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Thinking ahead for Europe

R&D and the Financing of Ideas in Europe

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Foreword by
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Abstract

In March 2000 in Lisbon, EU heads of state and government set the strategic goal to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion. These goals were confirmed at the Barcelona European Council, which added that investment in European R&D should be increased to 3% of GDP by 2010.

This Working Document argues that the weakness of R&D and the slow accumulation of knowledge in the EU is probably a major reason why Europe has failed to catch up with the US productivity performance during recent decades. But the emphasis of the Barcelona Council on the spending target for R&D could be misplaced as the question is not so much one of increasing the level but rather of enhancing the efficiency of R&D in Europe. Thus it is important to understand how countries compare in their abilities to encourage greater levels of knowledge, and asks why the countries vary in their abilities to turn R&D into innovative and commercial products through the creation of new, successful companies (and consequently more employment).

After an examination of various potential constraints on innovative entrepreneurship, efforts towards the enforcement of competition policy, the introduction of a European patent, adaptations of the tax systems in favour of entrepreneurship, a reduction of red tape, the adaptation of bankruptcy rules and the easing of finance for new ventures are all welcome measures. Nevertheless, actively subsidising investment by venture capitalists may not necessarily deliver the desired results. Consequently, policy measures aimed at enhancing the efficiency and productivity of R&D in Europe should focus on the level of knowledge of workers and the capacity of entrepreneurs to translate scientific excellence into viable technological innovation.

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FOREWORD

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The Barcelona R&D targets

In March 2000 in Lisbon, EU heads of state and government set the strategic goal to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion. The Lisbon conclusions also outlined what was presented as a new working method: the open method of coordination (OMC) designed to bring about a high degree of convergence of member states' policies in fields not covered by the traditional common policies such as, notably, fiscal policy and social policy but also a number of other policies normally reserved for national competences. Policies supporting and stimulating R&D constitute a prominent example of the latter.[1]

The Lisbon targets were confirmed at the Barcelona European Council in March 2002. Furthermore, the latter Council meeting agreed that investment in European research and development (R&D) must be increased to 3% of GDP by 2010, with at least two-thirds of the total investment coming from the private sector. This goal is intended to focus the attention of the Commission and member states on the reforms necessary to deliver not only higher but also more productive business investment. To achieve this objective, the Commission in its recommendation for the 2002 Broad Economic Policy Guidelines (BEPGs) for the economic policies of the member states and the Community called for better incentives for firms to invest in R&D while preserving sound fiscal policies.

In September 2002, the Commission adopted the Communication entitled *More Research for Europe: Towards 3% of GDP* (European Commission, 2002) with recommendations for member states, industry and other stakeholders for achieving the 3% objective. The Brussels European Council in March 2003 reinforced the member states' commitment to the Barcelona objective and called for concrete action to attain the 3% target and for strengthening of the European Research and Innovation Area to the benefit of all in the enlarged EU. Finally, in a Communication on *Investing in Research: An Action Plan for Europe* (European Commission, 2003) in June 2003 the Commission outlined a series of detailed steps to be taken at the level of the EU, member states or even regions in pursuit of the Barcelona target.

The weakness of R&D in the EU: A diagnosis

As Laura Botazzi highlights in this Working Document, the weakness of R&D and the slow accumulation of knowledge in the EU is probably a major reason for the unsatisfactory productivity performance during recent decades.

In fact, most or all available indicators on the level of R&D confirm that the EU as a whole is lagging seriously behind other OECD countries, notably the United States and Japan. Thus,

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[1] For an assessment of the potential of the OMC see Gràinne de Búrca and Jonathan Zeitlin (2003).

on average for the period 1995-99, total R&D expenditure in the EU amounted to about 1.8% of GDP as against some 2.5% in the US and close to 3% in Japan. With respect to private R&D expenditure the relative difference was even larger, with the EU at around 1% of GDP compared with nearly 2% in Japan and the US.

The gap between Japan and the US on one side and the EU on the other was equally striking when measured by the number of researchers. In fact, over the same period the number of researchers amounted overall to some 0.5% of employment in the EU as against 0.8% in the US and close to 1% in Japan. The number of researchers in the business sector was only some 0.2% in the EU or about a third of the level in Japan and the US. As far as patent intensity (the number of patents during a year per thousand persons employed) is concerned, the EU is also seriously lagging behind when measured by the number of patents registered in the (most important) US Patent and Trademark Office.

While the European R&D intensity on average lags behind Japan and the US, the detailed country-by-country data show huge differences between the north and the south of Europe. Among the EU member states, Finland and Sweden appear to be in a class of their own, with a research intensity in the same range as in Japan and the US. The high level of the Scandinavian countries (also including Norway) contrasts sharply with the low level seen in Greece, Italy, Portugal and Spain. In this respect the new member state Poland is in the same category as the Mediterranean countries. Other EU member states (Belgium, Denmark, France, Germany and the UK) are in a more favourable situation that the latter group, but typically show research intensity at roughly half the level of Japan and the US.

According to Bottazzi, the low research intensity in the EU is not in the main owing to a high share of industries with a low intensity of research (composition effect) but essentially the result of a low level of R&D in all branches of the economy. Digging further into the analysis of the nature and effects of the low R&D intensity, she shows convincingly that the low intensity of research gradually translates into a low level of accumulated knowledge.

Using the cumulated number of patents (with each patent weighed with the average yearly number of citations that a patent posted with the US Patent Office receives in its first three years of existence) as a proxy for the production of innovation, she calculates an index for knowledge per worker accumulated during the 1973-96 period for a number of OECD countries. According to these estimates, the knowledge capital per worker more than trebled in the US and Japan from 1972 to 1995 while it rose much less in the EU countries. Although the US and Japan maintained their leadership, the dispersion of the indices fell moderately, indicating a certain catching-up by EU countries such as Spain and Finland, which initially had a very low level of knowledge capital.

Bottazzi then turns to decomposing the average creation of new ideas as measured by “patent productivity” into three components: 1) expenditure on R&D per worker in R&D; 2) stock of patents per worker in R&D; and 3) a general productivity-enhancing factor in R&D creation. She concludes that within the EU, certain member states (notably Denmark and Finland) obtain more innovation than other member states from a given level of R&D. By including the stock of ‘world knowledge’, she finds a strong impact on domestic innovation in a number of countries, an observation that confirms the findings of a number of other studies of the productivity of R&D expenditure (in terms of innovation). Consequently, the main problem for most (major) EU countries is not the *level* of R&D but the capacity to translate scientific excellence into viable technological innovation.

Bottazzi agrees that the scarcity of risk capital and of venture capital in particular may harm the innovative ability of start-ups. Venture capital has been shown to benefit start-ups beyond the supply of finance. In other words, there is a 'soft' side to venture capital that adds value to the 'hard' financial side: venture capitalists are often a 'coach' for entrepreneurial start-ups. At least in the US, venture capital adds to national innovative capabilities by affecting both the efficiency of the knowledge-production function (more and better patents per given inputs) and the overall total factor productivity. There is not such evidence, however, for Europe. In fact, in Europe venture capital investment in the early stages of ventures is only one-fifth of what is invested in the US. Furthermore, nearly half of the funds come from banks and established companies, while in the US venture firms are most often small independent partnerships working more closely with the management of the firms in which they invest. This seems to confirm that venture capital investment in Europe is much less 'adventurous' than in the US.

Concluding from an examination of various potential constraints on innovative entrepreneurship, Bottazzi argues that enforcing competition policy, introducing a European patent, adapting the tax systems in favour of entrepreneurship, reducing red tape, adapting bankruptcy rules and easing finance for new ventures are all welcome measures. She argues, however, that actively subsidising investment by *venture capitalists* may not necessarily deliver the desired results. In fact a large part of European venture capital finds its way to the American capital market and thus does not benefit innovation in Europe.

Consequently, policy measures aimed at enhancing the efficiency and productivity of R&D in Europe should therefore particularly focus on the level of knowledge of workers and the capacity of entrepreneurs to translate scientific excellence into viable technological innovation.

Assessing the action plan for investing in research

The action plan presented by the Commission in June 2003 included four main sets of actions, comprising a total of 46 new initiatives, including:

- steps to enhance the coordination of policies through active use of the *open method of coordination* and the creation of European 'technology platforms' (five new initiatives);
- strengthening the quantity and quality of the flow of human resources into research (23 new initiatives);
- redirecting public spending towards research and innovation (six new initiatives); and
- improving framework conditions for private investment in research through adaptation of intellectual property rules, regulation of products and standardisation, competition rules and adaptation of the financial and fiscal environment (12 new initiatives).

As stressed by Bottazzi, all or most of these measures would be welcome and useful steps to build up the momentum of innovation in the EU. Yet among the 46 new initiatives listed in the action plan, very few, if any, actually involve the proposal and implementation of common policies. Although it should be noted that a number of cases subject to the open method of coordination policies are mainly within the exclusive competence of member states and must be both decided and implemented within the framework of national competences.

The Commission is thus on the whole restricted to efforts that "encourage those that are willing to improve the conditions to do more and better research in Europe".[2]

An issue to consider is whether the relative inefficiency of European R&D is not to a considerable extent the result of the segmentation of public research efforts and overlapping of competing research programmes, and thus underutilisation of the available human resources. Beyond doubt the 6th Framework Programme constitutes a powerful tool in the endeavour to streamline research and promote cross-frontier collaboration and a certain degree of integration of research projects. Nevertheless, the total resources of the 6th Framework Programme only amount to some 5% of the total public spending on research in the EU and thus can only exert marginal influence on the structure and direction of research.

Therefore the time has now come to create an integrated EU market for research and researchers as already proposed by the Commission a decade ago.

[2] Extract from the conclusions of European Commission (2003).

R&D AND THE FINANCING OF IDEAS IN EUROPE

CEPS WORKING DOCUMENT NO. 203/OCTOBER 2004

LAURA BOTTAZZI

Introduction

A possible culprit of Europe's poor economic performance is its research achievements, i.e. the production of innovative ideas and the translation of these ideas into productivity. At the microeconomic level, innovation allows firms to respond to more sophisticated consumer demand and to stay ahead of their competitors. Recent innovation surveys (European Commission, 2001) for 12 European countries show that almost 35% of the annual revenues in the manufacturing sector are derived from new and improved products.

At the macroeconomic level, innovation contributes to the three drivers of output growth: capital, labour and total factor productivity (TFP). A country's innovative capacity is therefore important for the creation of growth and new employment for the country itself.

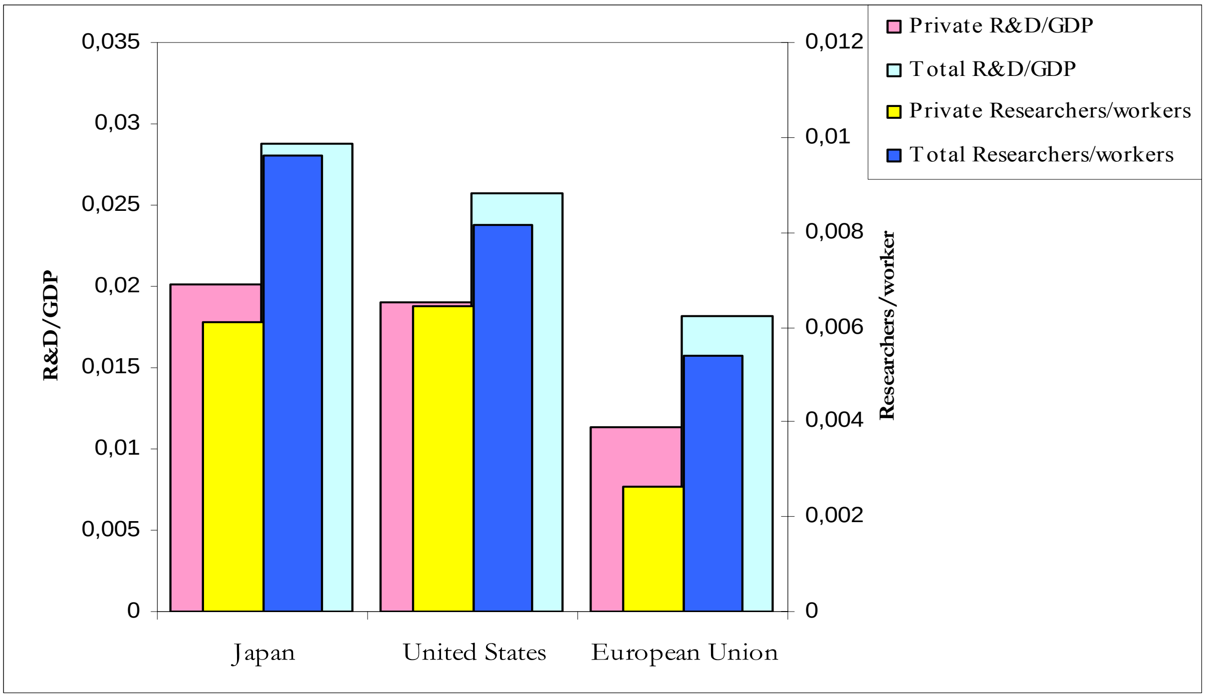
Product and process innovation, however, which transforms scientific and technological ideas into new products and processes, is very hard to measure. Common measures include inputs, such as R&D expenditure or personnel, and (intermediate) outputs, e.g. patents or citations. While innovation increases the quality of physical capital, research has started to look at the link between innovation and TFP. Recent empirical studies (European Commission, 2001) document that the correlation between innovation and productivity is statistically weak if we consider direct measures of R&D (expenditure, R&D personnel as a share of the labour force, patents and publications per inhabitant), but becomes significant if we look at 'structural' measures such as PCs or internet connections per inhabitant, the share of firms engaged in cooperative agreements and with a continuous engagement in research and countries' knowledge.

Since knowledge (which we measure with the stock of a country's patents that are registered in the US, weighted by citations) is an important determinant of TFP, and therefore of the differences in growth rates not accounted for by changes in the accumulation of physical and human capital, we think it is important to understand how countries differ in their ability to create new knowledge. In sections 2 and 3, we start by looking at the differences in R&D among countries and we then ask, in sections 4 and 5, why countries differ in their ability to turn R&D into innovation and into commercial products through the creation of new, successful firms and employment. In section 6 we identify the organisation and the financing of European research as likely candidates to explain Europe's poor economic performance.

1. R&D in Europe

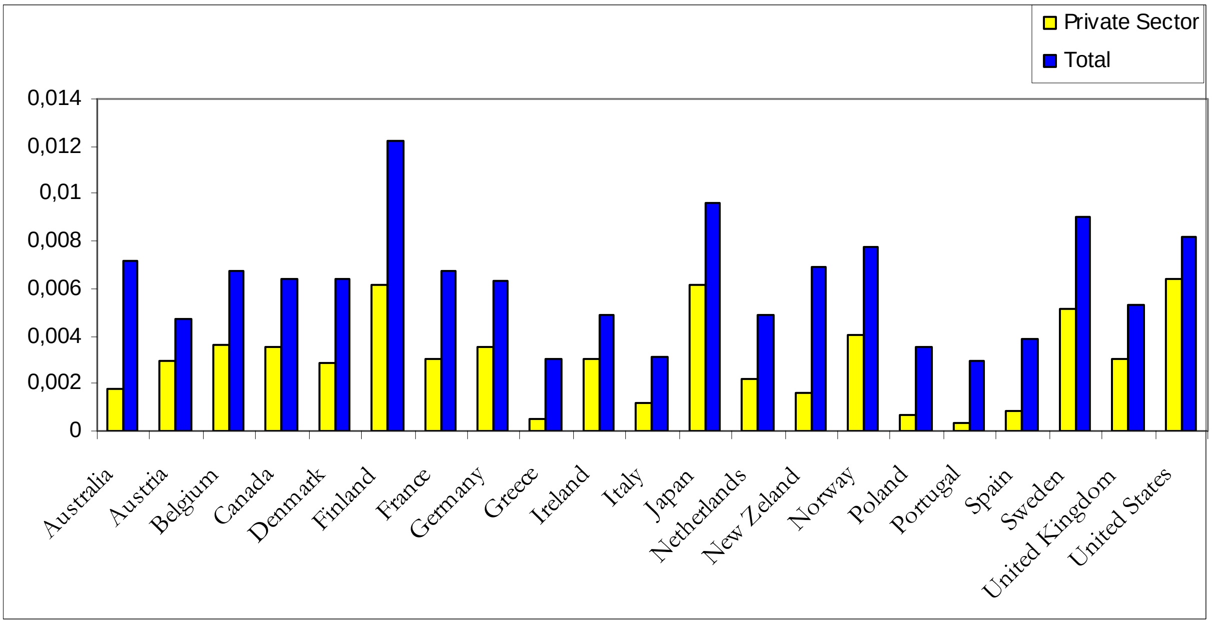
We start by looking at research expenditure in Europe. Figure 1 presents four different measures of research intensity for Europe, Japan and the US during the period 1995-99.

Figure 1. Research intensity indicators



Notes: Private R&D (BERD) refers to expenditure on R&D performed and funded by business enterprises (OECD Main Science and Technology Indicator); Total R&D (GERD) is the total R&D spending (OECD Main Science and Technology Indicator). Private researchers are R&D research scientists and engineers employed in business enterprises; total researchers refer to the total number of R&D research scientists and engineers (OECD Main Science and Technology Indicator); and the number of workers is OECD total employment (OECD national accounts, main aggregates). The four different measures of research intensity have been considered during the period 1995-1999; the figures represent their average.

Figure 2. Researchers as a fraction of the work force



Notes: Total refers to the total research scientists and engineers as a fraction of the total force; private sector represents only those who both work in and are funded by the business sector. For further details (source of data, period covered), see Notes in Figure 1.

For both the expenditure-based and the employment-based measures of R&D Figure 1 shows the research done in all sectors as well as private sector research in the period 1995-99. While Japan is ahead of the US according to expenditure-based and the employment-based measures, Europe is consistently third. Not only this. The fraction of private R&D expenditure over total expenditure is lower than in the US and Japan.

Figure 2 focuses on the employment-based measures of R&D across 21 countries. The shaded bars show total research scientists and engineers as a fraction of the total labour force, while the light bars show only those who work and are funded by the business sector. It is clear from the picture that we see a lot of variation between the US and Europe, but also among the EU countries we do not see homogeneity, especially in the private sector: public expenditure in R&D is higher in the peripheral EU countries – especially Portugal, Greece and Poland.

If we look at the resources spent by countries on R&D, we have a similar picture. Table 1 shows that Europe on average devotes a smaller share of its resources to R&D than does either the US or Japan. The third column of Table 1 reports the employment of researchers divided by total employment as a measure of research intensity. Here the EU again comes after the US and Japan. But figures for the EU overall mask considerable variability within its membership. Some European countries, such as Germany, Sweden and Finland, appear to be important innovators as measured by either research intensity or patenting intensity.

Table 1. Research and patent intensity, 1999

Country	GDP per worker	Researchers in business	Research intensity (%)	Patent intensity (EPO)	Patent intensity (USPTO)*
Belgium	$62,854	16,476	0.410	0.318	0.171
Denmark	$52,926	9,081	0.328	0.290	0.169
Finland	$53,532	17,309	0.770	0.608	0.349
France	$59,083	75,390	0.320	0.299	0.167
Germany	$53,154	150,150	0.394	0.536	0.298
Italy	$60,807	26,192	0.115	0.160	0.078
Netherlands	$52,756	19,359	0.244	0.362	0.165
Spain	$49,605	15,178	0.100	0.047	0.019
Sweden	$51,792	22,822	0.548	0.509	0.421
UK	$47,861	92,133	0.318	0.189	0.138
EU	$53,154	466,600	0.284	0.287	0.165
US	$62,680	1,015,700	0.691	0.191	0.625
Japan	$47,365	433,758	0.650	0.262	0.474
Australia	$54,234	15,506	0.174	0.099	0.093
Canada	$54,592	49,500	0.333	0.101	0.261
Norway	$58,125	9,737	0.424	0.155	0.120

Notes: *Data are for 1998; GDP is translated to current dollars by OECD using their PPPs (source of data: OECD national accounts, main aggregates). The number of workers is OECD total employment (national accounts, main aggregates). Researchers in business are R&D research scientists and engineers employed in business enterprises; the series is expressed in full time equivalent (FTE) (OECD main science and technology indicator). Research intensity is business enterprise researchers over total employment. Patenting intensity is the number of patent applications to either the EPO (Monaco) or the USPTO (US) per 1,000 workers in the inventor's country (source of data: OECD main science and technology indicator).

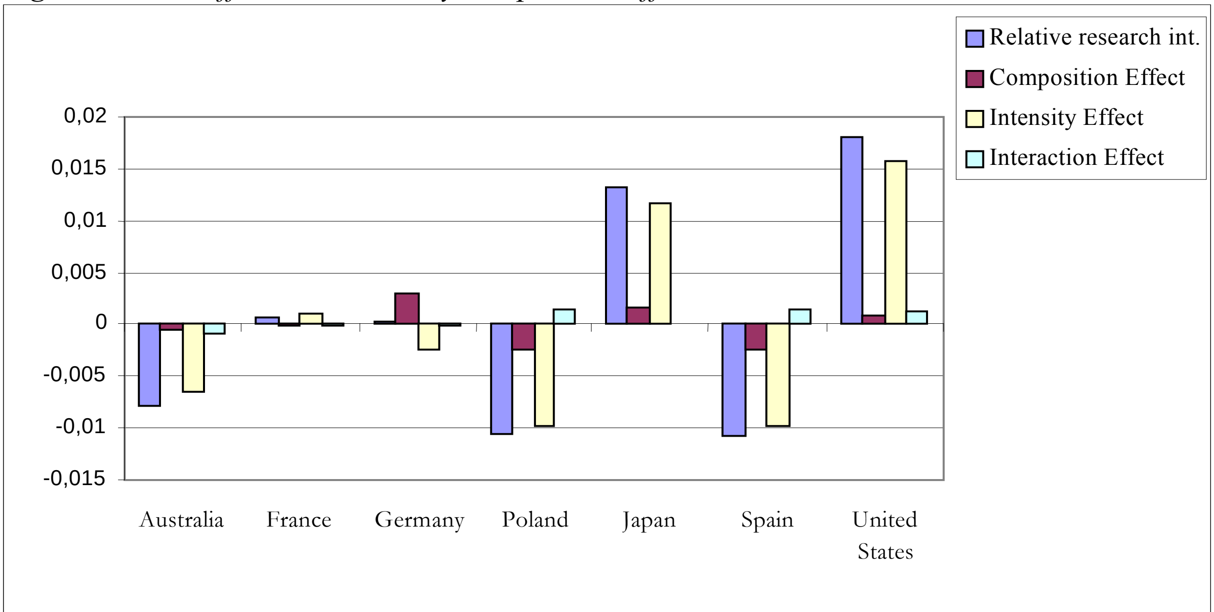
Clearly, it becomes interesting to shed light on the possible reasons for such cross-country variation. One potential explanation lies in the cross-country variation in industry composition.[3] Since industries vary widely in their reliance on research, a country's high research intensity might well reflect its specialisation in research-intensive industries. To disentangle the role of overall level effects versus an industry composition effect, we decompose total research intensity (business enterprise research scientists and engineers as a fraction of employment in country c) denoted by r_c as:

$$r_c - r_w = \Sigma_i(s_{ic}-s_{iw})r_{iw} + \Sigma_i(r_{ic}-r_{iw})s_{iw} + \Sigma_i(r_{ic}-r_{iw})(s_{ic}-s_{iw}) \qquad (1)$$

where r_w is the research intensity across 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 the 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 then 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 towards 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 towards industries in which it is unusually research intensive.

Figure 3. Level effects and industry composition effects



Notes: The industries that have been considered are: chemical linked (food products, beverages, tobacco; textiles; rubber and plastics); earth linked (wood, paper, printing, publishing; coke, refined petroleum; other non metals; miscellaneous); chemical; metal and metal products; machinery; electrical and transportation. For each industry the total number of workers (OECD STAN database for industrial analysis) and the total number of researchers (OECD Basic Science and Technology Statistics) have been used to produce series. For Germany, data on researchers are available only for odd years. We simply averaged the previous and the following odd year to fill in missing even years. The relative research intensity refers to the difference between country *i* research intensity (total number of researchers over total employment for the seven industries have been considered) and the 'world' average. It has been decomposed in three different effects following Eaton et al. (1998): the composition effect, the intensity effect and the interaction effect. The relative research intensity can also be obtained through the algebraic sum of those effects. Data refer to the period 1995-99.

[3] See Eaton et al. (1998).

Figure 3 reports this decomposition for seven countries across seven industries in the period 1995-99. Each country has four bars. Results show that in general the cross-country pattern of overall research intensity is explained by the intensity effect, i.e. by how much a country is research intensive across all industries. Therefore, to understand why some countries emerge as research centres we need to understand why they do more research overall.

2. Research and patenting

We believe that one of the possible causes of the difference in R&D expenditure among countries rests on their possibility to access cutting-edge knowledge. We think of knowledge as a particular form of capital, which is accumulated due to innovation, depreciates with obsolescence and needs some inputs to be created.[4] The inputs of our 'production function of innovation' (Bottazzi and Peri, 2002) are R&D resources, human 'brains' and the stock of existing ideas:[5]

$$dA(t) = (S \quad R\,\&\,D(t))^{\alpha}\, A(t)^{1-\alpha} - \delta\, A(t) \tag{2}$$

The two factors identified as the inputs in the production of new ideas are R&D(t), the total expenditure in R&D or total number of skilled workers employed in R&D and A(t), the total stock of existing useful ideas that could be used to improve on existing knowledge. δ is the obsolescence parameter and S is a shift parameter that measures the national productive capacity of making R&D more productive. The production function of new ideas can also be written as:

$$\frac{d\,A(t)}{A} + \delta = (S \quad R\,\&\,D(t))^{\alpha}\, A(t)^{1-\alpha} \tag{3}$$

We construct the stock of knowledge, i.e. of ideas A(t), using patent counts and to correct for the uneven importance of different ideas, we weight by the average yearly number of citations a patent receives in its first three years.

The decision to identify the new ideas with patents can be considered restrictive from two different perspectives, the first being that not all ideas are patented and we measure only a subset of the whole production of innovation. This is a well-known critique that applies to most of this literature. Nevertheless, there is no comparable measure of the flow of commercially relevant ideas across time and countries that can be used.

The second limitation is owing to the fact that we consider only international patents, i.e. the patents granted by the US patent office to foreign firms. This choice should not lead to the

[4] Difficulties arise from the lack of consensus on how to measure knowledge, from the less than precise data on R&D inputs, and from absence of any theoretical prediction on what aggregate returns to scale should be in this case. In the extant literature the only specific contributions to the estimation of a production function of ideas across countries or regions are those of Porter and Stern (2000), Bottazzi and Peri (2001) and Porter, Stern and Furman (2001). We follow Bottazzi and Peri, and estimate the returns to factors in generating new ideas in the way in which returns to factors in the aggregate production function are usually estimated.

[5] The data on (time-equivalent) research employees and on spending in R&D (in constant dollars) are from the ANBERD and OECD databases. The data on total employment are from OECD.

conclusion that we consider locally patented ideas as less relevant, but that international patents can be used as an overall index of innovation activity.

Since patenting in the United States costs a company more than patenting in its own country, the usual presumption is that only the most valuable ideas are patented in this country. Moreover, with the United States being the largest and most competitive market in the world, the inventions with a potentially profitable content are all patented at its patent office. Hence the flow of new, innovative ideas that become international patents are only those whose novelty exceeds the novelty of the knowledge reached in the world (i.e. the world knowledge frontier).

The evolution of knowledge generated in each country should lead countries that benefit from a larger pool of ideas 'in the air' to produce more new ideas, for given resources, and to exhibit higher innovation rates. In Figure 4 we plot the time behaviour of knowledge stock per employee in the 15 largest patent-producing countries, which account for 96% of the world patenting.

When we take into consideration the dispersion across levels of knowledge per worker, the standard deviation of the distribution has decreased from 1.08 in 1973 to 0.86 in 1998. Those countries such as Spain and Finland, which start with low levels of knowledge per capita, have accumulated much faster than countries such as Germany and the US, which were starting from a high level of knowledge. The difference between countries is still high, however.

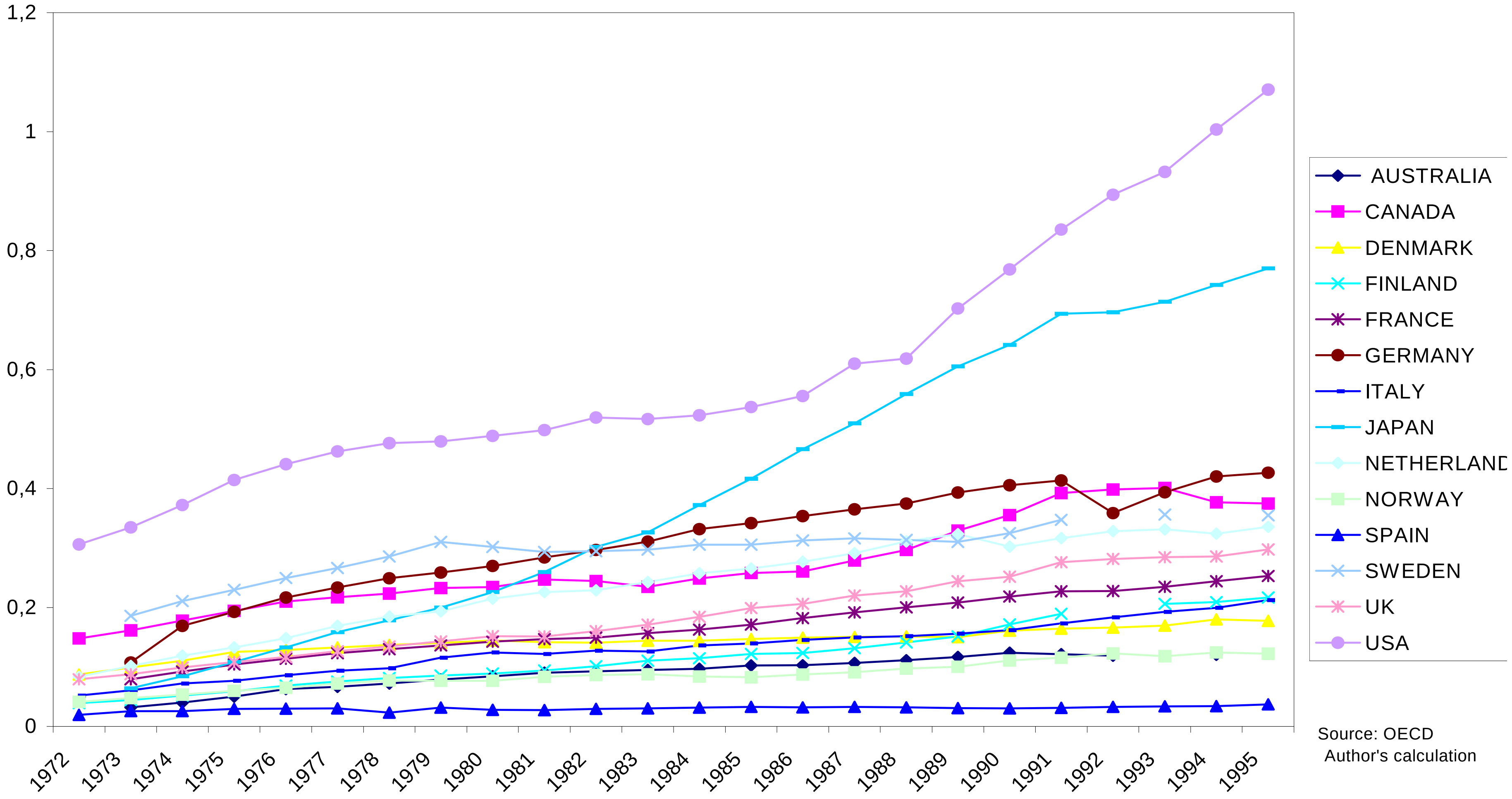
To have a proxy of the elasticity of inputs in the idea production function, we estimate equation (3) in logs to obtain the value of the α and 1- α (see Table 2).

Table 2. The production function of ideas

Dependent variable Log((dA(t)/A+δ)	
Log(A(t-1)	-0.18
	(0.069)
Log(R&D(t-1))	0.34
	(0.093)
Country dummies	Yes
Time dummies	Yes
Prob(F-statistic)	0.0000
Observations	300

Notes: We let α = 0.35.

Figure 4: Knowledge per worker in 15 OECD countries, 1973-96



Source: OECD
Author's calculation

3. A growth accounting exercise

To dig further into the determinants of the different capability of countries to create innovation, we first perform an exploratory exercise: as in Hall & Jones (1999), we decompose the average creation of new ideas (dA/L) in its main three components: 1) expenditure in R&D per worker in R&D, 2) stock of knowledge (patents) per worker in R&D and 3) an R&D augmenting productivity factor S:

$$\frac{d\,\mathrm{A(t)}+\delta\ \mathrm{A(t)}}{L}=(\mathrm{S}\frac{\mathrm{R\ \&\ D(t)}}{\mathrm{L}})^{\alpha}\left(\frac{\mathrm{A(t)}}{L}\right)^{1-\alpha} \tag{4}$$

We then perform a growth accounting exercise. Table 3 reports our decomposition of the production function for each country and, to make comparisons easier, all terms are expressed as a ratio to US values. Interestingly, based on this table, in the ‘production’ of new ‘valuable patents’, the EU lags behind the US as the expenditure per worker employed in the R&D sector is lower (almost 50% lower than in the US), but also because the stock of accumulated knowledge is lower and productivity in the R&D sector is lower. European productivity in the R&D sector is not only below the US level, it also shows a high level of heterogeneity among countries.[6] Again while some countries such as Finland and Denmark have productivity levels close to the US and even higher, that is not the case for the remaining EU countries.

Table 3. Patent productivity calculation, ratios to US values

	(dA/L)	*(A/L)*	*rd/L*	*S*
	1992-98	1992-98	1992-98	1992-98
Denmark	0.28	0.16	0.56	1.09
Finland	0.31	0.19	0.53	1.40
France	0.21	0.23	0.73	0.32
Germany	0.34	0.40	0.71	0.56
Italy	0.22	0.19	0.71	0.41
Netherlands	0.25	0.32	0.57	0.44
Norway	0.15	0.12	0.58	0.63
Spain	0.039	0.031	0.40	0.46
Sweden	0.24	0.34	0.92	0.51
UK	0.18	0.28	0.71	0.31
European avg.	***0.23***	***0.16***	***0.68***	***0.61***
Standard dev.	*0.11*	*0.12*	*0.91*	*0.61*
US	**1.00**	**1.00**	**1.00**	**1.00**
Australia	0.15	0.12	0.45	0.65
Canada	0.47	0.37	0.61	1,20
Japan	0.59	0.73	0.76	0.64
US	1.00	1.00	1.00	1.00

Sources: OECD Statistics and author’s calculation.

[6] We obtain similar results when we use workers employed in R&D instead of R&D per worker in the patent production function.

This exercise should be taken with caution: our results partly depend on the particular form of the production function assumed. Also our functional form does not take into consideration that countries benefit from the knowledge created by other countries. Hence, our term S might well hide the effect of the stock of world knowledge on the production of domestic innovation.

The creation of world knowledge might well play a double role: it pushes the frontiers of innovation, making it more difficult to innovate for a country, decreasing the proportion of ideas that are really innovative and suitable to be patented internationally. It also fosters the creation of new ideas. Hence it is important to understand which of the two effects prevail, especially if we want to understand how to foster innovation. In fact if we find out that world knowledge and not locally-produced knowledge is more important as an input in the creation of innovation, we might prefer not to invest in cutting-edge research and rely more on the knowledge produced by the rest of the world.

When we add the stock of world knowledge as an input in the creation of new ideas and we perform a deeper analysis, we obtain interesting results. It turns out, in fact, that indeed a long-term relationship exists between a country's domestic stock of knowledge, domestic expenditure in R&D and the rest of the world stock of ideas for each country. In particular we can quantify this long-term relationship: a 1% increase in domestic R&D would benefit innovation by 0.30%, while an increase of 1% in the stock of foreign ideas increases innovation by 0.25%.

Hence, we find out that domestic R&D and the international stock of knowledge have a similar impact on domestic innovation. This is consistent with the estimates of Coe and Helpman (1995) and of Kao et al. (1999) who estimate elasticities of productivity to domestic and international R&D similar to each other. In fact several studies of R&D spillovers (some of them reviewed in Griliches (1990) find that the impact of external R&D on productivity of firms or countries is between half as large and 50% larger than the impact of own R&D. Our estimates are of the same order of magnitude as the internal effect of R&D are therefore right in the same ballpark.

But what is the dynamics of knowledge when we increase R&D in a country? To answer this question, which is relevant for policy decisions, we need to analyse the propagation and the impulse response to such shocks in the short run. We adopt an 'error correction' representation of our dynamic relationship between $\ln(R\&D_{i,t})$ and ln(Ai,t): in particular we consider the change of each variable as depending on the past changes in the other variables as in a VAR in differences, but we include a term that captures the deviation from the estimated long-term relationship.

In order to estimate the co-integration relation between R&D and stock of ideas, we estimate the following co-integration equation for 11 European countries:

$$\ln(A_{it-1}) = c_i + \theta_t + \mu \log(R\&D_{i,t}) + \gamma \log(A_{ROWi,t-1}) + \varepsilon_{it} \tag{5}$$

where c_i and θ_t are a fixed effect and a time trend, respectively. The estimates of parameters μ and γ are reported in the Table 4.

Table 4. Estimates of the Co-integration Vector

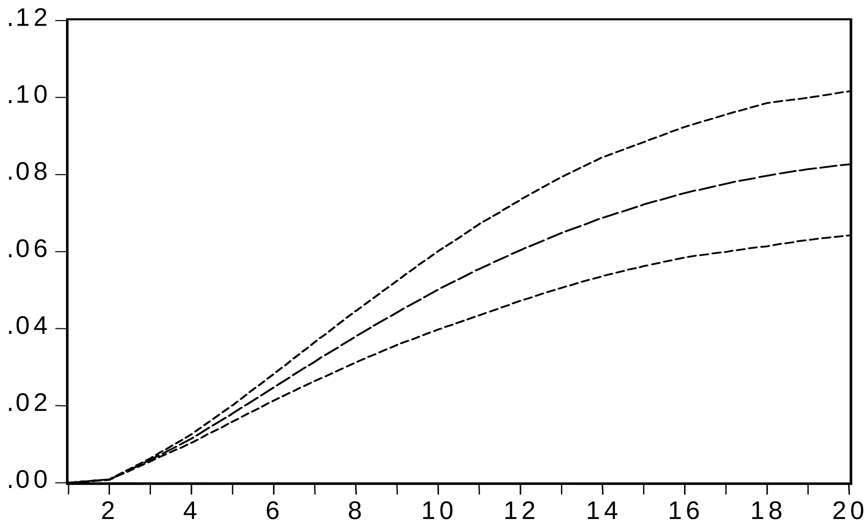
Dependent variable Log(A(t-1))	
Log($A_{RWORLD(t-1)}$)	0.247**
	(0.068)
Log(R&D(t-1))	0.305**
	(0.093)
Country fixed effect time trend	Yes
Time trend	Yes
R^2	0.943
Number of obs.	220
Test of co-integration Pedroni (1997)	-2.65**

Notes: Method of Estimation: Dynamic Ordinary Least Squares with country-specific intercepts and common time-trend. Consistent standard errors in parenthesis.

** = significant at 1% confidence level.

We then analyse the impact of a shock to a country's ln(R&D) resources on its stock of knowledge. If we look at the impulse response, Figure 5, we notice that a shock of a 1% increase in ln(R&D) affect knowledge with a delay as it takes few periods for these resources to generate knowledge. Therefore such positive shocks result in a further increase in R&D resources. The increase in knowledge stabilises after 20 years at a level equal to 1.2% (+0.08) of the average initial (ln) stock of the country knowledge. The impulse response function shows a progressive increase and by the 20th year, it reaches a plateau.

Figure 5. Impulse Response of Patenting to the Increase in R&D expenditure (in log)



4. R&D, productivity and employment

We now look at the relation between stock of accumulated knowledge and TFP. Here, we want to measure the partial elasticity of the $TFP_i(t)$ with respect to $A_i(t)$. As is shown below, the estimated elasticity is equal to 0.10. Considering the log-linear form of the TFP function, we can write:

$$\log(\ TFP_i\ (t)\ ) = a + \beta\ \log\ (\ A(t)\ ) + \theta \log\ (\ X_i(t)\ ) \tag{6}$$

where $X_i(t)$ are country characteristics that could affect productivity. In order to control for country- and time-specific factors, we estimate the partial elasticity of $TFP_i(t)$ with respect to $A_i(t)$ controlling for country and time effects as follows:

$$\log(TFP_i(t)\ =\ b\ \log(A_i t)) + \mu_i + \theta\ (t) + u_i(t) \tag{7}$$

The estimate of such elasticity b is reported in Table 5 where we have calculated TFP using the average countries' shares for labour and capital income. We employ three-year averages of labour adjusted for the accumulation of human capital (we obtain very similar results even using unadjusted labour stock).

As we include country and time dummies, we are sufficiently confident that major cross-country differences in institutional settings and political institutions are captured by these variables, such as common trends towards larger international integration. The elasticity, identified is nevertheless significant and equals 0.10. As we fear that the yearly data might identify the elasticity on short-term fluctuations, we estimate the parameter with the observations averaged over three-year intervals. We take our results as evidence of the importance of local innovation in leading to a technological advantage, i.e. that the level of knowledge related to innovative activity improve the productivity in the country. Total factor productivity is, among other things, also a function of local innovation.

Table 5. Knowledge and TFP

Dependent variable *TPF*	
Log(A(t))	0.10
	(0.0125)
Country dummies	Yes
Time dummies	Yes
R^2	0.9
Observations	102

Our findings suggest that while R&D workers may 'stand on the shoulders' of prior (domestic) research, these technical achievements have had only a limited impact on measured aggregate productivity. Indeed, there seems to be a gap between the increasing level of resources devoted to R&D and the ability of advanced economies to translate these new technologies into higher TFP.

5. Financing and organising research

We have learnt that to foster growth and employment, it is necessary to increase productivity and investment in R&D. A necessary condition to improve the investment prospects in Europe is to increase R&D profitability and solve the 'European paradox' (the EU

Commission's 1993 Green Paper on Innovation), i.e. the inability of European firms to translate scientific competence into commercially successful innovations. Two factors may be responsible for the ability to translate ideas into growth: the organisation of research and entrepreneurship, and its financing.

5.1 The organisation of research

That the European problem is not that of a deficiency of scientific competence is reflected, for example, in the annual growth rate of its share of both publications and citations in the first half of the 1990s: the former was 2.8% for the EU, -0.3% for the US and 2.8% for Japan, while the latter was 2.8% for the EU, -0.6% for the US and 0.8% for Japan (European Commission, 2000). Yet pure scientific competence does not automatically translate into valuable technological ideas.

Another telling fact emerges from the pattern of patents in high-tech fields. The share of patents granted to US and Japanese firms in high-tech fields is higher than their share of all patents, as emerges from Table 6 below.

Table 6. Shares of high-tech patents

	EPO (1996-98)		**USPTO (1993-98)**	
	All	***High-tech***	***all***	***high-tech***
EU-15	46%	35%	16%	12%
US	28%	41%	56%	57%
Japan	19%	27%	21%	28%

Sources: European Commission (2000) and Bottazzi et al. (2004a).

Another indicator of the unsatisfactory performance of the EU is the 'technological balance of payments', defined as the balance of payments in high-tech. While the US nearly doubled its growth rate in exports between 1990-94 and 1995-98, the EU basically stagnated.

Table 7. High-tech balance of payments, annual growth rates

	1990-94	*1995-98*
EU-15	10.8%	12.0%
US	8.4%	15.5%
Japan	11.6%	-0.5%

Source: European Commission (2000).

One possible explanation of these facts lies in the role played by the organisational dimension of innovation. Europe is characterised by a relatively large degree of 'intra-preneurship,' i.e. creation of new businesses *within* established firms rather than as independent start-ups. This contrasts with the US pattern, where the entrepreneurial channel has become particularly important with the acceleration of innovative activities and the shortening of product and process life-cycles (Baldwin, 1995).

A link between entrepreneurship and innovation has been documented by Audretsch (1995), among others. For the 1976-86 period, he finds that the share of start-ups (new firms) is higher in science-based, fast-growing industries (such as chemicals, drugs, communications equipment, electronic components, computers and scientific instruments) than in the more traditional and stable industries.

These industries are also characterised by higher attrition rates: although there are more opportunities for entry by new start-up firms, these come with lower chances of survival.

European policy-makers have extensively dealt with the obstacles to entrepreneurial activity (see the recent European Commission's 'Innovation in a Knowledge-based Economy' Communication). The case is often made that the level of entrepreneurship is below its social optimum and deserves some attention from policy-makers. Here much has already been said (OECD, 1998) but there has been relatively little empirical analysis of the role played by the government-policy environment. Research on entrepreneurship has examined the role of human capital and financial considerations in the decision to become an entrepreneur. Some recent works in the literature have developed some new insights that might be useful to consider when setting up a policy agenda:

- *Competition*. It has been shown that the fatality rate of start-ups depends, among other things, on the degree of competition of an industry (Acs and Audretch, 1988). Therefore competition policy might, although (indirectly), contribute to innovation. A recent paper by Aghion et al. (2002) has shown however that there is an optimal level of competition that authorities have to enforce if they want to foster innovation.

- *Intellectual property rights (IPR)*. The design of property rights is an important determinant of the accumulation of entrepreneurial capital (see for example Eaton, 1997). The recent discussion regarding the European patent has been an important step towards the harmonisation of IPR legislation – a single IPR system favours the commercial exploitation of ideas.

- *Taxation*. There are several dimensions along which taxation affects innovation and entrepreneurship. One is the degree to which taxation affects the choice between different forms of business, such as incorporation versus partnerships. Another is the burden of higher labour taxes on labour and non-labour intangible investments. Finally, taxation affects the supply of both risk capital and entrepreneurship, especially through capital gains tax. Empirical studies on entrepreneurship have focused on personal income tax rates, with the expectations that higher tax rates should limit entrepreneurship. Almost all studies have, however, found a positive relationship between tax rates and the aggregate rate of entrepreneurship and between tax rates and the probability of entrepreneurship (Long, 1982 and Scheutze, 2000). The divergence between expectations and results is attributed to the perception that being an entrepreneur allows for greater opportunity to avoid taxation. Yet Gentry and Hubbard (2000) find that the more progressive a tax system is, the less likely an individual will become entrepreneur. Therefore there is not a clear, unique, causal relationship between taxes and entrepreneurship.

- *Regulations and legal barriers*. Cumbersome administrative practices make it costly to set up a firm. Several OECD studies document a large variation of such costs across countries (see OECD, 1998).

- *Bankruptcy laws*. Bankruptcy laws affect the number of entrepreneurs (Berkowitz & White, 2002, White, 2001). US bankruptcy laws allow individuals filing for personal bankruptcy to exempt some of their assets and income from distribution to their creditors. The direct effect of these exemptions is to provide a sort of wealth insurance in the event that an entrepreneur fails.

In Europe bankruptcy rules are much more stringent, affecting the choice to become self-employed. Gromb and Scharfstein (2001), for example, show that the prevalence of 'intra-preneurship' in Europe may also depend on the type of bankruptcy rules.

- *Financial factors*. The view that limited access to credit and financial markets can limit the emergence of entrepreneurship is documented empirically. Blanchflower and Oswald (1998) show that liquidity constraints affect the choice of becoming self-employed even after controlling for individual ability.
- *Education*. Education influences where and how people invest and has an impact on their choice to become entrepreneurs.

All these factors seem relevant and should enter the European policy agenda since they affect not only R&D productivity but create an incentive to increase R&D expenditure.

5.2 The financing of research

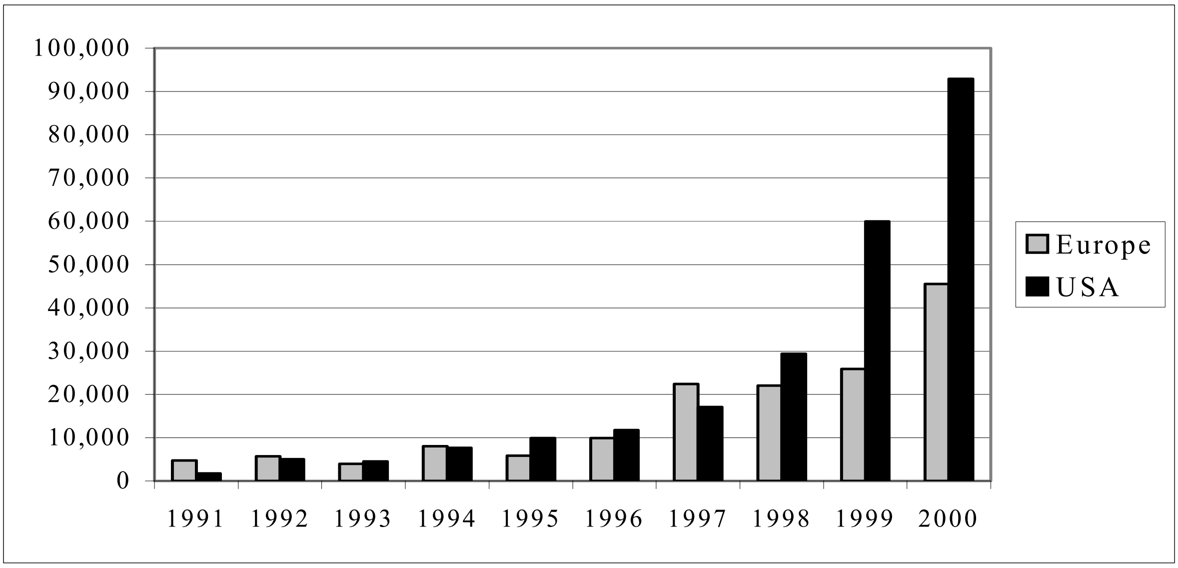
Once ideas are ready to be translated into entrepreneurial firms, these still need finance to grow and unfold their growth potential. Availability of financial capital is crucial at this stage. Two facets of the European situation seem particularly troubling. One is the lack of financial resources available for start-ups, especially for innovative, riskier firms. For smaller and younger companies, which rely on external finance in the early stages of their existance, this constitutes a serious problem: Guiso (1998) shows that European high-tech companies suffer from substantial credit rationing.

The scarcity of risk capital, and of venture capital in particular, may harm the innovative ability of start-ups. Venture capital has been shown to benefit start-ups beyond the supply of finance. In other words, there is a 'soft' side to venture capital that adds value to the 'hard' financial side: venture capitalists are often a 'coach' for entrepreneurial start-ups (Hellmann, 2000). In fact, Hellmann and Puri (2000, 2002) persuasively argue that venture-backed companies in the Silicon Valley are faster in developing their products and bringing them to market, and need less time to recruit professional management. Similarly, Kortum and Lerner (2000) argue that venture-backed companies in Massachussets develop a larger number of and more relevant patents than other start-ups.

There is thus evidence that, at least in the US, venture capital adds to national innovative capabilities by affecting both the efficiency of the knowledge production function (more and better patents per given inputs) and the overall TFP. There is not such evidence, however, for Europe.

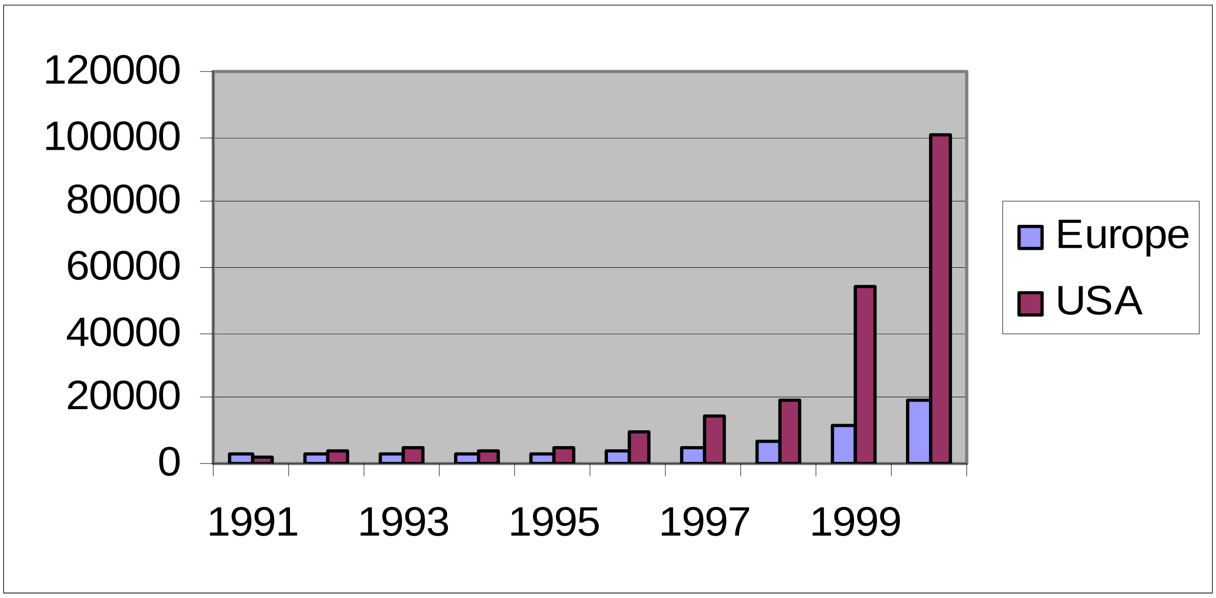
Figures 6 and 7 compare the development of funds raised and invested into venture capital in the EU (light bar) and in the US (dark bar) over the 1990s. The histogram suggests that the amount of funds raised in Europe between 1995 and 2000 increased nearly twelve-fold. Nevertheless, this is not the case since these funds also include funds raised by firms that specialise in management buy-out (MBO). These are financing operations that enable management to buy out an existing business from its original owner. If we compare the funds raised with those invested into venture capital we see that the performance of Europe is less striking.

Figure 6. Venture capital funds raised in the EU and the US (in millions of US$)



Source: Bottazzi and Da Rin (2002) calculations on EVCA and NVCA data.

Figure 7. Venture capital investment in the EU and US



Source: Bottazzi and Da Rin (2002) calculations.

These patterns probably reflect the structural differences that exist between venture capital on the two sides of the Atlantic. For instance, the US venture-capital industry has developed over half a century and has experienced sustained growth for more than 30 years, whereas venture capital has been around in Europe for only two decades.

Also, another important difference between European and US venture firms is that the latter are small independent partnerships that finance themselves mostly from institutional investors. In Europe, by contrast, nearly half of the funds come from banks or established companies. Such institutional differences translate into different behaviour – as Bottazzi, Da Rin and Hellman (2004) have shown. Yet in Europe as well as in US the majority of funds go to expansion investment. Nevertheless, the amount invested in early stage in Europe is almost one-fifth of what is invested in the US.

To understand this phenomenon, in a recent work, Bottazzi, Da Rin and Hellman (2004) look at micro-disaggregated data and indeed find that the European venture capital sector has a professional experience that is not less than that of their American colleagues. Nevertheless, venture capitalists are more heterogeneous and less institutionalised than in the US. Interestingly, most of the heterogeneity rests in their educational background, which strongly influences their investment behaviour.

Figure 8 shows that more than three-quarters of venture capitalists have a graduate degree. A higher business degree is common: about one-third have an MBA. Graduate scientific education, while less common, is far from negligible: 11% have a master's degree in engineering or sciences, and over 16% have a Ph.D. Most of the Ph.Ds are in hard sciences.

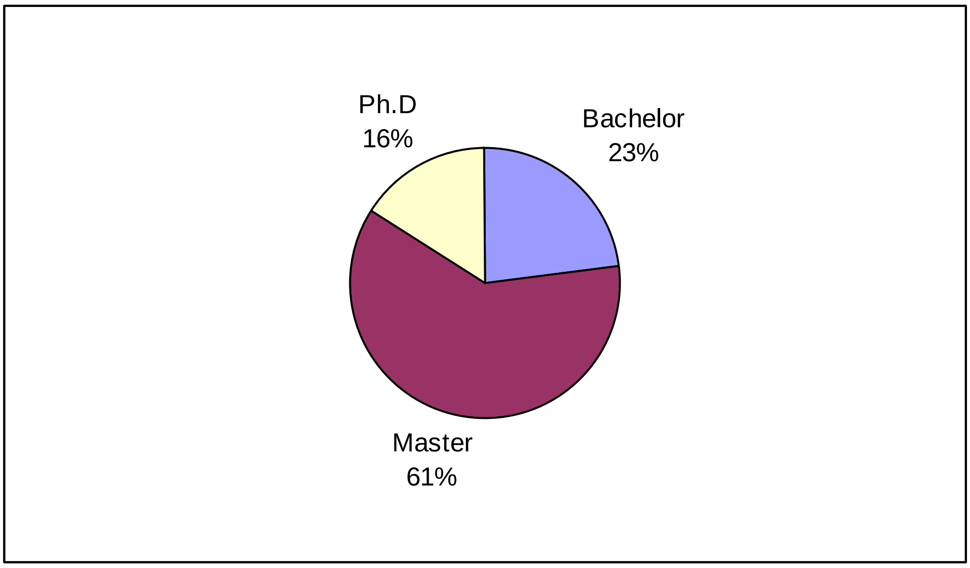
Interestingly, even though business education is still relatively young in Europe, Figure 8 shows that a vast majority of venture capitalists have some. This is largely because of the high number of MBAs. What may come as a surprise is that less than one-third actually have an education in engineering or science. This suggests that although relatively few, science-educated partners have a very strong background and can thus contribute to the effectiveness of investment decisions. More educated partners with a scientific background broadly seem to be taking on a more active role and invest more aggressively in high-tech, early-stage companies.

Overall, human capital is extremely important and needs to be considered as the first place where venture capitalists invest and relate their portfolio of companies. As we have seen that higher scientific education is becoming a more common feature among European venture capitalists, one should probably be positive about the industry's future ability to play an active role in the creation of successful innovative, high-growth companies.

These findings provide support for the European Commission's stated policy of promoting European venture capital. The major action of the Commission in this respect has been the transformation of the European Investment Fund (EIF) into a major investor in venture capital funds. Nevertheless, it seems that the 'quality' of European venture capital should be as urgent a concern for the EIF as its sheer 'quantity', so as to advance both the size and the maturation of the industry.

Improving the availability of post-graduate education, including executive education or other professional training, is likely to have a very positive effect on the level of professionalism in the industry. Our results, instead, do not provide support for the European Commission's policy of actively subsidising investment by the venture capitalists. Bottazzi, Da Rin and Hellmann (2004) show that almost 24% of the venture capitalists they surveyed in Europe do not invest domestically but rather prefer to investment abroad, particularly in the US. This finding shows that a subsidy to venture capital investment would end up increasing investment in the US and not necessarily in Europe.

Figure 8. Venture capitalists' educational background, by degree qualifications



Conclusions

This paper has documented that accumulated knowledge, which we measure with the stock of 'valuable' patents, is an important determinant of total factor productivity. In the production of these patents the EU is characterised by low productivity and low R&D expenditure relative to the US. What appears to explain the lower level of productivity is a relatively lower accumulated stock of knowledge per R&D worker and a low R&D expenditure.

In the attempt to understand these developments this paper moves in two directions: the 'organisation' of innovation and its financing.

With regard to organisation, the EU has significant scientific competencies (at least when compared with the US). These however translate into a smaller and less innovative flow of new start-ups. The latter are rarely independent and more often happen within the boundaries of a larger established company ('intra-preneurship' versus 'entrepreneurship'). Concerning financing, the nature of venture capital in Europe is different from the US. The venture capital industry is, contrary to the US, still dominated by banks.

The outcome is that listed 'ventured-backed' companies do not grow faster than 'non-venture backed' ones. Flows are also limited: from 1995 to 2000 the flow of venture capital investments in Europe has increased by a factor of 6, but the gap with the US has become larger – there investment has increased, over the same period, by a factor of 24.

This, however, is not enough to conclude that national innovative capacity is hampered by a (venture capital) financing constraint: it could well be that the flow of ideas that look for financing is scarce.

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