

Helmers, Christian; Schulte, Christian; Strauss, Hubert

Article

Business R&D expenditure and capital in Europe

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ABSTRACT

This study presents new estimates of business R&D capital stocks for 22 countries at the aggregate and industry levels. At 9 percent of GDP, the EU business R&D capital stock falls short of its US and Japanese counterparts. Within the EU, R&D capital stocks are much lower in the southern and the new member states, reflecting large and persistent disparities in R&D expenditure. There was hardly any convergence over the past decade. The R&D capital stock is concentrated on three technology-intensive manufacturing industries and is positively correlated with growth in total factor productivity across countries and industries. Finally, the ratios between the stocks of R&D capital and tangible capital suggest marked differences in how R&D and tangible capital are combined in production.

Christian Helmers (christian.helmerts@economics.ox.ac.uk) and **Christian Schulte** (christian.schulte@lrz.uni-muenchen.de) are PhD candidates at the University of Oxford and Ludwig-Maximilians University Munich, respectively. **Hubert Strauss** (h.strauss@eib.org) is Economist in the Economics and Financial Studies division of the EIB.

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The R&D capital stock estimates produced for this study may be used provided reference to this article is made. They are available at: <http://www.eib.org/about/events/conference-in-economics-finance-2009.htm>



Business R&D expenditure and capital in Europe

1. Introduction

The economic literature has long recognized the importance of innovation and its organized production in the form of research and development (R&D) in fostering productivity (Arrow 1962; Griliches 1979; Romer 1990; Grossman and Helpman 1991; for an overview see Uppenberg 2009a, in this issue). One specific feature of knowledge is that it has public-good characteristics: non-excludability and non-exhaustibility. This means that knowledge, whose producers incur private costs, can “spill over” to other private entities (Arrow 1962). In the presence of spillovers, increasing returns to scale can be achieved in production, translating into long-run economic growth (Romer 1990).

Considering the eminent role attributed to R&D in promoting productivity growth, a country’s total R&D expenditure is widely regarded as an informative measure of its technological innovation capacity and, hence as one of the determinants of its long-run growth. Moreover, there is evidence for own R&D being important for the absorption of new knowledge produced by others (Cohen and Levinthal 1989; Griffith *et al.* 2004). Thus a country’s own R&D expenditure is also regarded as a measure of its ability to benefit from international knowledge spillovers.

Conceptually, R&D is an input measure of innovation and does not necessarily reflect the actual amount of innovation produced. Indeed, producing an invention and turning it into a commercial success usually involves a considerable time lag and is subject to uncertainty. This means that the relation between R&D expenditure and resulting innovations – let alone productivity advances – is not easily identifiable. The economic literature has nevertheless extensively looked at the input side when assessing innovation activities of countries, industries and firms because finding good empirical measures of innovation outputs is challenging. R&D expenditure is the most precise and best-researched innovation input measure available so far, albeit not the most comprehensive one.¹

When firms develop new products and processes, they do not only build on knowledge acquired in the current year but use a large stock of knowledge accumulated inside and outside the firm over many years through basic research, experimental development, prototypes, and learning from past failures. Hence, just as for tangible capital, it is the size of the R&D capital stock rather than the last vintage of R&D expenditure that determines output in a given year. The R&D capital stock may be interpreted as the value of the business sector’s aggregate scientific and engineering knowledge.

The principal motivation for measuring the stock of R&D capital is to assess its widely-recognised contribution to GDP growth. Yet, knowing the R&D capital stock requires treating R&D expenditure as an investment in the first place. The fundamental shift away from treating R&D as an intermediate input for firms towards treating it as an investment represents one of the major changes to the System of National Accounts agreed internationally in 2008 (European Commission *et al.* 2009, p. 206). The move has consequences for the estimated levels and growth rates of GDP, labour productivity and factor income shares.

¹ For broad estimates of intangible capital, which also include brands, novel designs, firm-specific human capital and efficiency-enhancing innovations of firms’ organisational structures, and their role in productivity growth see van Ark *et al.* (2009) in this issue. See also Bontempi and Mairesse (2008).



Christian Helmers



Christian Schulte



Hubert Strauss

This study gives an overview of R&D in Europe, the US and Japan and presents new estimates of business R&D capital stocks.

This study gives a broad-brushed overview of R&D in Europe, the US and Japan, thereby zooming in on the business sector and focusing more on R&D capital stocks than on R&D expenditure. Acknowledging the conceptual and measurement problems surrounding the construction of R&D capital stocks, we present updated and new estimates of business R&D capital stocks for 22 countries at the industry² level.

We uncover substantial variation in R&D capital stocks even across relatively homogenous industrialized economies. Differences exceed by far those in tangible capital and labour. There is hardly any sign of convergence in R&D capital stocks, both within the EU and between the EU, the US and Japan (the so-called triad). Throughout the triad, R&D capital stocks are concentrated on three broad manufacturing industries: Chemicals and pharmaceuticals, Transport equipment, and ICT and other equipment. Furthermore, we examine to what extent differences in estimated R&D capital stocks help understand diverging productivity dynamics across countries and industries. Finally, we illustrate how countries and industries differ with respect to how they blend R&D capital and tangible capital in producing output.

The paper is structured as follows. Section 2 provides a brief overview of trends and broad patterns of R&D expenditure in Europe. Section 3 presents estimates of R&D capital stocks and discusses their evolution over time as well as industry patterns. Section 4 illustrates factor input ratios by relating R&D capital stocks to the stocks of total tangible capital and of specific types of tangible assets. Section 5 summarises the main findings and discusses some policy implications. Since the concepts presented in this article are quite technical, readers find a glossary of technical terms in Annex 1.

2. Business R&D expenditure in Europe: Trends and patterns

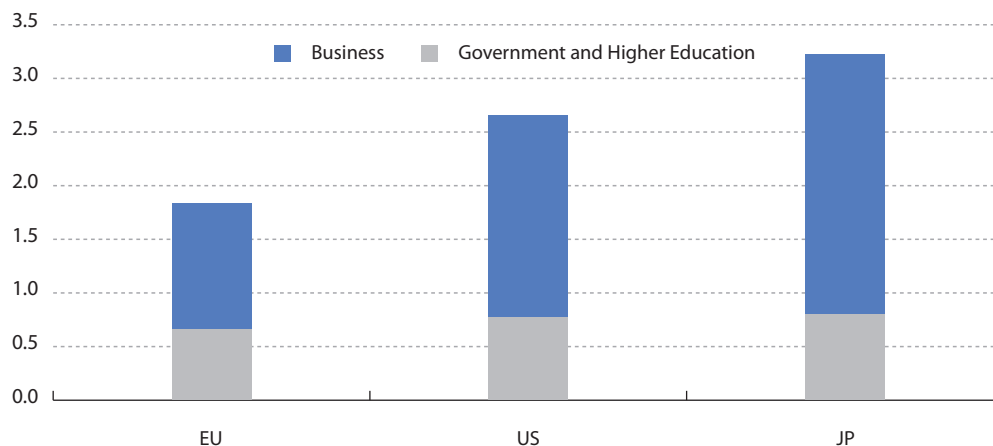
2.1 Total and business R&D: Stable over time and below target

At the summit in Lisbon in 2000, EU heads of state launched an ambitious strategy for growth and jobs, which has since been known as the Lisbon strategy. The main objective is to close Europe's gap in productivity growth *vis-à-vis* the US and to make the EU economy the most productive and competitive economy in the world. To help governments reach this overarching goal, the strategy sets a number of quantifiable objectives in a wide range of policy fields relevant for GDP growth such as labour markets, product market competition, entrepreneurship, higher education, and research and innovation.

One of the most visible Lisbon targets is that of increasing total R&D expenditure to 3 percent of GDP, with 2 percent of GDP coming from the business sector. It is also one of the targets that have been missed most markedly. Economy-wide, the EU has spent, on average, only 1.8 percent of GDP on R&D this decade, compared with 2.7 percent for the US and 3.2 percent for Japan (Figure 1). The breakdown of these figures by institutional sector indicates that the gap is in the business sector whereas R&D by governments and higher-education institutions is on par with the US and Japan. In 2007, Business expenditure on R&D (BERD) represented close to 1.2 percent of GDP. An increase by 70 percent would be required to meet the Lisbon objective of 2 percent of GDP. This is why we focus on business R&D from Sub-section 2.2 onwards.

² In this paper, "industry" refers to the branches of the International Standard Industrial Classification (ISIC) or regional variants thereof (e.g. the NACE for Europe) and, hence, may refer to services as well as to manufacturing. By contrast, "sector" relates to institutional sectors of the national accounts such as households, non-financial corporations and the government.

Figure 1. R&D expenditure by sector (percent of GDP), 2000-07

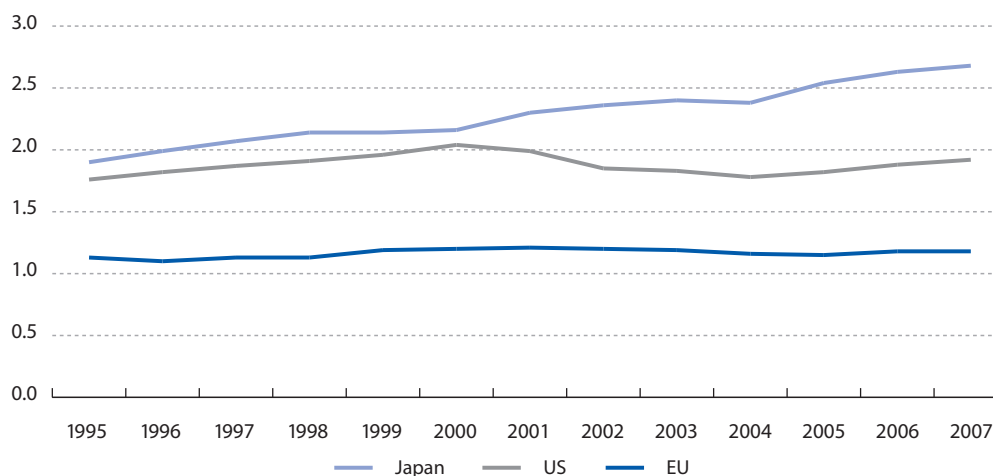


Source: Eurostat, own calculations

Not only was the EU missing the 2-percent target for BERD in the late 2000s but there is no sign that the Union has started moving towards the target over time. BERD in the EU has been stuck at about 1.2 percent of GDP for more than a decade and there is no catching up with the US and Japan (Figure 2). On the contrary, Japan is speeding ahead.

The EU has not moved closer to the Lisbon target for R&D expenditure.

Figure 2. Business R&D expenditure (percent of GDP), 1995-2007



Source: Eurostat

Among the EU member states, only Finland and Sweden have total R&D expenditure above 3 percent of GDP, followed by Austria, Denmark and Germany at around 2 ½ percent (Annex 2). The apparent stagnation of R&D expenditure in the EU masks remarkable increases in some countries. For example, BERD has sharply increased in Austria and Denmark. Starting from a much lower level, Spain, Portugal and the Baltic countries have also recorded significant growth in BERD even though their total R&D expenditure is still at or below 1 percent of GDP.

2.2 The EU is less R&D intensive than the US and Japan also at the industry level³

A natural question to ask in further diagnosing Europe’s comparatively low BERD is whether it persists at the level of individual industries. Indeed, Europe’s low overall BERD could reflect (i) low R&D intensity

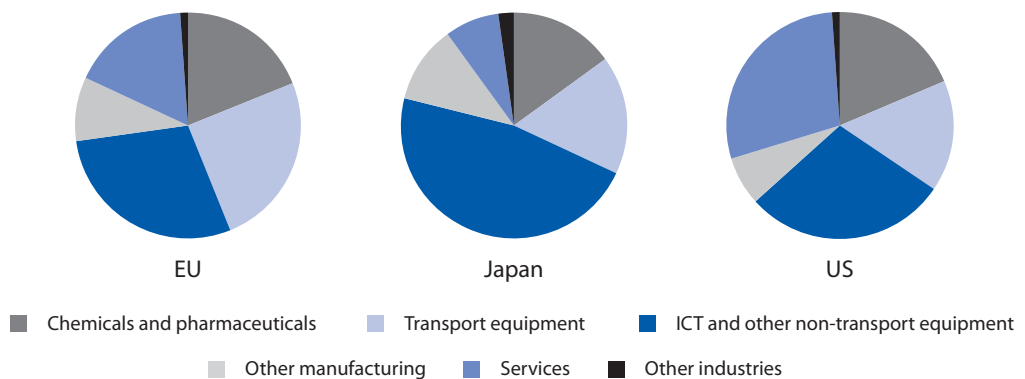
³ This section draws on and updates Uppenberg (2009b).

Chemicals and pharmaceuticals, Transport equipment and ICT and other equipment industries account for three quarters of business R&D in the EU.

– defined as BERD relative to value added – in most or all industries (R&D intensity effect), (ii) an industry composition effect whereby Europe might be specialised in industries relying less on formalized R&D, or (iii) a combination of (i) and (ii).

In answering this question, it is useful to start by showing which industries spend most on R&D. Figure 3 gives this information for the three economic zones of the triad. Three main insights emerge. First, three broad manufacturing-industry groups account for the brunt of R&D: Chemicals and pharmaceuticals (ISIC 24), Transport equipment (ISIC 34 and 35) and ICT and other non-transport equipment (ISIC 29 to 33). These industries make up three quarters of aggregate BERD in the EU and even 80 percent in Japan although they produce less than one-tenth of GDP.⁴ Second, within these three leading industry groups, Japan’s R&D is more concentrated on ICT equipment than R&D in the EU and the US while Europe has a stronger focus on Transport equipment. Third, outside the three leading manufacturing industry groups, the US records a significant share of BERD – almost one third – in services whereas Japan spends a lot on other manufacturing.

Figure 3. BERD by industry groups, EU, 2005



Source: OECD ANBERD, own calculations

However, a strong *caveat* must be put on international comparisons of BERD at the industry level. According to international conventions, R&D statistics should allocate each R&D activity to the targeted product field (e.g. a new computer) rather than the main activity (measured by turnover) of the R&D-performing company. Moreover, R&D activities by specialised R&D service firms (ISIC 73) should be allocated to the industries purchasing these services. Countries differ as to whether they follow these conventions. This matters for the reported industry breakdown of BERD (Box 1).

We therefore distinguish between three groups of countries by decreasing degree of comparability when comparing individual EU countries and their industry-level R&D data. Country group 1 comprises countries that follow the product field approach in collecting R&D data. These are Belgium, Finland, France, Sweden and the UK. We also include Germany and the Netherlands which, albeit following the main-activity approach, break down the R&D expenditure of their biggest R&D-performing companies by product field. The other countries collect BERD by companies’ main activity. Country group 2 comprises countries that reallocate part or all of the BERD by R&D service firms to the consuming industries, most often located in manufacturing. All other countries are in Country group 3. The bulk of BERD in the EU is done in group-1 countries whereas the US and Japan fall into group 3.

⁴ Because of their high R&D intensity, the individual industries in the three broad groups are all labelled as either high-technology or medium-to-high-technology in the OECD’s classification of technology intensities in manufacturing while the remaining manufacturing industries are “low-technology” or “medium-to-low technology”. See Table A1 of Danguy *et al.* (2009, in this issue) for an overview of individual manufacturing industries.

Box 1. Cross-country comparability of R&D data at the industry level

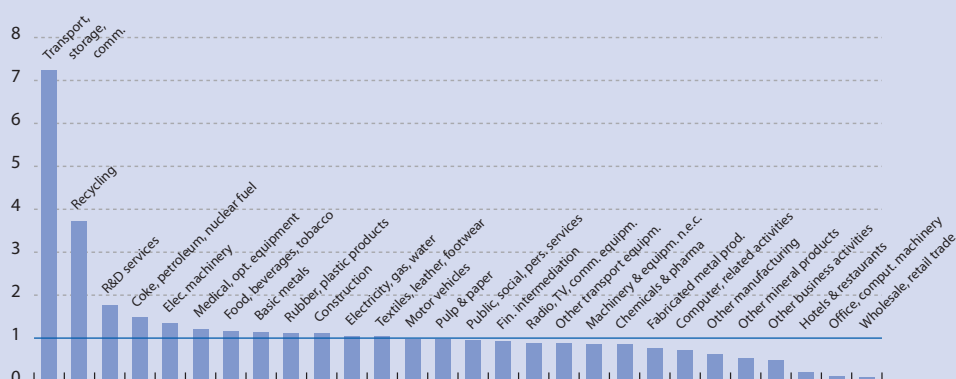
As stated in the main text, the comparability of industry-level R&D data is limited across countries because countries differ as to whether they follow the main-activity or the product-field approach in collecting R&D data from companies and compiling BERD at the industry level.

How to treat the R&D activity of a large multi-product enterprise in the compilation of R&D statistics by industry? Consider the example of a corporation which achieves 75 percent of its sales in steel production (ISIC 271) whereas the remainder of its sales constitutes special purpose machinery (ISIC 292). R&D expenditure can now either be allocated entirely to the main activity of the company (ISIC 271) or be divided between its two activities according to the actual R&D expenditure in both fields. In practice, both ways of allocating R&D expenditure across industries exist. Another problem is how to allocate the activity of the R&D services industry (ISIC 73). In a number of countries, the practice has changed over time. Furthermore, data may not be available on an annual basis and for all industries in certain countries (e.g. Austria), for example due to a lack of annual surveys or confidentiality issues (OECD 2009b).

While most of the R&D heavyweights among EU countries follow the product field approach, Japan and the US apply the main-activity approach. For the US, this leads to significant amounts of R&D expenditure being recorded in service industries. For example, the main activity of IBM is business services because it achieves most of its turnover in that industry. But since most of its R&D is devoted to developing new ICT equipment, the current practice gives a misleading picture of the kind of R&D carried out.

The Czech Republic is the only country to publish data by product field and main activity (as from 2004). Figure B1 shows the ratio of R&D expenditure by product field to that by main activity for 2005. For example, the economy spends seven times as much on R&D in the field of transport, storage and communication than the R&D expenditure by firms mainly active in this industry (ISIC 60-64) suggests. Turning to the most R&D-intensive industries, the differences are small for Chemicals and pharmaceuticals and Transport equipment. In industry group ICT and other equipment, the main-activity approach under-reports R&D in Electrical machinery and Medical and optical equipment (ratio above 1) while it over-reports R&D in Radio and TV, Machinery n.e.c. The difference is very large in Office and computing-machinery, the smallest industry in this group. All in all, differences are large for individual industries but using main-activity R&D numbers is relatively unproblematic for R&D-intensive industry groups. However, there is no guarantee that these conclusions from the Czech example hold for other countries.

Figure B1. Ratio of BERD by product field to BERD by main activity, Czech Republic, 2005

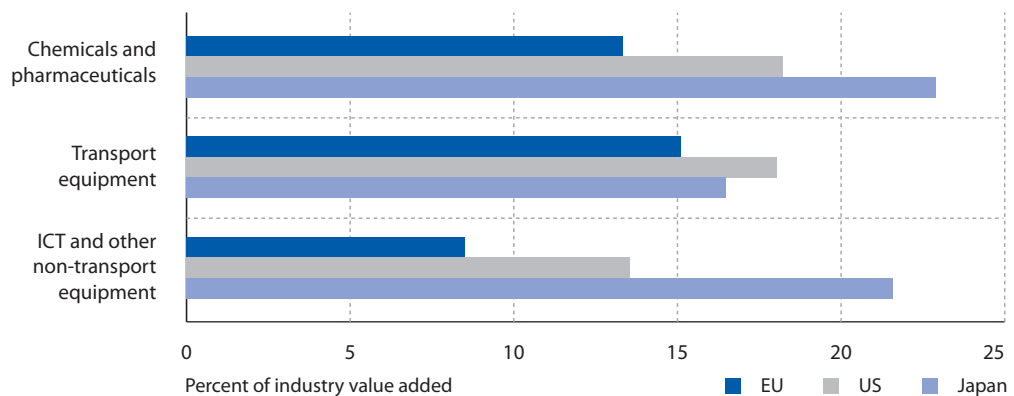


Source: OECD ANBERD, own calculations

Lower R&D intensity in individual industries accounts for a good part of Europe's R&D gap vis-à-vis the US and Japan...

With that *caveat* in mind, we now look at industry-level R&D intensities and industry composition in order to understand what accounts for Europe's gap in overall BERD. In doing so, we focus on the three most R&D-intensive manufacturing industry groups. Figure 4 shows that the lower overall R&D intensity in the EU compared with the US and Japan applies to all three industry groups. The chemical and pharmaceutical industry of Japan spent 23 percent of its value added on R&D in 2005, compared with 18 percent and 13 percent for their US and EU counterparts, respectively. Europe's gap is even larger in ICT and other non-transport equipment industries. By contrast, it is small in Transport equipment where R&D intensities are broadly the same throughout the triad at between 15 and 18 percent. The first conclusion therefore is that the R&D intensity effect is at work in key industries. Arguably, this accounts for a good part of Europe's gap in overall R&D expenditure *vis-à-vis* the US and Japan.

Figure 4. R&D intensity in technology-intensive industries in the triad, 2005



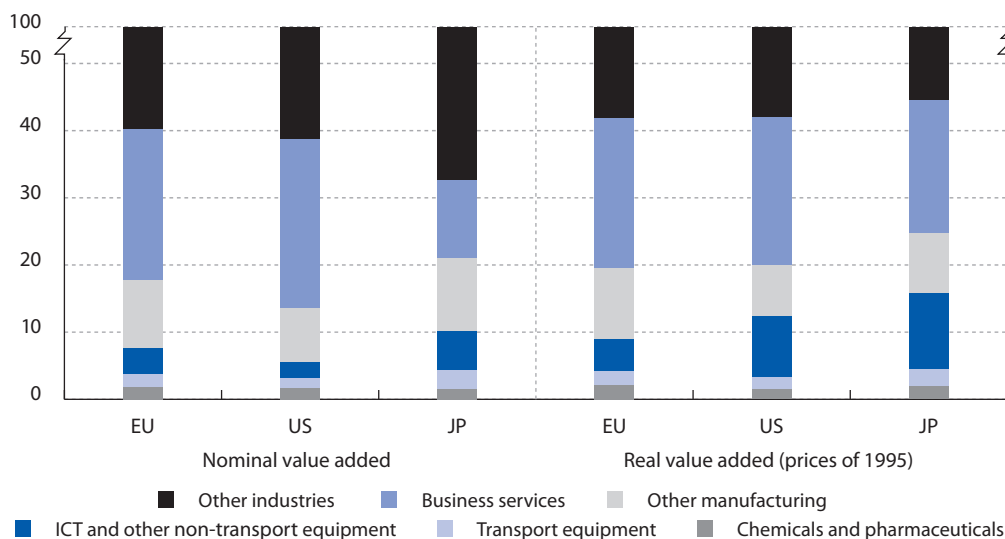
Source: OECD ANBERD, Eurostat, own calculations

Nevertheless, this does not necessarily mean that lower R&D intensity accounts for all of the gap because differences in specialization might matter, too. This would be the case if the output of technology-intensive manufacturing industries were smaller in the EU compared with the US and Japan. Figure 5 shows the share of each industry group's value added in aggregate value added for the EU, the US and Japan. When measured at current prices – as is done in the left half of Figure 5 – technology-intensive manufacturing contributed 8 percent to aggregate value added in the EU, more than in the US (6 percent) but less than in Japan (10 percent). Thus, it seems that the EU is more specialized in technology-intensive manufacturing production than the US and, hence, that the gap *vis-à-vis* the US is entirely due to lower industry R&D intensities.

However, things look different when basing the analysis on real value added. The right half of Figure 5 depicts each industry's contribution to real value added, *i.e.* value added in prices of 1995. From this perspective, the EU is less specialized than the US in technology-intensive manufacturing (share of 9 percent compared with 12½ percent) while Japan continues to be most specialized (16 percent). The difference between real and nominal shares stems from ICT and other non-transport industries and is particularly pronounced in the US and Japan but small for the EU. This is because within this broad industry group, the US and Japan are specialized on ICT-equipment production where prices decline much faster than in other industries such as machine-tools and optical instruments. Since these price declines are themselves to a large extent technology-driven and, hence, dependent on R&D, it makes sense to assess the industry's contribution to the level of GDP on real value added.⁵ Closer inspection of the right half of Figure 5 suggests that the share in real value added of ICT and other non-transport equipment is significantly smaller in the EU than in the US and in Japan, pointing to an industry composition effect alongside the R&D intensity effect mentioned above.

⁵ By contrast, nominal value added is more appropriate to assess the resource cost of R&D as compared to other inputs.

Figure 5. Industry composition of value added in the triad (percent), 2005



Source: Eurostat, own calculations

Note: In the left half of the figure, the share of each industry is defined as the ratio of the industry's nominal value added to aggregate value added. In the right half of the figure, the share of each industry is defined as the ratio of the industry's real value added to aggregate real value added.

All in all, this section has shown that R&D expenditure in the EU lags behind that in the US and Japan, which is attributable to the business sector rather than the government sector. There has been no sign of the EU catching up with the other areas of the triad over the past 15 years. BERD is heavily concentrated on three technology-intensive manufacturing industry groups: Transport equipment, ICT and other equipment, and Chemicals and pharmaceuticals. The lower R&D intensities in the latter two and the modest size of Europe's ICT-producing industries account for most of the shortfall in overall BERD.

...but the smaller scale of ICT equipment production also plays a role.

3. Business R&D capital stocks: New evidence at the country and industry levels

As stated in the introduction, deriving R&D capital stocks from annual investment flows allows to approximate a country's or an industry's scientific and engineering knowledge with a single number. It is a necessary step in using R&D in the analysis of economic growth.⁶ This section first presents estimates of R&D capital stocks for the business sectors of 22 countries and illustrates how they have evolved over time. It then discusses how the stocks are distributed across industries and to what extent productivity is associated with R&D capital.

3.1 Estimates of aggregate business R&D capital stocks

In general terms, the capital stock (K) is a function of all past and current investment (I) and of depreciation. Specifically, the capital stock today equals the part of last year's capital stock that survives – that is, the part that has not depreciated – plus current investment – here the R&D expenditure of the current year. This is the intuition of the perpetual-inventory method, which can be written as:

$$K_t = K_{t-1}(1-d) + I_t$$

where d denotes the depreciation rate and subscripts t and $(t-1)$ stand for the current and previous year, respectively. The computation of R&D stocks is conceptually straightforward but it is fraught with practical challenges (Box 2).

⁶ Ideally, the analysis should go one step further. As with capital services (OECD 2009a), the ideal input indicator for GDP accounting is R&D capital services. Their use is complicated by varying estimates of returns to R&D. In using R&D capital stocks, we assume that they are proportional to R&D capital services, thereby abstracting from cyclical fluctuations and assuming a geometric depreciation pattern.

Box 2. Assumptions made in computing R&D capital stocks

The construction of R&D capital stocks raises the same practical questions and difficulties that are known from the construction of tangible capital stocks. First, should all R&D expenditure be treated as investment? Second, the choice of the depreciation rate has an impact on the level of the R&D capital stock but little is known about the “service lives” of industrial R&D projects. Third, the initial R&D capital stock is unknown. A final problem is deflation: R&D investment of different years can only be added if adjusted for changes in the price of R&D over time. This box discusses these four issues in turn.

Capitalization rate. It is assumed that 100 percent of R&D expenditure represents investment. At first glance, this seems to be a bold assumption. Nevertheless, business R&D is carried out mainly to increase profits in the medium and long term. R&D expenditure therefore fits the definition of investment as “any use of resources that reduces current consumption in order to increase it in the future” (Corrado *et al.* 2005, p. 19). Assuming that all R&D expenditure is undertaken to generate an economic benefit to the firm, it is justified to fully capitalize R&D expenditure. This is also in line with the guidelines of the System of National Accounts 2008.

Depreciation rate. There is no consensus about the appropriate depreciation rate. We use a 12 percent rate that is constant across industries, countries and time. This assumption implies that if a country completely stopped investing in R&D, its R&D capital stock would be halved within five and a half years. We opt for this depreciation rate to be consistent with the existing R&D capital stock estimates of EUKLEMS on which we build (O’Mahony *et al.* 2008, p. 12). Indeed, the choice of an appropriate rate is not straightforward as only few and divergent studies are available. A depreciation rate of 12 percent lies at the lower end of rates used in the literature. In an overview, Mead (2007) finds plausible rates between 12 and 20 percent. Van Ark *et al.* (2009) quote a range between 11 and 26 percent and use a rate of 20 percent in their estimates. The high variation in depreciation rates partly stems from different methods (*e.g.* patent renewal or market valuation models), none of them being completely satisfying. Moreover, in line with O’Mahony (2008) and van Ark *et al.* (2009), we do not account for potential differences in depreciation across industries, countries or over time because estimates in the literature are not converging. If anything, some tentative evidence is available for differences across industries. Starting in 2007, the US statistical authority has been writing off R&D capital in Transport equipment somewhat faster (18 percent) and that in Chemicals and pharmaceuticals somewhat more slowly (12 percent) than R&D capital in other industries, for which a rate of 15 percent is applied (Mead 2007).

Initial capital stock. The initial capital stock is calculated by extrapolating R&D expenditure growth of the initial years back to the past. Ideally, one should use a long time series and assume an initial capital stock of zero. Since time series of R&D expenditure are relatively short, we follow the strategy used by EUKLEMS. We calculate the average expenditure growth rate of the first seven years with available data and assume that this growth rate prevailed in the past. Taking depreciation into account, an initial capital stock is calculated for the first year of available data. The impact on the initial capital stock of violating this assumption diminishes over time. To illustrate, assume that (i) the initial capital stock obtained through the described procedure is 100, (ii) the true (but unknown) initial stock is 120, and (iii) R&D expenditure is equal to 12 in every year with available data. In year 7, the measured R&D capital stock is still 100 while the true one has come down to 108, converging to 100 over time. To be on the safe side, we do not show the R&D capital stocks obtained from the first seven years of R&D expenditure data.

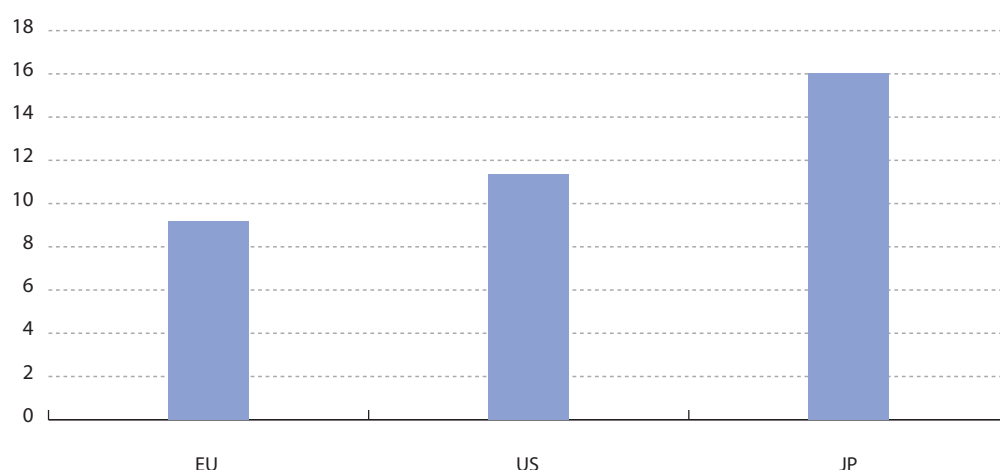
Deflator of R&D expenditure. As EUKLEMS, we use the GDP deflator. Alternatively, one could combine labour costs and output price indices of relevant industries in order to account for extraordinary productivity gains in “producing” R&D. For an overview and practical problems, see Fraumeni and Okubo (2005).

We present first estimates ever of R&D capital stocks for Austria, Greece, Hungary, Portugal, Slovakia, Slovenia and Turkey.

This study covers all OECD countries with available data. In terms of cross-country comparability, the best data source for R&D expenditure at the industry level is the OECD's Analytical database on Business expenditure on R&D (ANBERD). This data source has also been used by the EUKLEMS project in the computation of R&D capital stocks up to 2003 (EUKLEMS 2008). We use these R&D capital stocks and extend them to 2005 for some countries and to 2006 for others, thereby taking advantage of the most recent release of ANBERD (OECD 2009b). Moreover, we estimate R&D capital stocks for seven more countries: Austria, Greece, Hungary, Portugal, Slovakia, Slovenia and Turkey. In total, we get estimates for 22 countries: the US, Japan, Turkey as well as 19 EU countries. The latter cover about 95 percent of EU GDP and an even higher share of EU BERD, allowing for the calculation of EU aggregates. Further details about the data sources are given in Annex 3.

Figure 6 below illustrates the results in their most aggregate way. The business R&D capital stock in the EU was equal to 9 percent of total real value added⁷ in 2005 against 11½ percent in the US and 16 percent in Japan. Put differently, production is more R&D capital intensive in the US than in the EU and is even more R&D capital intensive in Japan. Akin to R&D intensity in Section 2, we refer to R&D capital intensity when expressing the R&D capital stock as a ratio of the size of the economy, notably of value added (also see Annex 1).

Figure 6. Business R&D capital stock estimates (percent of real value added), 2005



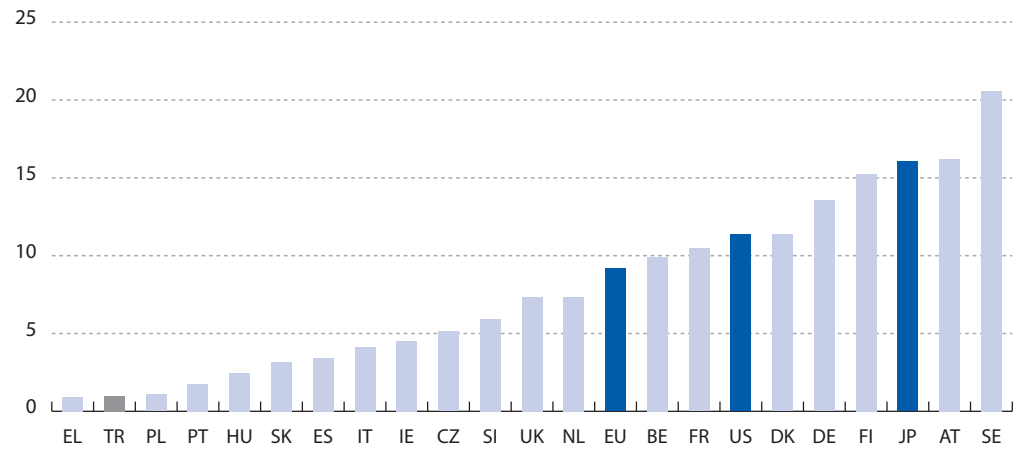
Source: EUKLEMS, OECD ANBERD, own calculations

Europe's low R&D capital intensity masks dramatic cross-country differences, which are shown in Figure 7. Overall, R&D capital is thinly spread throughout the southern and eastern parts of the EU. In 2005, the business R&D (BERD) capital stock represented 20 percent of value added in Sweden, around 15 percent in Finland and Austria but only 1 to 2 percent in Poland and Greece. A range from 1 to 20 is clearly in excess of the range of international differences in the use of other factors of production such as tangible capital and labour. As to the countries for which we present first estimates ever, business R&D capital stocks in 2005 were below the EU average in all of them except in Austria: 5.9 percent in Slovenia, 5.1 percent in the Czech Republic, 3.2 percent in Slovakia, 2.5 percent in Hungary, 1.8 percent in Portugal and 1 percent in Turkey. Another finding of our analysis is that more than 90 percent of the EU R&D capital stock is located in the western and northern EU countries.

⁷ In relating aggregate business R&D capital stocks to the size of the economy (*i.e.* output), we use aggregate real value added rather than real GDP in order to be consistent with the industry detail presented in Figure 4 and in Sub-sections 3.3, 3.4, 3.5 and 4.2. The two concepts are slightly different and, hence, the numbers of aggregate value added and GDP are not the same. For one thing, value added is evaluated at basic prices, GDP at market prices. What is more, the deflators used to obtain real measures are not the same for value added and GDP. As capital stocks are a real concept, we always divide them by real value added when discussing R&D capital intensities.

The low EU R&D capital stock masks huge differences: Sweden is 20 times as R&D capital intensive as Greece.

Figure 7. R&D capital stocks across countries (percent of real value added), 2005

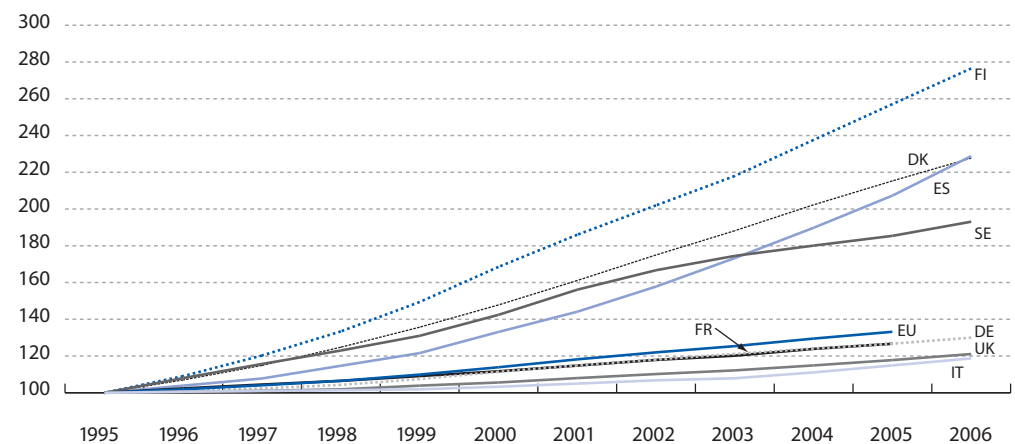


Source: EUKLEMS, OECD ANBERD, own calculations

3.2 Convergence and divergence of R&D capital stocks in the EU

To illustrate how persistent differences in the level of R&D expenditure translate into diverging R&D capital stocks, Figure 8 sets each country's business R&D capital stock equal to 100 in 1995, thus abstracting from its size relative to the economy or to other countries' stocks. For selected EU countries, the figure shows how the index evolves over time compared to each country's own starting position. Countries that swiftly increased their R&D expenditure saw their R&D capital stocks expand over the past decade, sometimes by 100 percent or more (Finland, Denmark, Spain and Sweden). However, R&D capital stocks have expanded only by 20 to 30 percent in the EU's largest economies, with the pace of expansion falling slightly short of the EU average in France and Germany and staying more significantly behind in Italy and the UK.

Figure 8. R&D capital stocks of EU countries, 1995-2006



Source: EUKLEMS, OECD ANBERD, own calculations
 Note: For each country, the R&D capital stock in 1995 is set equal to 100.

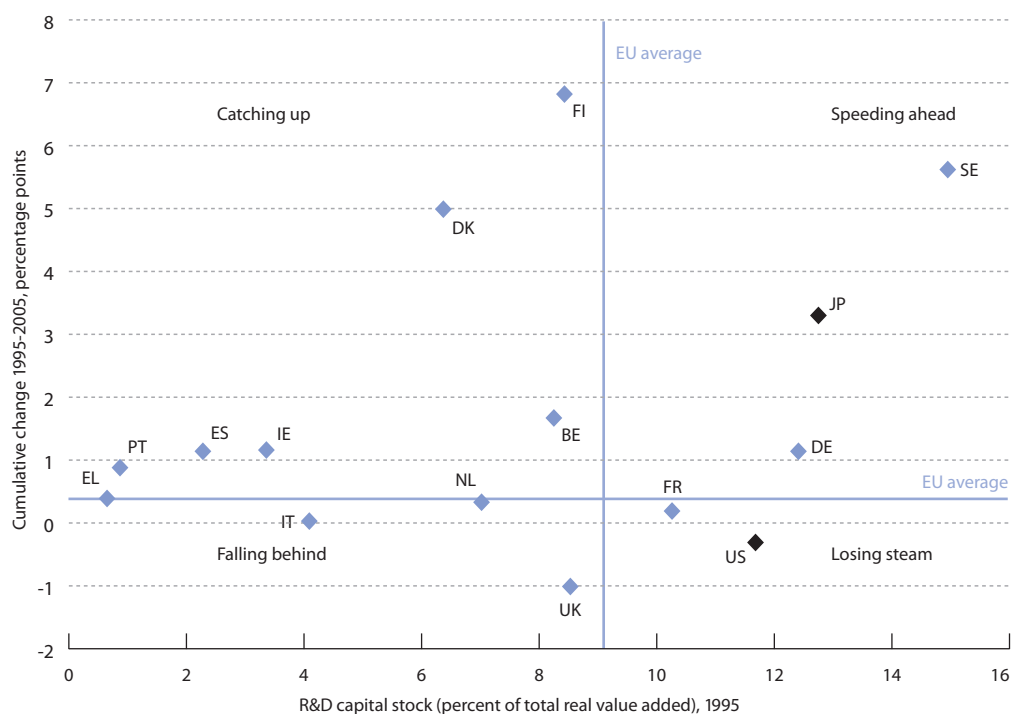
It takes a combination of the two views presented above – the size of the R&D capital stock relative to the economy and the evolution of R&D capital stocks over time – to make statements about whether EU countries converge or diverge in terms of R&D capital intensity. This is done in Figure 9, which depicts the R&D capital stock as a share of value added in 1995 on the horizontal axis and the change

in that ratio during the subsequent decade on the vertical axis. The cross-lines represent the EU average for each dimension. They cut the figure into four areas. Countries in the upper-left area (e.g. Belgium) are catching up. They had below-average R&D capital stocks in 1995 but stocks have since grown faster than the EU average. Countries in the upper-right area are speeding ahead. A drastic example is Sweden. Already in 1995, it had Europe's largest R&D capital stock. Nevertheless, it recorded one of the strongest increases in that stock during the following decade. Below the horizontal line are countries with R&D capital stocks expanding more slowly than the EU average in the past decade, either because they are losing steam from a strong position (lower-right area) or because they are falling further behind the EU average (lower-left area). If all dots were aligned on a downward sloping line or at least situated in the upper-left and lower-right areas of the figure, countries would be converging. Conversely, all dots being aligned on an upward-sloping line would signal divergence.

There has been hardly any convergence in R&D capital stocks between EU countries since 1995. True, six out of 13 EU countries are in the catching-up area while four are in the divergence zone with two speeding ahead (Germany and Sweden) and two falling behind (Italy and the UK). France, Greece and the Netherlands expanded their R&D capital stocks in line with the EU average and, hence, were neither converging nor diverging. Yet, a closer look at the countries in the catching-up area calls for a distinction between countries close to the average and those far behind. The close followers (Belgium, Denmark and Finland) overtook the EU average during 1995-2005 and are now actually speeding ahead. In contrast, the true laggards' progress has been so slow that at the current pace it will take decades before they reach the EU average. Besides, the new EU member states are not shown in this picture due to missing data for 1995 but they further increase the number of countries far behind the EU average, for which convergence to the EU's average R&D capital intensity cannot be taken for granted and would, in any case, be a matter of decades, not years. Finally, the figure shows that the EU as a whole has fallen behind compared to Japan but has marginally caught up with the US.

There is hardly any convergence in R&D capital stocks within the EU.

Figure 9. Convergence and divergence of R&D capital stocks at the country level



Source: EUKLEMS, OECD ANBERD, own calculations

Note: The vertical line represents the R&D capital stock of the EU in 1995 (13 countries with available data) and the horizontal line the cumulative change of this stock. The intersection of the lines represents the data point for the EU.

As R&D capital is deemed an important input in production in advanced economies, one would expect marked cross-country differences in the size of R&D capital stocks to shape countries' comparative advantage in technology-intensive manufacturing. This should especially be the case if higher R&D intensity of a given industry in one country is conducive to higher productivity of that industry compared with its counterparts in other countries. The connection between R&D capital and productivity will be shown in Sub-section 3.4 below.

Convergence is unlikely to happen by itself as knowledge-intensive activities tend to cluster in space due to spillovers.

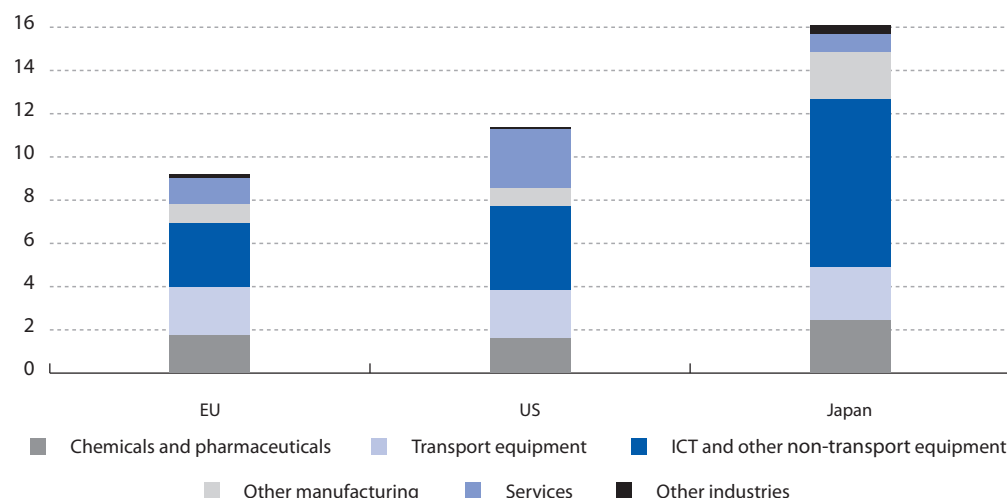
A comprehensive policy discussion on whether it is sensible to design policies that speed up convergence in national R&D capital stocks and whether governments in lagging EU countries are doing enough to that end is beyond the scope of this paper. Suffice it here to note that full convergence is unlikely to happen by itself because of the spillovers implied by knowledge-intensive activities and the resulting tendency for these activities to cluster in space. As a consequence, aiming at full convergence by all means would be very costly. Nevertheless, the economic literature on R&D stresses that R&D capital is not only needed in the most advanced economies to push the technology frontier further out. It is also required for lagging countries to catch up with the frontier since understanding and imitating new technological developments requires at least some domestic R&D activity (Griliches and Lichtenberg 1984; Griffith *et al.* 2003 and 2004; Cameron *et al.* 2005; Acemoglu *et al.* 2006). In line with these considerations, recent policy simulations find that countries with low R&D capital intensity would benefit the most from R&D-promoting and skill-upgrading policies (D'Auria *et al.* 2009).

3.3 The distribution of R&D capital stocks across industries

This section has so far taken a bird's eye view on R&D capital stocks. We now ask where in the economy the R&D capital stock is actually located, as it was done for R&D expenditure in Sub-section 2.2 above. We answer the question for the EU as a whole before considering intra-EU differences.

Figure 10 depicts the estimated R&D capital stocks for the three zones of the triad and breaks the total down by large industry groups. There are two main insights, both broadly in line with Figure 3 above. First, about three quarters of the total R&D capital stock are located in three industries: Chemicals and pharmaceuticals, Transport equipment and ICT- and other equipment.

Figure 10. R&D capital stocks by industry in the triad (percent of total real value added), 2005



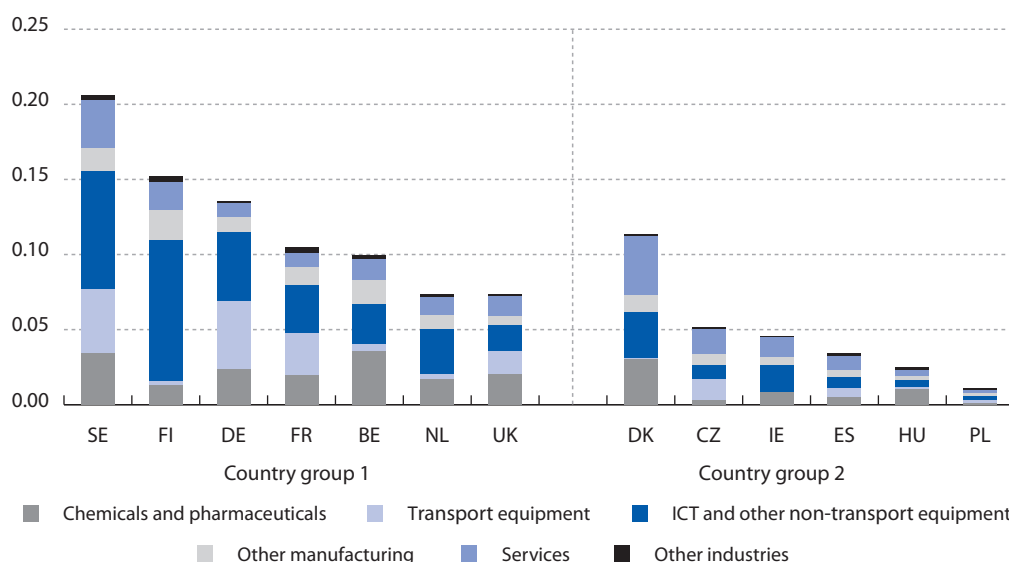
Source: EUKLEMS, OECD ANBERD, own calculations

Second, the comparison between the EU and each of Japan and the US suggests that only one industry group accounts for the differences in economy-wide R&D capital intensities. In particular, the difference between the EU and Japan is mainly due to Japan's high stock of R&D capital in ICT-producing industries. In turn, the difference between the EU and the US seems to be due to higher R&D capital stocks in the US services industries. This latter result, however, should be taken with a pinch of salt due to the comparability issues of industry-level R&D data discussed in Sub-section 2.2 above. Redistributing some of the US R&D capital stock from services to manufacturing would bring the industry breakdown in line with that in the EU. This suggests that the EU-US gap results from higher R&D capital intensity throughout the US economy.

The difference between the EU and Japan is due to Japan's high R&D capital stock in ICT-producing industries.

Turning to intra-EU differences, countries differ not only with respect to the overall size of their R&D capital stocks but also with respect to the industry structure of these stocks. Figure 11 depicts the ratio of the total R&D capital stock to real value added (height of the bars) like Figure 7 above. In addition, it shows how much each industry group contributes to that ratio (height of the individual colour segments). Countries are sorted into two groups whereby data comparability is highest in Country group 1 and lower in Country group 2, as described in Sub-section 2.2 above. The other countries (group 3) are not shown since their industry-level R&D data are hardly comparable with those of countries in groups 1 and 2.

Figure 11. R&D capital stocks by industry within the EU (percent of total real value added), 2005



Source: EUKLEMS, OECD ANBERD, own calculations

Note: Country group 1 contains countries with high degree of international comparability of industry-level R&D data. Countries in Country group 2 are less comparable but comparability is higher than for group-3 countries, which are not shown. See Sub-section 2.2 and Box 1 for details.

The seven countries in Country group 1 cover the lion's share of the R&D capital stock in the EU and are therefore fairly representative for the EU total in terms of industry structure. The frontrunners Sweden and Finland have huge R&D capital stocks in industries producing ICT and other non-transport equipment, both compared with R&D capital stocks in other industries and with the size of the overall economy. They also display larger R&D capital stocks in services. While R&D in Finland is concentrated on ICT equipment, Sweden has a more balanced industry composition of R&D capital. Sizeable R&D capital stocks in ICT-equipment industries are observed for France and Germany, too, but they are matched by the R&D capital stocks in Transport equipment. In Belgium and the Netherlands, in turn, the chemical and pharmaceutical industry is the most important and second-most important host of R&D capital, respectively, alongside ICT and other non-transport equipment.

Denmark is the only R&D-capital-intensive EU country in group 2. Chemicals and pharmaceuticals is the largest contributor in manufacturing. Services seem to be important, too, even though part of this might just be due to the main-activity approach in R&D data collection. Finally, we find that the broad industry structure of R&D capital in Hungary resembles that of Belgium, with Chemicals and pharmaceuticals being the main and ICT and other non-transport equipment the second contributor.

One should bear in mind that the industry contributions to aggregate R&D capital stocks shown in Figures 10 and 11 might be affected by industry-composition effects: if a given industry is equally R&D capital intensive in two countries but is larger (relative to GDP) in country A than in country B, the industry contributes more to the total R&D capital stock in country A than its counterpart in country B.

3.4 R&D capital stocks and productivity

As R&D capital is arguably an important factor of production in advanced economies, the marked cross-country differences both in the size and the industry composition of R&D capital stocks could shape countries' comparative advantage in technology-intensive manufacturing. We now look at the association between productivity and R&D capital stocks to see whether the latter could be a source of dynamic comparative advantage.

Accounting for labour and tangible capital alone leaves a significant part of GDP growth unexplained (Solow 1956). The growth-accounting literature documents that the contribution to labour productivity growth of total factor productivity (TFP) is indeed large (see Uppenberg 2009a). TFP is a summary index of the overall efficiency with which capital and labour are combined in producing output and, hence TFP growth measures the gains in this efficiency. When TFP is estimated in a conventional growth-accounting framework featuring only labour and tangible capital, the resulting TFP levels are likely to be correlated with factors omitted from the accounting. R&D capital stocks are one of these factors. For example, firms that obtain an innovative production process from investment in R&D may enhance their productivity without a need to increase labour or tangible capital.

There is a positive correlation between the R&D capital stock and subsequent TFP growth at the industry level.

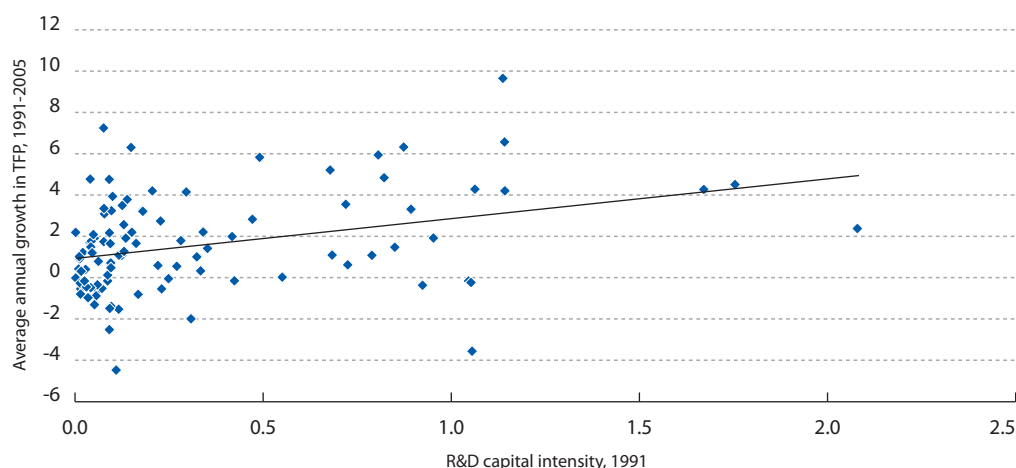
Figure 12 illustrates that there is indeed a positive link between R&D capital and conventional TFP at the industry level. It plots average annual TFP growth over the 15-year period 1991-2005 (vertical axis) against R&D capital intensity (horizontal axis) at the beginning of that period for 13 manufacturing industries and nine countries for which TFP data are available: Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, the UK and the US. The scatter plot suggests a positive association between initial R&D capital intensity and subsequent TFP growth at the industry-level across countries. The correlation coefficient of 0.34 is significant, based on a country-industry sample cleaned for a few extreme outliers, *i.e.* country-industry pairs with average annual TFP growth rates larger than 20 percent or less than -5 percent. But the graph also suggests considerable heterogeneity across countries and industries, both in terms of TFP growth and of initial R&D capital intensity. A number of industries achieve rapid TFP growth while some others are characterised by a decline in TFP over the sample period.⁸ R&D capital intensities are also strongly dispersed, with R&D capital stocks ranging from near zero to the equivalent of two years' value added.⁹ Overall, TFP growth tends to be higher in more R&D capital intensive industries.

8 The industry with the sharpest drop in TFP is Coke, refined petroleum and nuclear fuel in Japan and the US. The fastest growing industries in the sample are ICT and other non-transport equipment in Japan, Wood and products of wood and cork in Finland and Chemicals and pharmaceuticals in Germany.

9 The lowest R&D capital intensities are in Wood and products of wood and cork and in Textiles and leather products in Italy. The highest R&D intensities are in Transport equipment and in ICT and other equipment in the Netherlands, the US, France and the UK.

The positive correlation between R&D capital intensity and TFP growth comes as no surprise in light of a large body of theoretical endogenous-growth models attributing knowledge a key role in generating long-run growth. It has also been confirmed in the empirical literature assessing the link between R&D capital stocks and TFP growth at the industry level. A classic reference is the study for the US by Griliches and Lichtenberg (1984) that examines the relation between privately funded R&D capital intensity and TFP for the manufacturing industry in the 1960s and 1970s. Notably, they find average TFP growth to be higher in relatively more R&D-intensive industries.¹⁰

Figure 12: The connection between R&D capital stocks and productivity



Source: EUKLEMS, OECD ANBERD, own calculations

Note: Each dot represents a country-industry pair from a sample of 13 manufacturing industries in nine countries with available data from 1991 to 2005. TFP is taken from EUKLEMS' growth accounting results based on double-deflated value added and accounting for hours worked, labour quality and various types of tangible capital. R&D capital intensity is the industry-specific ratio of R&D capital stock (our estimates) to real value added (from EUKLEMS).

3.5 Summing up

This section has presented new and updated estimates of business R&D capital stocks for 22 countries. The EU business R&D capital stock at 9 percent of GDP falls short of its US and Japanese counterparts, mostly due to much lower R&D capital intensity in industries producing ICT and other non-transport equipment. What is more, the R&D capital stock is geographically concentrated in the western and northern EU countries but scarce in southern EU countries and in the new member states. While all countries with above-average overall R&D capital stocks have substantial R&D capital in ICT and other non-transport equipment, some of them are R&D-intensive in Transport equipment or in Chemicals and pharmaceuticals, too. These marked cross-country differences are likely to shape countries' comparative advantage in technology-intensive manufacturing.

The R&D capital stock is concentrated in the western and northern EU countries but scarce in southern EU countries and the new member states.

This section has discussed R&D capital intensities, that is, the ratio of R&D capital to output in an industry or in the economy at large. Further insights are gained by relating R&D capital stocks to the stocks of tangible capital, *i.e.* to other inputs. This is done next.

¹⁰ Guellec and van Pottelsberghe (2004) compute industry capital stocks differentiated by sources of their funding (private domestic, public and foreign) and compare their impacts on TFP. For a derivation of TFP measures in country-industry growth regressions accounting for labour, tangible capital and our estimates of R&D capital stocks and controlling for cross-sectional dependence see Eberhardt *et al.* (2010).

4. R&D capital and tangible capital

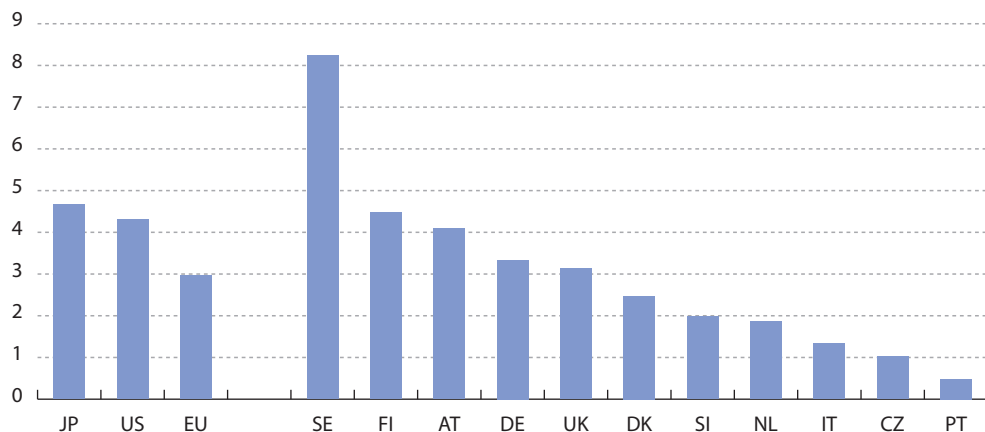
We now change the perspective and analyze the R&D capital ratio, which we define as the ratio of the R&D capital stock to the stock of tangible capital. By tangible capital, we refer to all asset types for which gross fixed capital formation is reported in the national accounts. It includes transport vehicles, ICT equipment, other machinery and equipment, residential constructions and non-residential structures, and some assets that are, strictly speaking, intangible such as software and expenditure on mineral exploration. R&D capital ratios are presented both for total tangible capital and for selected asset types. Again, we first look at countries as a whole and then take an industry perspective.

4.1 Economy-wide R&D capital ratios

The EU R&D capital stock is equal to 3 percent of the aggregate stock of tangible capital.

Figure 13 shows that the EU business R&D capital stock is equal to 3 percent of its total stock of tangible capital. The EU has the lowest R&D capital ratio within the triad. This is as expected given the gap in R&D capital discussed above. More surprisingly, however, the US R&D capital ratio is virtually at par with Japan's 4½ percent. This is because Japan's considerably higher R&D capital stock (relative to value added) is matched by a higher stock of tangible capital. Indeed, in 2005, Japan's aggregate output was produced with a tangible capital stock roughly 3½ times the size of GDP, compared with 2½ times GDP in the US.

Figure 13. R&D capital ratios (percent of total tangible capital), 2005



Source: EUKLEMS, OECD ANBERD, own calculations

Note: Total tangible capital refers to all asset types for which gross fixed capital formation is reported in the national accounts.

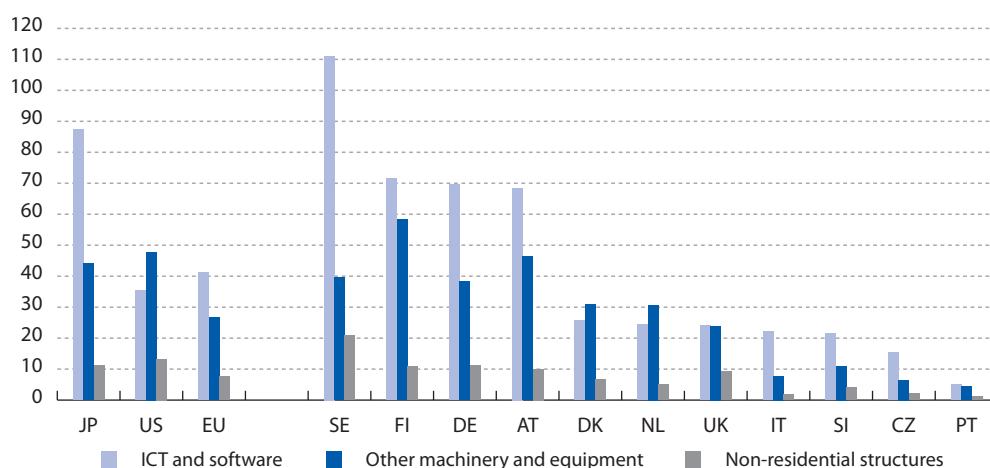
Again, there are considerable cross-country differences within the EU, too. The range of R&D capital ratios spans from 0.5 percent in Portugal to 8.2 percent in Sweden and, hence, broadly matches that of R&D capital intensities. Nevertheless, there are notable differences in the ranking of countries from the one shown in Figure 7 above. For instance, the UK is now a close neighbour to Germany, which spends considerably more on R&D but also on tangible capital. In addition to the ranking, some of the cross-country differences in the size of the R&D capital ratios are surprisingly large, others surprisingly small. Take the two European R&D frontrunners, Sweden and Finland, for example. Sweden has almost twice the R&D capital ratio of Finland because it uses less tangible capital in production. All in all, the connection between total business R&D capital stocks and total tangible capital appears to be rather loose.

Breaking down total tangible capital into several asset classes and looking at specific R&D capital ratios (*i.e.* R&D capital ratios with respect to each asset class) delivers further evidence that a given stock of R&D capital might be associated with any stock of tangible assets. To see this, we divide the R&D capital stock by the aggregate stocks of certain types of tangible assets. We consider the following three asset types:¹¹ ICT and software, other machinery and equipment and non-residential structures.¹² It is important to note the change in perspective. This is not about R&D in the industries producing certain capital goods (as in Section 3) but about the economy-wide stock of a certain type of tangible asset such as ICT and software.

Figure 14 depicts the R&D capital ratio with respect to these three asset types. The following insights emerge. First, the EU business R&D capital stock is equal to 40 percent of its aggregate stock of ICT and software, about one quarter of its stock of other machinery and equipment and some 8 percent of its stock of non-residential structures. Second, there are deviations from the familiar R&D ranking “Japan first, US second and Europe third”. On the one hand, the US economy uses ICT so intensively that the US R&D capital ratio with respect to ICT and software is less than half that of Japan and even lower than that of the EU. On the other hand, the US stocks of other machinery and equipment and of non-residential structures are so small relative to the US economy that the US R&D capital ratios with respect to each of these two asset types are higher than their counterparts in Japan despite Japan’s considerably higher R&D capital intensity.

The EU business R&D capital stock is about 40 percent the stock of ICT and software, one quarter that of machinery and 8 percent that of non-residential structures.

Figure 14. R&D capital ratios with respect to specific types of tangible capital (percent), 2005



Source: EUKLEMS, OECD ANBERD, own calculations

Note: Each bar represents the ratio of a country’s R&D capital stock in percent of the stock of a specific tangible asset.

Third, also within the EU, the pattern of specific R&D capital ratios differs from what is expected given the distribution of R&D capital stocks alone. As far as the R&D capital ratio with respect to ICT and software is concerned, Germany is at par with the more R&D-capital-intensive countries Finland and Austria, suggesting that production in Germany is less ICT-intensive. Moreover, we find an unlikely similarity in R&D capital ratios between the UK on the one hand and Denmark and Italy on the other, which in comparison to the UK points to higher ICT intensity in Denmark but lower ICT intensity in Italy.

11 EUKLEMS distinguishes the following asset types: information technology, communication technology, software, transport vehicles, other machinery and equipment, residential constructions and non-residential structures. We lump the first three into “ICT and software”. We exclude residential constructions, which are not part of the productive capital stock. We also omit the stock of transport vehicles.

12 Non-residential structures include buildings (warehouses, industrial and commercial buildings, hotels, restaurants, educational and health buildings etc.) and other structures (e.g. highways and roads, railways, airfield runways, tunnels, waterways, harbours, long-distance pipelines and cables).

Sweden's economy is more R&D- and machinery-intensive than Finland's but has lower stocks of ICT and software and of non-residential structures.

Turning to the R&D capital ratio with respect to other machinery and equipment, the first interesting comparison is once more between Sweden and Finland. The ratio is lower in Sweden, suggesting that Sweden's higher R&D capital intensity is more than reversed by its much larger stock of other machinery and equipment: the latter was equal to half of total value added in 2005, compared with one quarter in Finland. As a consequence, it is Sweden's comparatively low stocks of non-residential structures and ICT and software that account for its higher overall R&D capital ratio shown above in Figure 13. A second comparison is among countries with lower R&D capital ratios. The ratios are equal for Denmark and the Netherlands as Denmark's larger R&D capital stock is matched by a larger stock of machinery and equipment. By contrast, Slovenia's ratio of 11 percent is half that of the UK reflecting Slovenia's strong manufacturing base and its correspondingly larger stock of machinery.

Finally, there are marked cross-country differences in the R&D capital ratio with respect to non-residential structures, for example between Sweden on the one hand and Finland, Austria and Germany on the other. Sweden's relatively lower stock of non-residential structures results in a higher bar in Figure 14. In a similar vein, the stock of non-residential structures relative to the economy is also lower in the UK than in both the Netherlands and Slovenia. All in all, the discussion of economy-wide R&D capital ratios suggests that the cross-country differences with respect to the stocks of various types of tangible assets are not systematically aligned with those in R&D capital stocks.

4.2 Industry-specific R&D capital ratios

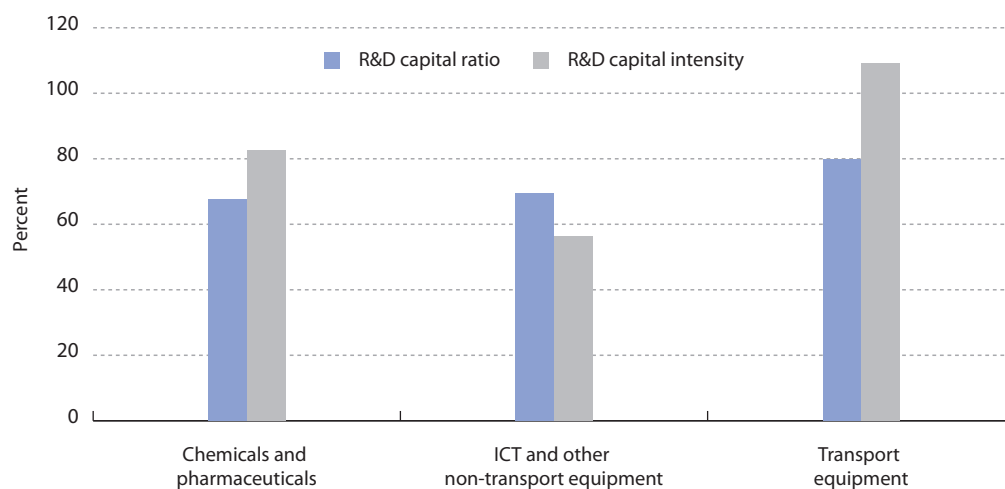
We conclude this section by illustrating R&D capital ratios with respect to total tangible capital¹³ in the EU for selected groups of industries. In addition, we show how these ratios compare with the pattern of R&D capital intensities. This is done in Figures 15a and b. Figure 15a presents the results for technology-intensive manufacturing industries and Figure 15b those for other industry groups. Figure 15b also recaps Europe's economy-wide R&D capital intensity and R&D capital ratio, illustrating that the latter is equal to about one third of the former at the aggregate level.

The following facts are worth noting from Figure 15. First, technology-intensive manufacturing is characterized by higher R&D intensity (by a multiple of about 10) and higher R&D capital ratios (multiple of about 30) than the economy as a whole. Among the three industry groups, Transport equipment is the most R&D capital intensive with an R&D capital stock of 110 percent of value added in 2005, followed by Chemicals and pharmaceuticals (80 percent) and ICT and other equipment (close to 60 percent). By contrast, the R&D capital ratios are about the same in all three industry groups. This means that the same hierarchy applies for R&D capital intensities as for tangible-capital intensities, with Transport equipment having the largest tangible capital stock relative to value added, Chemicals and pharmaceuticals the second-largest etc.

Second, other manufacturing is still considerably more R&D intensive than other parts of the economy such as services. A final – albeit indirect – insight from Figure 15 is that the tangible capital stock in all manufacturing industry groups by and large corresponds to about one year of value added whereas it is three years of value added in services.

13 The even finer analysis of industry-specific R&D capital ratios with respect to specific assets is not presented in this article. We find that across countries and industries, R&D capital stocks are slightly correlated with the stocks of ICT and software but only in the sub-sample of high-tech manufacturing industries. No such correlation is found between R&D capital and tangible capital other than ICT. Results are available from the authors upon request.

Figure 15a. R&D capital intensities and R&D capital ratios: Technology-intensive manufacturing industries, EU, 2005

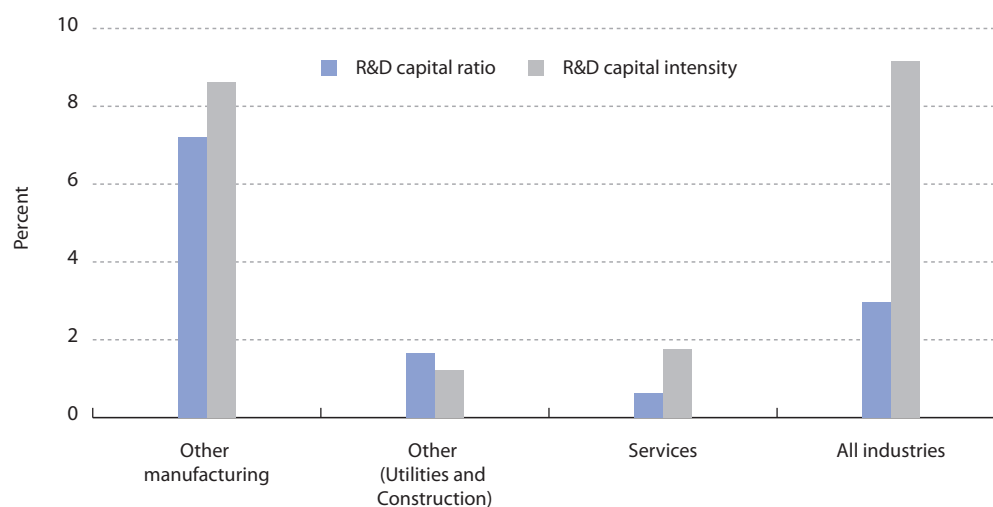


Compared to the overall economy, technology-intensive manufacturing is ten times as R&D intensive and has 25 times the R&D capital ratio.

Source: EUKLEMS, OECD ANBERD, own calculations

Notes: The left bar represents the ratio of the R&D capital stock to the total stock of tangible capital in an industry. The right bar represents the ratio of the R&D capital stock to real value added in an industry.

Figure 15b. R&D capital intensities and R&D capital ratios: Other industries, EU, 2005



Source: EUKLEMS, OECD ANBERD, own calculations

Notes: The left bar represents the ratio of the R&D capital stock to the total stock of tangible capital in an industry. The right bar represents the ratio of the R&D capital stock to real value added in an industry.

All in all, the comparison of R&D capital ratios in this section has highlighted marked differences across countries and industries in how R&D capital and (specific types of) tangible capital are blended together in producing goods and services in the economy. As a consequence, the ranking of countries in terms of R&D capital ratios differs from that in terms of R&D capital intensities. For the R&D capital ratio with respect to particular asset types, we discover notable deviations from the familiar pattern “Japan first, US second, EU last”.

5. Conclusions

R&D capital stocks are an important economic variable. Since it is the R&D capital stock rather than annual investment flows that matters for growth, this article has set out to compute R&D capital stocks for all industrialized countries with available data and has discussed how these stocks are linked to the flows that contribute to them.

Section 2 has shown that R&D expenditure in the EU lags behind that in the US and Japan, which is attributable to the business sector rather than the government sector. EU business R&D expenditure did not start increasing to get closer to that in the other countries of the triad over the past 15 years. Business R&D is heavily concentrated on three technology-intensive manufacturing industry groups: Chemicals and pharmaceuticals, Transport equipment and ICT and other equipment. It is lower R&D intensity in the latter two as well as the small size of Europe's ICT-producing industries that account for most of the shortfall in overall business R&D expenditure.

New estimates of business R&D capital stocks for 22 countries have been presented in Section 3. They show that the EU business R&D capital stock at 9 percent of GDP falls short of its US and Japanese counterparts, mostly due to much lower R&D capital intensity in ICT and other non-transport equipment-producing industries. The section has also highlighted the strong geographical concentration, especially the scarcity of R&D capital in the southern periphery and in the new member states of the EU. Using our R&D capital stock estimates, we have found a positive correlation, across industries and countries, between the initial stock of R&D capital in the early 1990s and the growth in TFP in the subsequent decade.

Section 4 has put R&D capital stocks in relation to tangible capital (R&D capital ratio), thus providing insights that cannot be gained from looking at R&D capital intensities alone. It has revealed pronounced differences in the way R&D capital and tangible capital are combined in production across the triad but also within the EU. Put differently, variations in the intensity of tangible-capital use are not strongly aligned with variations in R&D capital intensity.

Even if the EU met the Lisbon target, convergence to the US R&D capital stock would take a long time.

As far as Europe's gap *vis-à-vis* the US and Japan in business R&D is concerned, the estimates in this study suggest that there is so much inertia in these capital stocks that reaching the Lisbon target of 2 percent of GDP spent each year on business R&D (and 3 percent economy-wide) is just a necessary but by no means sufficient step to close the EU-US gap in R&D capital any time soon. To allow for convergence in R&D capital stocks within the triad, significant increases in R&D expenditure need not only to happen but to be sustained for a long period of time.

Finally, our discussion of the geographic concentration within the EU has also shown that there is hardly any sign of convergence in business R&D capital stocks. A sharp geographical division of labour into R&D-intensive and less R&D-intensive areas might be efficient given the spillovers implied by knowledge-intensive activities and the resulting tendency for these activities to cluster in space. However, countries with very low R&D capital stocks need to ensure that they have sufficient technological absorption capacity to avoid getting disconnected from growth in productivity and living standards in the most advanced economies.

Annex 1. Technical terms used in this article

Table A1. Glossary of technical terms

Term	Definition
R&D investment	The part of a year's R&D expenditure that lives longer than one year and, hence becomes part of the R&D capital stock. Broadly in line with the new convention of the 2008 System of National Accounts, this ratio is assumed to be 100 percent
R&D capital stock	The part of last year's capital stock that has not depreciated <i>plus</i> R&D investment of the current year
R&D intensity	Ratio of R&D expenditure to value added (industry level or aggregate)
R&D capital intensity	Ratio of R&D capital stock to value added (industry level or aggregate)
Gap in R&D	Fact that one country has lower R&D intensity or lower R&D capital intensity
R&D capital ratio (with respect to total tangible capital)	Ratio R&D capital stock to total tangible capital stock
R&D capital ratio with respect to <i>i</i>	Ratio R&D capital stock to stock of tangible asset <i>i</i>
Triad	Countries consisting of the EU, the US and Japan
Industries	
Chemicals and pharmaceuticals	ISIC 24
Transport equipment	ISIC 34-35
ICT and other (non-transport) equipment	ISIC 30-33 (or 29-33 in Figure 12)
Sector	Institutional sector
Industry	ISIC industry (one-letter, two-letter or two-digit)
ISIC	International Standard Industrial Classification of All Economic Activities
Asset types	
Tangible capital	Stock of all assets recorded in existing national accounts, which includes ICT and software, transport vehicles, other machinery and equipment, residential structures, non-residential structures and other assets (<i>e.g.</i> live stock of plants and animals)
ICT and software	Computing equipment, communication equipment and software
Other machinery and equipment	Any equipment other than ICT and transport vehicles
Non-residential structures	Any building or infrastructure for non-residential use

Annex 2. Additional country detail on R&D expenditure

Table A2. R&D expenditure in EU countries by institutional sector, 1995-2007 (percent of GDP)

	Total			Business			Government and Higher education		
	1995-99	2000-03	2004-07	1995-99	2000-03	2004-07	1995-99	2000-03	2004-07
Belgium	1.8	2.0	1.9	1.3	1.4	1.3	0.5	0.6	0.6
Denmark	2.0	2.4	2.5	1.2	1.7	1.7	0.7	0.8	0.8
Germany	2.3	2.5	2.5	1.5	1.7	1.8	0.7	0.7	0.8
Ireland	1.3	1.1	1.3	0.9	0.8	0.8	0.4	0.3	0.4
Greece	0.5	0.6	0.6	0.1	0.2	0.2	0.4	0.4	0.4
Spain	0.8	1.0	1.2	0.4	0.5	0.6	0.4	0.4	0.5
France	2.2	2.2	2.1	1.4	1.4	1.3	0.8	0.8	0.8
Italy	1.0	1.1	1.1	0.5	0.5	0.5	0.5	0.6	0.6
Luxembourg	..	1.7	1.6	..	1.5	1.4	..	0.2	0.2
Netherlands	2.0	1.8	1.7	1.1	1.0	1.0	0.9	0.7	0.7
Austria	1.7	2.1	2.4	1.1	1.4	1.7	0.6	0.7	0.7
Portugal	0.6	0.8	0.9	0.1	0.2	0.4	0.5	0.5	0.5
Finland	2.7	3.4	3.5	1.8	2.4	2.5	0.9	1.0	1.0
Sweden	3.5	4.0	3.6	2.6	3.0	2.7	0.9	1.0	1.0
United Kingdom	1.8	1.8	1.7	1.2	1.2	1.1	0.6	0.6	0.7
EU-15	1.8	1.9	1.9	1.2	1.2	1.2	0.7	0.7	0.7
Bulgaria	0.6	0.5	0.5	0.2	0.1	0.1	0.4	0.4	0.4
Czech Republic	1.1	1.2	1.4	0.7	0.7	0.9	0.4	0.5	0.5
Estonia	0.6	0.7	1.0	0.1	0.2	0.5	0.5	0.5	0.6
Cyprus	0.2	0.3	0.4	0.0	0.1	0.1	0.2	0.2	0.3
Latvia	0.4	0.4	0.6	0.1	0.2	0.2	0.3	0.3	0.3
Lithuania	0.5	0.6	0.8	0.0	0.1	0.2	0.5	0.5	0.6
Hungary	0.7	0.9	0.9	0.3	0.4	0.4	0.4	0.6	0.5
Malta	..	0.3	0.6	..	0.1	0.4	..	0.2	0.2
Poland	0.7	0.6	0.6	0.3	0.2	0.2	0.4	0.4	0.4
Romania	0.4	0.4	0.4	0.3	0.2	0.2	0.1	0.1	0.2
Slovenia	1.4	1.4	1.5	0.7	0.8	0.9	0.7	0.6	0.6
Slovakia	0.9	0.6	0.5	0.5	0.4	0.2	0.3	0.2	0.3
EU-27	1.8	1.9	1.8	1.1	1.2	1.2	0.7	0.7	0.7
United States	2.6	2.7	2.6	1.9	1.9	1.9	0.7	0.8	0.8
Japan	2.9	3.1	3.3	2.0	2.3	2.5	0.9	0.8	0.8

Annex 3. Data sources and methods for the computation of R&D capital stocks

Our main data source for the construction of R&D capital stocks is the ANBERD database of the OECD (2009b), henceforth ANBERD. This dataset contains R&D expenditure by industry performed in the business enterprise sector classified according to ISIC revision 3.1. ANBERD data are based on official data of business expenditure on R&D (henceforth OFFBERD), provided by national statistical authorities. In contrast to OFFBERD, ANBERD includes estimates for missing years as well as for industries that were suppressed for confidential reasons. The industry breakdown is quite detailed but must be used cautiously as there is some over- and underestimation in some countries where R&D expenditure data are not available on a product field basis (see Sub-section 2.2). This problem is relevant especially with respect to lower industry aggregates. The potential bias becomes smaller with aggregation over industries provided a bottom-up approach is applied (see below). In this paper we only show aggregates of the main ISIC industries (one- and two-letter industries).

This aggregation over industries is also necessary in order to ensure compatibility with EUKLEMS data for R&D capital stocks up to 2003, which represent our second main data source. For a general description of the EUKLEMS project and databases see O'Mahony and Timmer (2009). EUKLEMS offers data for 13 EU countries (Belgium, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Poland, Spain, Sweden and UK), the US and Japan. EUKLEMS also used ANBERD data as their primary source. We replicate their methodology by using the Perpetual Inventory Method (described in Box 2) for the construction of capital stocks out of current R&D expenditure, using the GDP deflator to obtain real expenditure.

With respect to data coverage, R&D capital stocks of EUKLEMS are available from 1980 onwards for all countries except Belgium (1994), the Czech Republic (1999) and Poland (2001). We update the EUKLEMS estimates using the newest ANBERD edition (covering years up to 2005 or 2006). Moreover, we add seven additional EU countries not available in the EUKLEMS database: Greece, Hungary, Austria, Portugal, Slovenia, Slovakia and Turkey. The time coverage of our additional, countries is more limited due to the requirement of consistent R&D expenditure data for a sufficient period. More precisely, we have estimated an initial capital stock as early as possible (*e.g.* 1993 for Slovenia). As done by EUKLEMS, we suppress the first seven years due to their sensitivity to the estimated initial stock (see Box 2). As a result of this suppression, our R&D capital stock estimates have the following starting years: 1995 for Greece and Portugal, 2000 for Slovenia, 2001 for Hungary, 2004 for Turkey and 2005 for Austria and Slovakia. For Slovakia, the limitation is that the R&D expenditure data of OECD (2009b) are in fact OFFBERD data with relatively low industry coverage.

As far as the aggregation of single industries to higher aggregates is concerned, we apply a bottom-up approach whenever sufficient industry information is available in order to avoid aggregation bias in the computation of initial capital stocks. Specifically, we calculate initial R&D capital stocks of two-letter ISIC industries to aggregate them to one-letter industries. Moreover, we use R&D capital stocks of one-letter industries in the computation of "total manufacturing" and "total services" but not for the overall computation of "total industries".

Finally, EU aggregates are computed as follows. For non euro area members, all relevant variables (R&D capital stocks, tangible capital stocks and value added) at the aggregate and industry levels are converted into euros using average market exchange rates of the year 1999. Then the euro values for the available countries of EU-27 are added together separately for each variable, thereby ensuring that the same sample is used for the component variables of ratios. For example, the EU R&D capital stock used in computing the EU's R&D capital ratio comprises fewer countries than that used for the R&D capital intensity because tangible capital stocks are available for fewer countries.

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