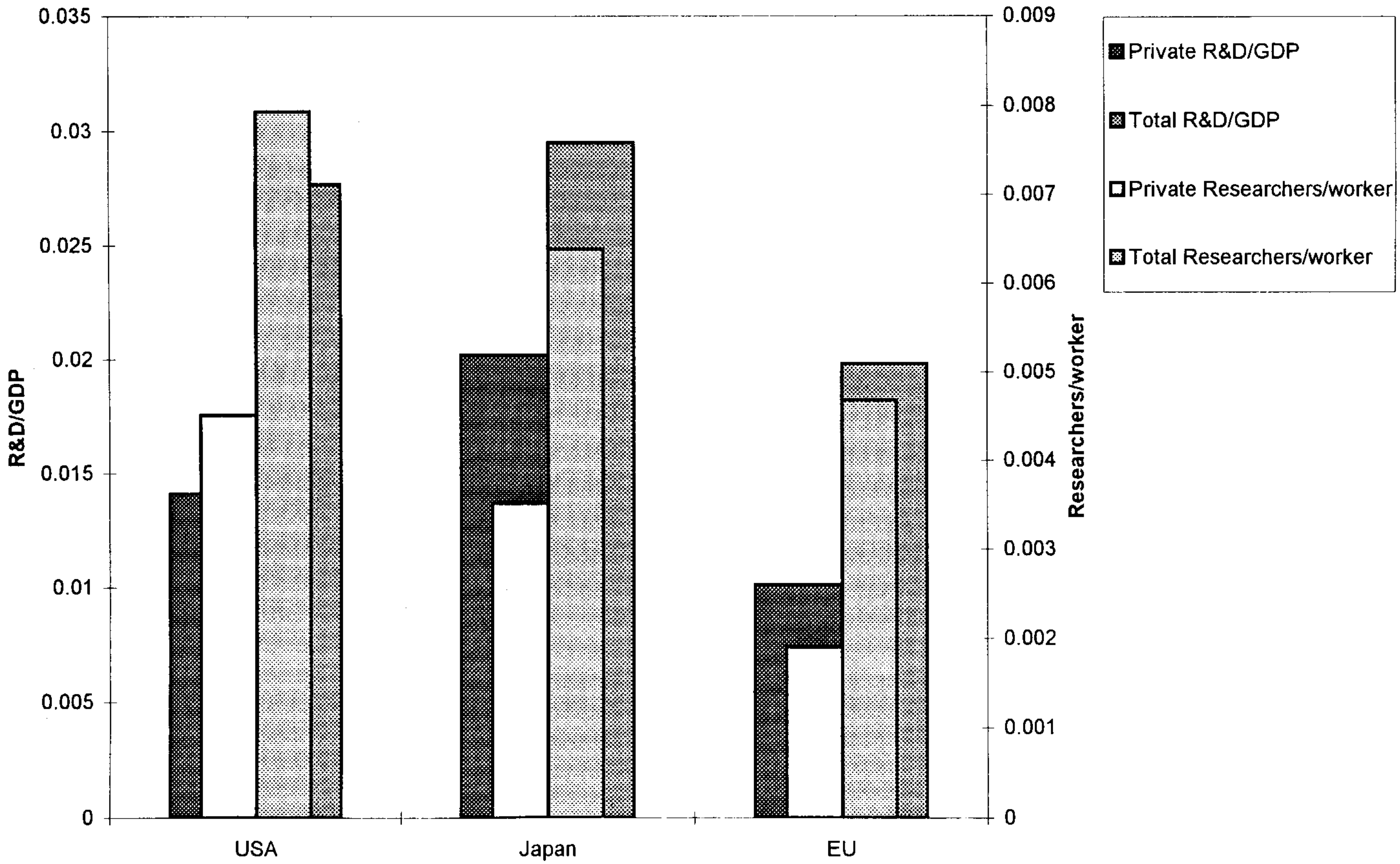

Figure 2: Researchers as a Fraction of the Work Force

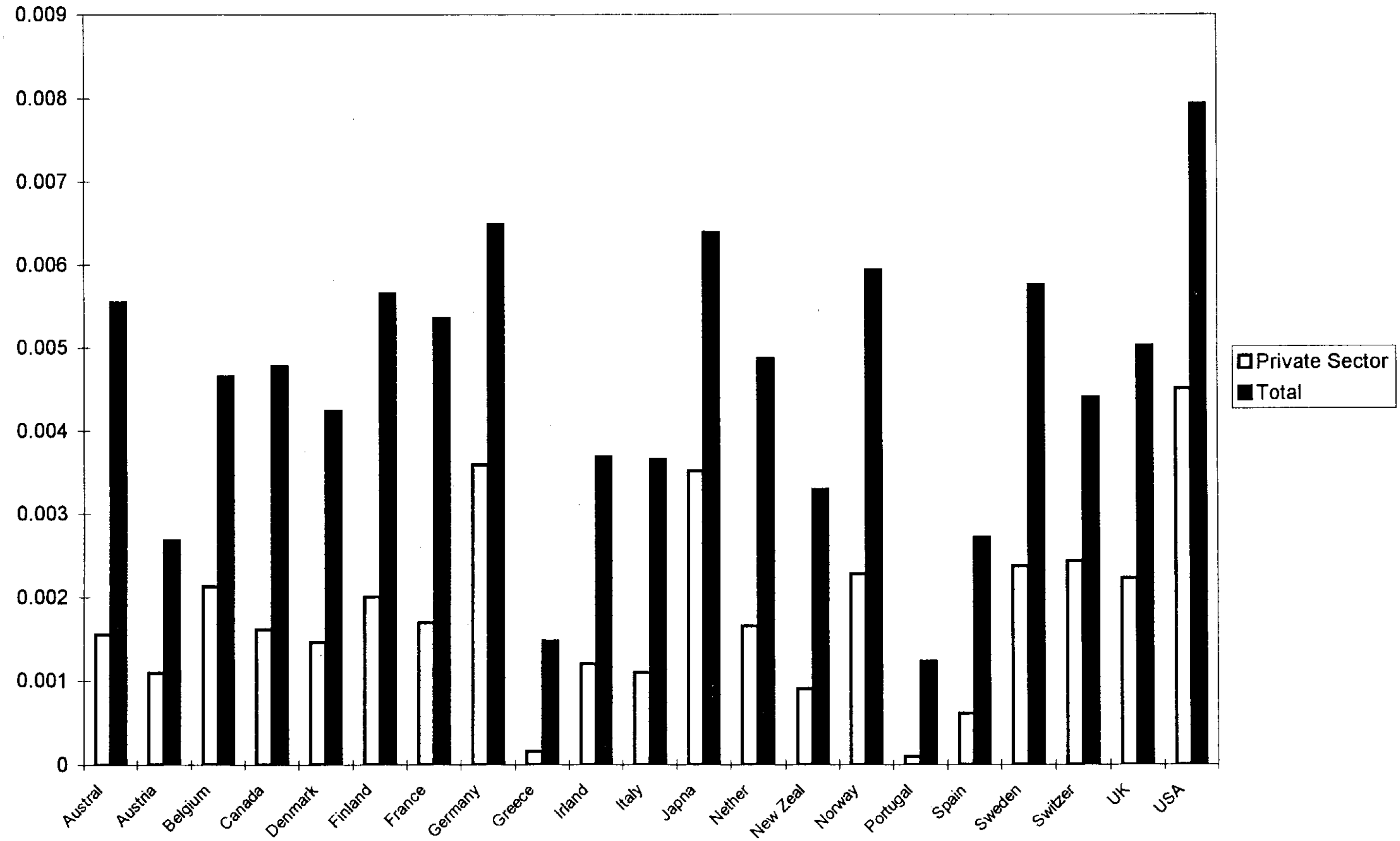

Figure 3: The Effect of Industry Compostion on Research Intensity