CHAPTER 6

Outputs and efficiency of science and technology in Europe

HIGHLIGHTS

In 2009, the EU produced 33.4% of world’s total scientific publications, the largest scientific centre in the world. However, the capacity of the EU to produce high-impact scientific publications, a proxy for scientific quality, is lower than that of the United States. Among the scientific publications in 2007, the ratio of EU’s contribution to the 10% most cited scientific publications in 2007-2009 was 1.16, which is well above the ratio for Japan, South Korea and China, but behind the ratio of 1.53 for the United States. However, since 2001, the EU has improved its scientific quality from 1.04 to 1.16, while the United States has stagnated. In Europe, it is Denmark the Netherlands, Iceland, Belgium and Switzerland, which have achieved the highest quality in their scientific publications according to this indicator. In absolute and quantitative terms the United Kingdom, Germany, France and Italy are the countries with the highest number of scientific publications.

Concerning technological output, the latest available data is from 2007. Contrary to the strong European scientific production, the technological production in the EU is less competitive. In 2007, the EU Member States only accounted for 43% of the EPO patent applications. In other words, more than 50% of all EPO patent applications were generated outside the EU. Relative to GDP, the inventing activity of EPO patents in the EU has decreased since 2000, while it increased dramatically in South Korea and Japan. About half of the Member States do not produce high-tech EPO patents. Evidence at regional level shows a strong concentration of patents in a few of Europe’s regions.

The divergence between scientific publications and technological production in Europe is an indication of a weakness in the European research and innovation system. However, estimating efficiency of the European R&I system is more complex, relating input to output, while analysing the impact of scientific output on innovation. This report presents some experimental and preliminary evidence on the efficiency of public research systems. In the EU, the ratio of quantity and quality of scientific production to the number of researchers is clearly below that of the United States. On average, a researcher in the public sector in the United States produces 2.25 articles among the 10% most cited articles worldwide, compared to 0.79 highly-cited articles per average researcher in the public sector in the EU. One of many explanations of this large difference is that public researchers in the United States benefit from total funding over 2 times higher per researcher than their colleagues in the EU. Further downstream, for almost all EU Member States and Associated countries, there is a positive relation between high-quality scientific output in the public sector and business sector investment in R&D. A growth of business sector R&D investment is in turn positively related to a growing patenting activity. Improving the efficiency producing high quality public research thus has potentially a positive impact on innovation. However, this relation is not linear or automatic, but depends on many dimensions of the public research system and its interaction with private actors, which will be further analysed in Part II of this report, capitalising on the emerging European Research Area.
6.1. Where does Europe stand in terms of scientific excellence?

Bibliometric indicators and patents are currently the most easily available and widely used proxies for measuring scientific and technological output. Bibliometric indicators give information on the codified knowledge produced by universities, research institutes and private firms. They also allow comparison of the scientific performance of different countries and regions. Patents, on the other hand, provide a valuable measure of the exploitation of research results and of inventiveness of countries, regions and firms. Both publications and patents play a role in the diffusion and exploitation of knowledge.

All the indicators and data on publications below refer to internationally peer-reviewed scientific publications which are indexed in Scopus (one of the largest abstract and citation databases of peer-reviewed literature)\(^156\).

The EU remains the largest producer of scientific publications in the world, followed by the United States. However both the shares of the EU and the United States worldwide are decreasing, whereas China is catching up rapidly.

In 2008, 33.4 % of the world’s peer-reviewed publications were signed by EU authors, compared to 25.9 % in the United States (figure I.6.1). Both shares have considerably decreased between 2000 and 2009 as a result of the increasing scientific capacity of Asia. China is catching up fast, from 6.4 % of world publications in the Scopus database to 18.5 % in 2008. The average annual real growth of peer-reviewed scientific publications between 2000 and 2008 was 6.9 % in the EU, 5.6 % in the United States and 28.2 % in China.

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156 http://www.scopus.com/home.url
FIGURE I.6.2
Number of scientific publications of the EU Member States and Associated Countries, 2008
### TABLE I.6.1 Scientific publications

<table>
<thead>
<tr>
<th></th>
<th>Total scientific publications</th>
<th>Scientific publications within the 10% most cited scientific publications worldwide</th>
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<tbody>
<tr>
<td>Belgium</td>
<td>11 820</td>
<td>20 285</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>1925</td>
<td>2896</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>5781</td>
<td>11 894</td>
</tr>
<tr>
<td>Denmark</td>
<td>8896</td>
<td>13 260</td>
</tr>
<tr>
<td>Germany</td>
<td>77 958</td>
<td>111 288</td>
</tr>
<tr>
<td>Estonia</td>
<td>603</td>
<td>1392</td>
</tr>
<tr>
<td>Ireland</td>
<td>3178</td>
<td>7799</td>
</tr>
<tr>
<td>Greece</td>
<td>5924</td>
<td>13 855</td>
</tr>
<tr>
<td>Spain</td>
<td>27 089</td>
<td>52 664</td>
</tr>
<tr>
<td>France</td>
<td>57 081</td>
<td>81 911</td>
</tr>
<tr>
<td>Italy</td>
<td>38 708</td>
<td>63 408</td>
</tr>
<tr>
<td>Cyprus</td>
<td>197</td>
<td>801</td>
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<tr>
<td>Latvia</td>
<td>359</td>
<td>613</td>
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<tr>
<td>Luxembourg</td>
<td>90</td>
<td>503</td>
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<tr>
<td>Hungary</td>
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<td>7419</td>
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<tr>
<td>Malta</td>
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<td>223</td>
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<tr>
<td>Netherlands</td>
<td>22 181</td>
<td>35 425</td>
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<tr>
<td>Austria</td>
<td>79 677</td>
<td>14 225</td>
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<tr>
<td>Poland</td>
<td>13 022</td>
<td>24 121</td>
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<tr>
<td>Portugal</td>
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<tr>
<td>Israel</td>
<td>10 709</td>
<td>15 279</td>
</tr>
</tbody>
</table>

Source: DG Research and Innovation
Data: Science Metrix / Scopus (Elsevier)
Note: (1) Full counting method.
The United Kingdom, Germany, France and Italy, followed by Spain and the Netherlands, remain the countries with most scientific publications in Europe in the last decade. Small countries register the highest growth rates in terms of number of publications between 2000 and 2008.

In 2008, the EU Member States with the highest number of scientific publications are the United Kingdom (21.9 % of the total EU-27 publications), Germany (20.8 %), France (15.1 %), Italy (11.3 %), and Spain (8.7 %). Figure I.6.2 and Table I.6 provides an overview of the absolute values.

The smallest countries (Luxembourg, Malta, and Cyprus) are leading in terms of growth rates between 2000 and 2008, both for the total number of publications and for the highly cited publications (see table I.6.1). Remarkable growth rates on publications are shown also by Lithuania (16.4 %), Turkey (15.6 %), Portugal and Romania (each with 13.9 %), whereas highly cited publications have increased spectacularly in Turkey (24.1 %), Croatia (18.5 %), Estonia (18.2 %), Portugal (16.9 %), and Greece (16 %).

The EU’s capacity to produce high-impact scientific publications is well above other world regions and on increasing trend since 2000, but it remains substantially lower than that of the United States despite the stagnation of American high-impact scientific publication numbers.

The number of citations that a scientific publication receives is an indication of the use of this publication in subsequent scientific works. It is, therefore, an indication of the impact of this publication on science. In each scientific field, one can assume that the top 10% most-cited scientific publications are among the most influential publications in that field. The values reported in Figure I.6.3 concern publications of 2001 with a 2001–2004 citation window, publications of 2004 with a 2004–2007 citation window and publications of 2007 with a 2007–2009 citation window.

On average, a country is expected to have 10% of its publications among the top 10% most cited ones worldwide. A higher value means that this country produces highly cited publications more often than expected. This is the case of the United States and the EU as a whole and for a number of European countries, led by Switzerland, Iceland, Denmark, the Netherlands and Belgium. The EU has progressed since 2000 and so has the EU average, which reached 11.6% in 2009 (from 10.4% in 2001), while the United States has stagnated overall at 15.3%. The EU–US gap in highly cited publications has, therefore, decreased since 2000, but it remains considerable. Japan, South Korea and China perform relatively lowly on this indicator, which is probably partly due to its English-language bias. However, China’s performance increased significantly between 2000 and 2007, as well as that of India, Brazil and Russia. According to this indicator, a substantially smaller proportion of EU publications than US publications have a high impact. In absolute terms, the United States produces about 5% more high-impact publications than the EU. This observation points to a difference in the efficiency of the research systems in both economies. The issue for the EU may not be only a deficit in translating excellent science into innovative products and processes - it may also be that the EU is actually producing excellent science less often than the United States.

The European countries with the highest ratio of highly cited publications out of the total number of publications are Denmark, the Netherlands, Belgium, Iceland, and Switzerland. EU-12 Member States have a low ratio of their publications among the 10% most-cited publications worldwide (figure I.6.4). However in terms of growth rates between 2000 and 2008 the leading countries are Turkey, Croatia, Estonia, Portugal and Greece (table I.6.1).
The 'contribution to the 10% most cited scientific publications' indicator is the ratio of the share in the total number of the 10% most frequently cited scientific publications worldwide to the share in the total number of scientific publications worldwide. The numerators are calculated from the total number of citations per publication for the publications published in 2001 and cited between 2001 and 2004, from the total number of citations per publication for the publications published in 2004 and cited between 2004 and 2007 and from the total number of citations per publication from the publications published in 2007 and cited between 2007 and 2009. A ratio above 1.0 means that the country contributes more to highly-cited high-impact publications than would be expected from its share in total scientific publications worldwide.
FIGURE I.6.4 Contribution to the 10% most cited scientific publications as % of total national publications, 2007
6.2. How large is Europe’s technological output?

The EU Member States only accounted for 43% of all EPO patent applications in 2007

Figure I.6.5 below shows the countries of invention of EPO patent applications. 47% of all EPO patent applications in 2007 were invented in Europe. In comparison, 24% of them were invented in the United States and 16% in Japan. The number of EPO patents invented in South Korea is about the same as the number of EPO patents invented in the United Kingdom or in Italy. Germany is by far the leading country in Europe in invention of EPO patent applications. Germany, France, the United Kingdom and Italy account for about one third of inventions of EPO patent applications.

Relative to GDP, the inventing activity of EPO patents in Europe and associated countries is highest in Israel, Switzerland and Germany. South Korea and Japan have dramatically increased their EPO patenting since 2000

Normalising the number of EPO patent inventions by GDP allows correction for the size of the country, as does the normalisation by population. It also allows assessment of the role of inventing activity in the economy of the country. Switzerland, Germany, Sweden, Finland, Austria and the Netherlands are the European countries where the EPO patent invention activity is the most intensive. The trend, however, has been sharply negative in Finland and the Netherlands since 2000, while it was more stable in the four other countries. With sharp progress since 2000, Israel has now become the best performing country.

**FIGURE I.6.5**

EPO patent applications(1) by inventor’s country of residence, 2007(2)

Source: DG Research and Innovation
Data: Eurostat
Notes: (1) Estimated values.
(2) Fractional counting; priority year.
(3) IS, LI, NO, CH, HR, TR, IL.
FIGURE I.6.6 EPO patents applications, 2007
FIGURE I.6.7

EPO patent applications\(^{(1)}\) by inventor's country of residence\(^{(2)}\) per billion GDP (current euro), 2000 and 2007\(^{(3)}\)

Source: DG Research and Innovation

Data: Eurostat

Notes: (1) The values for 2007 are estimates.
(2) Fractional counting; priority year.
(3) LI: 2006.
Among the medium and medium-low patenting European countries (Denmark, France, Belgium, Italy, Slovenia, Luxembourg and the United Kingdom), the trend has been negative since 2000, except in Slovenia. The number of EPO patents invented per GDP in these countries has been decreasing. In all other European countries, the situation did not change much between 2000 and 2007, with very few inventions of EPO patents. Altogether, relative to GDP, there were fewer inventions of EPO patents in EU in 2008 than in 2000.

In the majority of cases, inventions are applied for in the country where they were invented, hence a home bias in favour of European countries when considering EPO patent applications. The latter are, therefore, less suited to comparing European countries to non-European countries. However, the most striking observation in the figure below is the outstanding progress observed in South Korea and to a lesser extent in Japan. These two countries have by far overtaken the United States in inventing EPO patents, relative to the size of their economy. Inventions of EPO patents per GDP in China have been multiplied by almost four since 2000 but remain at a relatively low level.

**The level of patenting activity is positively correlated to the level of business investments in R&D**

Unsurprisingly, Figure I.6.8 below shows that countries that have high levels of patenting activity are countries with high levels of business R&D expenditure. However, the ratio between the two differs widely across countries. This ratio is an indication of the efficiency of business R&D in producing patents in a country. Switzerland, Germany and the Netherlands are the European countries inventing the most EPO patents relative to their business R&D expenditure. In contrast, Central and Eastern European countries are those which invent the fewest EPO patents per euro of business R&D expenditure.

**FIGURE I.6.8**

EPO patent applications\(^{(1)}\) by inventor's country of residence\(^{(2)}\) per million population and BERD as % of GDP, 2007\(^{(3)}\)

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157 Of course, this is only a first approximation. Many factors influence the level of patenting activity in a country. One prominent factor is the country’s degree of specialisation in technology areas which are intensive in patents.
FIGURE I.6.9 High-Tech\(^{(1)}\) EPO patent applications by inventor’s country of residence\(^{(2)}\) per million population, 2000 and 2006\(^{(3)}\)

Source: DG Research and Innovation

Notes: (1) High-Tech: Computer and automated business equipment; Semi-conductors; Aviation; Communication technology; Laser; Micro-organism and genetic engineering.
(2) Fractional counting; priority year.
(3) MT: 2002.
### About half of European countries do not invent high-tech EPO patents

The best performing countries in terms of high-tech EPO patents are the same as for all EPO patents (Figure I.6.9). However, Finland and Sweden are now ahead of Israel and Switzerland. The Netherlands, Japan and South Korea also go up the ranking, ahead of Germany. This indicates a higher concentration of patents in high-technology areas in these countries. Similarly, the United States is ahead of the EU in terms of inventions of high-tech patents per population, contrary to what happens when all EPO patents are considered (see Figure I.6.7 above). Germany invents fewer high-tech patents than its overall level of patenting activity would predict, indicating a concentration of patenting activity in medium technology areas. It is to be noted that half of the European countries produce virtually no high-tech EPO patents.

Surprisingly, in all countries, the number of high-tech EPO patent inventions decreased or remained unchanged relative to the population between 2000 and 2006, except in South Korea, Austria and Luxembourg. The progress observed in these three countries is larger than the one observed with all patents, suggesting an increasing concentration of patenting activity in high-technology areas in these countries.

### Patent activity varies strongly inside a single country from region to region, and strong disparities can be observed. Significant disparities were observed in Germany between the leading region of Stuttgart in the south, and the lowest-ranked region of Mecklenburg-Vorpommern in the east. Regional discrepancies are even larger in the Netherlands, between the regions of Noord-Brabant and Zealand. In contrast, discrepancies between regions are much lower in Finland and Sweden.

### Patent applications in the EU are concentrated in a few regions

The figure below shows the intensity of patent applications at the EPO, by residence of inventor, in the EU Nuts 2 Regions, by million inhabitants. For most of the countries, patent activity is concentrated in a few regions and these regions tend to be geographically close, independently of whether they belong to the same country or not. This is the case for the north of Italy, the south of Germany and the south east of France - the darker parts of the map. The Nordic countries are also very active regions in terms of patent applications, with more than 100 patents per million inhabitants.

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158 High-tech patents are patents in the following technology areas: Computer, Aviation, Semi-conductors, Micro-organisms and genetic engineering, Communication technology, Laser.

159 In the case of Luxembourg, one even observes a decrease in global patenting activity.
FIGURE I.6.10  Patent intensity in the EU NUTS 2 regions 2007

Patents per Million Inhabitants
- below 25
- 25 to 50
- 50 to 100
- 100 to 250
- 250 to 500
- above 500

Source: DG Research and Innovation
Data: Regional Key Figures
6.3. Estimating efficiency: what is the return on investments?

The public sector in the EU has a lower scientific output per researcher than the United States

In an innovation ecosystem, the public sector is in charge of delivering the cutting-edge knowledge and well-trained researchers which are needed to feed business inventiveness in the long run, but would be too costly for the private sector to train. Keeping in mind the importance of cutting-edge knowledge production by the public sector, one has to compare quantity and quality of public research in the EU and the United States.

The analysis can first measure the quantity of output of the public research sector. In this area, the publication output per researcher provides a rough measure of productivity of researchers in the public domain in both economies (Figure I.6.11). Taking the data relating to the number of publications in 2007, one can see that the average number of publications per year per researcher in the public sector is 1.54 in the United States versus 0.70 in the EU. Researchers in the EU public sector appear significantly less productive in terms of publication output compared to their US counterparts. However, it should be noted that research institutions in Europe have multiple ‘missions’, which are not all oriented towards scientific publications.

Concerning the relative quality of publications produced in a country, the best proxy available is the share of a country’s scientific publications which counts among the 10% most-cited publications worldwide. As presented in chapter 6.1 in Part I, the contributions of the United States and the EU to the 10% most-cited scientific publications in the citation window 2007-2009 are 1.53 for the United States and 1.16 for the EU.

To compare both quantity and quality of output per public researcher, one can calculate the Average Publication Quantity and Impact-10 that is publication per researcher \( \times 10\% \) most-cited publication ratio (APQI-10). As a result, the APQI-10/researcher is 2.35 in the United States versus 0.81 in the EU. Hence the APQI-10 per researcher in the United States is almost three times higher than in Europe (Figure I.6.11). This finding - with all its limitations - is very telling about the difference in output of public research in the United States and the EU. Taking the figures of 2007, we find that with just 38% of the number of researchers (FTE) of the EU, researchers of the public sector in the United States produce a Total Publication Impact (TPI, equal to APQI-10 x number of researchers) higher than the total TPI of the EU (663,000 in the United States versus 619,000 in the EU).

A better understanding of this difference in both quality and quantity of output in the public domain requires a correlation with the financial resources available per researcher (Table I.6.3). If we look for the capital endowment per researcher, the tremendous difference between European researchers and US researchers in the public domain becomes obvious: on average a researcher in the public domain in the United States has financial resources more than two times higher than their colleagues in Europe have at their disposal. Put differently: the public research sector in the United States provides few, but excellently equipped research capacities. Funding per researcher (including remuneration schemes) in the public sector of the United States is higher than in the private sector - but limited to a number of researchers much smaller than in Europe.
This difference in the efficiency of public research to produce high quality output has impacts on the capacity of European business to build on the knowledge, ideas, and skills provided by the European public research sector. The following considerations apply:

1. The race for innovation is a winner-takes-all game. The first inventor usually takes the major profit from an innovation. Expected financial returns are higher, the greater the distance ahead of the nearest competitor (it takes longer for the competitors to come up with a similar innovation). The data presented above, and other specific analysis¹⁶⁵ suggest that public-sector research in Europe - even under assumption of perfect and frictionless knowledge transfer into the private sector - provides insufficient cutting-edge input to the private sector to be a winner in a completely new field of technology.

2. The outstanding achievements of top researchers attract young talents. The bigger the fame of a top researcher, the more she or he will attract young researchers with high potential from elsewhere. Moreover, many of these talents will not stay in public (academic) research, and will subsequently move - with all their talent and knowledge - to the business sector close to the location of the top researchers. As indicated by the recent MORE study, the issue of working with a leading expert in the field is a far lesser motivation for American researchers to come to Europe than vice versa. In contrast, an important motivation for European researchers to leave Europe for the US is to work with leading experts in their field¹⁶⁶.

3. The relatively high level of concentration of high quality research in the public sector in certain States in the US facilitates the networking between researchers in the public sector and the business sector, in particular when it concerns matching venture capital, researchers and inventors. Europe also has pockets of excellent public research with ideas and knowledge which could be highly relevant for the private sector, but to find these outstanding ideas would take much more effort for venture capitalist and R&D intensive firms. These large transaction costs in turn reduce the profitability of private investment into cutting-edge innovations in the EU.

The reasoning presented here is not entirely new. Earlier work provided evidence that excellent public research generates additional business R&D, which is critical for innovation and ultimate productivity and economic growth as well as other societal benefits. Several authors have argued that private investment in R&D and its localisation is likely to be stimulated by the quality and size of academic research. To give two examples: Dosi, Llerena and Sylos Labini (2009) presented cross-country comparisons showing that industry-financed R&D appears positively related with both the per capita number of highly cited researchers and expenditure on higher-education R&D¹⁶⁷. Abramovsky, Harrison and Simpson (2007) investigated the relationship between the location of private sector R&D labs and university research departments in Great Britain and found that private R&D investment first of all co-locates with outstanding research departments of universities¹⁶⁸.


¹⁶⁶ See MORE Study 2010 - Report 3: Extra-EU mobility.


FIGURE I.6.11
Scientific publications(1) and APQI-10(2) per public sector researcher (FTE), 2007

Source: DG Research and Innovation
Data: Eurostat, OECD, Science Metrix / Scopus (Elsevier)
Notes: (1) Full counting method.
(2) APQI: Average Publication Quantity and Impact.

FIGURE I.6.12
Public(1) expenditure on R&D per public sector researcher (euro), 2003(2) and scientific publications in the 10% most cited scientific publications worldwide as % of total scientific publications, 2005-2007(3)

Source: DG Research and Innovation
Data: Eurostat, OECD, Science Metrix / Scopus (Elsevier)
Notes: (1) For this graph the public sector refers to the Government, Higher Education and Private non-Profit Sectors.
Public expenditure on R&D excludes R&D financed by business enterprise.
(2) MT, AT, FI, CH: 2004; UK: 2005
(3) Full counting method.
(4) US: R&D expenditure does not include most or all capital expenditure.
(5) South Korea: R&D expenditure does not include R&D in the social sciences and humanities.

Innovation Union Competitiveness Report 2011
Given the importance of the production of cutting-edge knowledge in the public sector for seeding high-tech industries in the private sector, the next pages provide some reflections on European research funding. Figure I.6.12 presents the relationship between public investment per researcher in 2003 and the share of highly cited publications in the period from 2005–2007 (under the assumption that an investment into research in year X produce cited papers 2-4 years later). The relationship is quite straightforward - with the interesting exception of Italy: the more resources are available per researcher the more likely research results are produced that are regarded as seminal and cited accordingly. It is also interesting to note the large differences between European countries, where several countries (such as Switzerland, Denmark, the Netherlands and Iceland) present a higher number of highly-cited publications for less funding per researcher than the United States as a whole.

**A higher scientific output in the public sector is positively related to a higher business sector R&D investment and innovation**

Figure I.6.13 follows this logic further downstream: The more cutting-edge knowledge has been produced, the more likely it is that such knowledge should spill over into new products and services and hence private R&D activities. Therefore, figure I.6.13 presents the relationship between the quality of public research in the period 2005-2007 (measured in the share of highly quoted papers) and the private R&D intensity in 2008. Quality of public research relates positively with private R&D activities.
Of course, quality of public research is not the only factor behind private R&D investments. A lack of adequate IPR protection and fragmented internal markets are also important determinants, and are detrimental to private R&D intensity\[^{169}\]. But the capacities of the public-research sector of Europe to deliver cutting-edge knowledge, ideas and discoveries might be an issue in helping high-tech industries flourish still further in Europe.

Figure I.6.14 shows that those countries which have increased their private research efforts the most have also achieved higher technological outputs, measured by the increased rate in the number of patents. The same positive correlation is visible for EPO patent applications\[^{170}\].

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\[^{169}\] For a more comprehensive review of the framework conditions for business R&D, see Part III, Chapter 2 in this report.

\[^{170}\] See Part I, Chapter 6.2, Figure I.6.8.