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EIB Papers

R&D and the financing of innovation in Europe

Stimulating R&D, innovation and growth

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Preface

Research and development and innovation are key drivers of economic growth and prosperity. European policymakers have long acknowledged their importance and, under the Lisbon Agenda, have set the objective of raising R&D expenditure to 3 percent of GDP. The operations of the European Investment Bank and its venture capital arm, the European Investment Fund, need to be seen in this context. In fact, a non-negligible portion of the EIB Group's finance is directed at the knowledge economy. In 2009, finance in support of research and development, innovation, and education and training amounted to EUR 14.5 billion, representing some 20 percent of the finance provided by the EIB Group.



Philippe Maystadt
President

To foster its impact on R&D, innovation, and growth, it is key that the Bank closely follow the debate on R&D and innovation and how they contribute to economic growth. More specifically, we must have a sound understanding of why investing in R&D and innovation is crucial, what drives such investment, what hinders it, and how possible roadblocks could be removed. The contributions to this volume of the *EIB Papers* aim at addressing these questions head on. Drawing on presentations made at the *2009 EIB Conference in Economics and Finance*, the contributions approach the topic at hand from three perspectives.

Seen from a macroeconomic perspective, the underlying rationale for investing in the creation of new knowledge through spending on R&D and innovation is to raise future output – just as spending on machinery and equipment. As obvious as this may seem, the link between investing in knowledge and the return to this investment is far from trivial and understanding this link is still in its infancy. To begin with, there is the basic issue of how to measure investment in the creation of knowledge. And then, there is the challenge of estimating to what extent this investment results in a stock of knowledge capital. Once that challenge is mastered, one can turn to analysing the link between increases in knowledge capital and economic growth. If one accounts for knowledge capital as for other macroeconomic factors of production – that is, tangible capital and labour – how does one's perception of the economy change? Specifically, to what extent does a too narrow definition of investment in the past result in underestimating the contribution of investment to economic growth? And what does acknowledging the rate of return of the hitherto unmeasured knowledge capital imply for where the resources of the economy would be put to their most productive use?

Seen from a microeconomic perspective, the key question is what drives and what impedes firms to invest in knowledge. Obviously, as with conventional investment, firms see investment in knowledge capital as an opportunity to make money. Again, as obvious as this may seem, things are far more complex. Knowledge capital differs from buildings, machinery and equipment in several important respects. The returns from knowledge are not as easily appropriated by the investor because some of the hard-won knowledge “spills over” to competitors, suppliers, clients and others. This tends to undermine the incentives of private firms to invest in its creation and, as a result, firms may not want to invest in knowledge capital as much as they should from society's perspective. Knowledge spillovers constitute a case of market failure, raising the question of whether public intervention can do anything about it. And if it can: which policy instruments are available, how effective are they, what experience is there in using them, and which lessons can one draw when designing future policies?

The third perspective considers the financing of R&D and innovation. The conference contributions on this theme are compiled in the companion issue (Volume 14, Number 2) to this issue of the *EIB Papers*. Suffice it to note here that these contributions focus on policies responding to the possibility that firms – even when they want to invest as much as they should – are unable to invest as much as they want because they cannot get finance for all the investment they consider profitable.

All in all, understanding what drives and what hinders R&D and innovation and how the creation of knowledge spurs economic growth is essential for putting Europe on a path that ensures prosperity in an ageing society. I am confident that the research findings presented in this volume of the *EIB Papers* will further enhance our understanding and I am happy we can share them with you.

A handwritten signature in blue ink, appearing to read "J. M. May". The signature is stylized, with a large, looped initial "J" and "M" followed by the name "May" in a cursive script. A horizontal line underlines the signature.

R&D and the financing of innovation in Europe

Stimulating R&D, innovation and growth

The *2009 EIB Conference in Economics and Finance* – held at EIB headquarters in Luxembourg on October 22 – examined the role of investment in R&D and other intangibles for innovation and growth and highlighted the importance of access to finance for innovative firms. It shed light on a number of policy-relevant issues including fiscal measures to boost R&D spending, the role of patents as an output of the innovation process and as a means to secure external finance for innovative firms as well as the importance of technology transfer and venture capital in transforming inventions into economically relevant innovations.

Speakers included:

Laura BOTTAZZI

of the University of Bologna, Italy

Werner RÖGER

of the European Commission, DG ECFIN

Dirk CZARNITZKI

of the Catholic University of Leuven, Belgium

Hubert STRAUSS

of the European Investment Bank

Jacques DARCY

of the European Investment Fund

Kristian UPPENBERG

of the European Investment Bank

Bronwyn H. HALL

of the University of California at Berkeley, USA

Bart VAN ARK

of The Conference Board, USA

Dietmar HARHOFF

of Ludwig-Maximilians University Munich,
Germany

Bruno VAN POTTELSBERGHE

DE LA POTTERIE
of the Université libre de Bruxelles,
Belgium

Jacques MAIRESSE

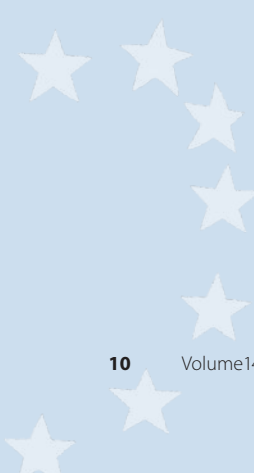
of Centre de Recherche en Economie et en
Statistique, Ecole Nationale de la Statistique et
de l'Administration Economique, Paris, France



ABSTRACT

The literature on economic growth has identified knowledge expansion as a key propellant. Early research derived this conclusion from the residual that remained after the growth contributions from capital and labour had been accounted for. Later modifications expanded the concept of fixed capital to include intangible capital. The underlying drivers of innovation have, meanwhile, been explored by the endogenous growth literature. Together, these efforts have reconfirmed the role of knowledge and innovation in growth. But they also point to the importance of competition and firm entry and exit as key motivators for firms to innovate. Policies aiming to boost growth must therefore look beyond the amounts invested in R&D and also provide for well-functioning labour, product and financial markets.

Kristian Uppenberg (k.uppenberg@eib.org) is a Senior Economist at the European Investment Bank (EIB).



Innovation and economic growth

1. Introduction

The financial crisis and the ensuing economic slump have temporarily overshadowed long-term growth issues in the minds of policymakers. When the house is still on fire, few concern themselves with renovation. But economic growth will likely come back on the policy agenda with a vengeance. The financial crisis will leave in its wake a legacy of higher unemployment, larger fiscal deficits and a mountain of public and private debt. In the meantime, the longer-standing challenges of population ageing and climate change have not disappeared. Policies that boost environmentally and socially sustainable economic growth are essential to meet these challenges.

From a European perspective, the challenge of how to raise the long-term growth rate of the economy is closely linked to the issue of innovation. Following its impressive economic convergence towards the United States (US) in the early post-war decades, Europe's ability to close the transatlantic income gap faltered long before the process was completed. Since the 1970s, average GDP *per capita* in the EU has been maintained at around three-quarters of the US level. Also in terms of labour productivity (*i.e.* output per hour worked), Europe's convergence towards the US prematurely ground to a halt, and then reversed (van Ark *et al.* 2008).

European policymakers have repeatedly stated, as one of their overriding goals in the past decade, their aim to address the causes of Europe's relative growth stagnation. In some areas there has been notable progress, such as the success in raising employment rates. Less progress is visible, however, in terms of innovation and productivity growth. Productivity growth in highly innovative societies is led by the activities of the business sector. Its motivations to innovate reflect a complex web of labour and product market institutions, property rights, academic research links, access to foreign and domestic markets, and finance. If Europe is to succeed in achieving higher economic growth by means of innovation, it is thus not enough to merely subsidise investment in research and development (R&D). A greater understanding of how to influence the different elements in this web is also needed.

The economic literature has investigated the drivers of economic growth for decades. Although substantial disagreements remain, there is also emerging consensus in several key areas. This introduction to the literature on innovation and growth aims to sort out some of the most important elements. It draws on several excellent surveys, including Temple (1999), Scotchmer (2004), OeNB (2004), Sala-i-Martin (2002), the OECD (2006) and Aghion and Howitt (2009).

This paper addresses two key questions. First, how important is innovation and the stock of knowledge in the process of economic growth? Second, what are the mechanisms that make firms invest in R&D and the accumulation of knowledge? The paper is structured as follows: Section 2 provides a brief discussion on the inherent characteristics of knowledge, and how these affect its treatment in the economic literature. Sections 3 and 4 draw on the neo-classical growth framework to discuss the overall importance of knowledge in economic growth. In Section 5 we shift the focus to discuss, with the help of the endogenous growth literature, why firms invest in R&D and how institutions and policies can influence these incentives. Section 6 broadens the perspective beyond the macroeconomic perspective to discuss the role of systems of innovation. Section 7 concludes, followed by an overview in Section 8 of the other contributions to this volume of the EIB Papers.



Kristian Uppenberg

2. Is knowledge a pure public good or just another form of capital?

To understand the role that knowledge plays in economic growth, we must first make a couple of observations on the nature of knowledge itself.

Tangible fixed investment by governments, households and firms results in a fixed capital stock consisting of roads, bridges, houses, machinery and equipment, computers, telecommunications networks, etc. Devoting part of today's resources to such investment helps increasing future output. As with other factors of production such as labour, fixed capital is a rival good, which means that its use by one firm makes it impossible for other firms to use it at the same time. It is also excludable, since an owner of a piece of machinery can prevent others from using it.

Knowledge resembles tangible fixed capital in some respects but is fundamentally different in others. Similar to tangible fixed capital, new knowledge is the outcome of investment, in this case in the form of spending on R&D and other intangible capital. If a society devotes some of its resources to innovation, this reduces current consumption in favour of an expansion of the stock of knowledge, which can raise future output. In this respect the stock of knowledge is just like other forms of productive capital. But unlike tangible fixed capital, knowledge is typically neither rival nor necessarily excludable. Non-rivalness means that one firm using the knowledge does not in any way diminish the ability of other firms to use the same knowledge. That knowledge is non-excludable means that it is difficult for one firm to prevent others from using it once it exists. When knowledge has these characteristics, it is a pure public good.

The characteristics of knowledge are crucial for how economists have chosen to treat it in their models.

If all knowledge had these characteristics, then no R&D would be conducted by the private business sector. In reality, however, more than half of R&D in most countries is in the hands of private companies. The main reason is that much of the knowledge generated by R&D is actually not a pure public good. A lot of knowledge is at least partially rival. Unlike a printed blueprint readable by anyone, some knowledge is "tacit", i.e. embedded in individual researchers or organisational structures. Such attachment makes the knowledge somewhat rival. Similarly, knowledge is also often excludable. An innovator can protect the newly acquired knowledge with the help of patent protection or secrecy, at least temporarily. The more rival and excludable the knowledge, the more knowledge behaves like a private good and the greater the incentive for individual firms to invest in its creation, even if there are some knowledge externalities. Intellectual property protection in the form of patents has been a means for governments to encourage private investment in the creation of new knowledge. On balance, innovation in the form of commercial application tends to be more proprietary, and thus more suitable for private investment. Pure scientific research, at the other end of the spectrum, is less proprietary and therefore in greater need of public financing.

The characteristics of knowledge outlined in this section are crucial for how economists have chosen to treat it in their models. The early literature on economic growth started from the extreme view that all knowledge is a pure public good. This view has become more refined over the years, allowing for knowledge to take on a wider range of characteristics.

3. The role of knowledge in economic growth: Neo-classical origins and growth accounting

Neo-classical growth theory initially treated all knowledge as a pure public good. In the modern literature, however, it has been recognised that at least some knowledge fits the bill of a private good, which can therefore be treated similarly as other forms of fixed capital. This distinction has allowed for a much more precise depiction of the different components of economic growth.

3.1 Knowledge in the neo-classical growth model

The realisation that “knowledge”, broadly defined, plays an important role in economic growth was first discovered, almost as an afterthought, by Robert Solow. Solow (1956) developed (alongside his contemporary, Swan, 1956) the simple neo-classical growth model, which has become the benchmark and starting point for modern theoretical and empirical work on economic growth. The model was designed for a closed economy, which was a reasonable way to characterise the US economy in the first half of the 20th century.

The neo-classical growth model has become the benchmark for modern theoretical and empirical work on economic growth.

A key feature of the neo-classical production function is that gross output is a simple function of only two factors of production: capital and labour. These two are smoothly but imperfectly substitutable. As an illustration, we show this feature here simply with the standard Cobb-Douglas production function with constant returns to scale:

$$(1) \quad Y = AK^\alpha L^{1-\alpha}$$

Output (Y) is a function of fixed capital (K), labour (L) and “knowledge” (A). In essence, what this function says is that aggregate output can be expanded either by increasing the amount of labour or fixed capital used in production, or through an expansion of the stock of knowledge, which increases the output for any given quantity of capital and labour.

Constant returns to scale means that a doubling of both capital and labour also leads to a doubling of output. At the same time there are diminishing returns to individual inputs, which means that increasing only one factor input while holding the other constant will yield ever smaller marginal increases in output. This is not an unreasonable assumption. Giving a worker an ever-larger number of machines to operate is likely to confront him with an increasingly challenging juggling act. But this property also implies that long-term growth in output per worker is driven entirely by “knowledge”. Because of diminishing marginal returns to capital, the marginal contribution to growth from steadily increasing the capital stock will be smaller and smaller. At the point when it equals the depreciation rate of capital, growth in output per worker comes to a stand-still. Consequently, the only way for the neo-classical economy to keep growing is by continuously expanding the stock of knowledge, A.

The seminal contribution of Solow was his pioneering empirical work on growth accounting. Applying his model to US data from the first half of the 20th century, Solow (1957) could calculate the shares of growth that stemmed directly from the expansion of labour and fixed capital¹. This led to a startling discovery: Solow found that some nine-tenths of US growth could not be explained by the growth in labour and capital. The bulk of US economic growth was left unexplained, as the residual A.

This residual, which has remained substantial – if somewhat smaller – in later growth accounting exercises in the US and elsewhere, became known as the “Solow” residual. Following the interpretation

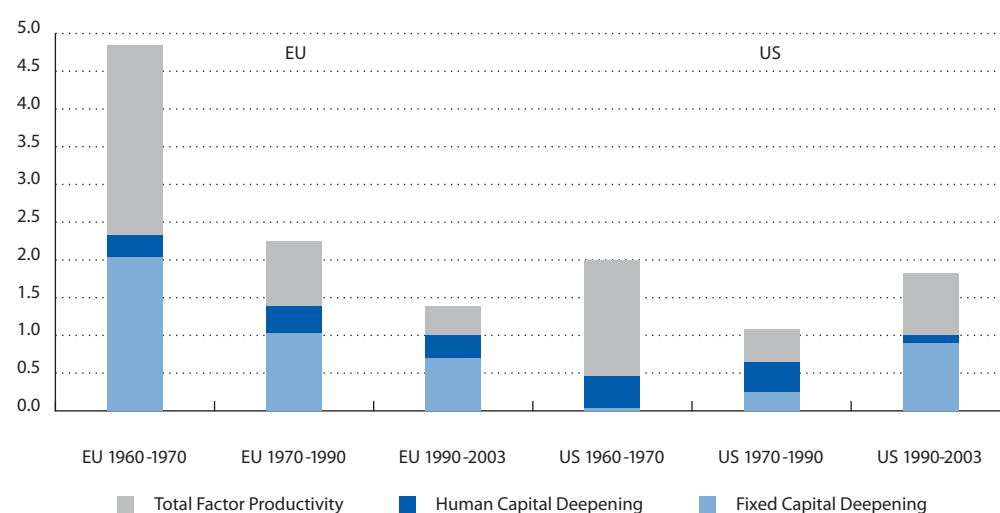
1 In order to do this using the relatively simple neo-classical production function and the limited set of data at his disposal, Solow had to make a few simplifying assumptions. First, he assumed that the US economy was on its equilibrium growth path, not unreasonably given its long history of having a relatively free market economy. This allowed him to draw on some generalised properties of the production function that are only true in equilibrium and under the additional assumption of perfect competition. Under these circumstances, the wage rate equals the marginal productivity of labour and the rate of return on capital equals the marginal productivity of capital. The income shares reflect the output elasticity of each input. Assuming constant returns to scale, they add up to one. These are the α and $1-\alpha$ shown in Equation (1). Consequently, while the output elasticities are not directly observable, one can simply calculate the contribution of an input to output growth as the growth rate of each input (capital and labour) multiplied by its own income share, which is observable.

of Griliches (1979), most later studies based on Solow's methodology have related the residual to the accumulation of a "knowledge stock". Since it refers to increases in output for a given combination of factor inputs, it is nowadays also referred to as "total factor productivity", or simply TFP. Since modern economies do not in reality operate under conditions of perfect competition, this residual captures not only technical progress and product market innovation, but also changes in returns to scale and mark-ups. It also captures measurement errors and the effects from unmeasured inputs, such as human capital, R&D and other intangible investments. As long as one only includes fixed capital and labour in the production function it is difficult to interpret the remaining residual as knowledge. The solution to this problem has been to come up with more complete measures of capital, which then reduce the unexplained residual.

The first substantial expansion of capital in growth accounting has been to explicitly account for human capital in the production function. An early effort in this direction was by Denison (1967). An influential modern reference is that of Jorgenson (1995). The inclusion of human capital has reduced the size of the unexplained knowledge residual, but it still remains substantial. We illustrate this in Figure 1 with the results from a recent growth accounting exercise by Crafts and Tonioli (2008).

A large portion of economic growth is not the result of labour inputs or physical and human capital, but of something else.

Figure 1: Contributions to annual growth in output per hour worked (percentage points)



Source: Crafts and Tonioli (2008)

Note: The figures for the EU are our own population-weighted averages based on the country-by-country estimates of the authors.

In the case of the US, when human capital is included, TFP still accounts for almost half of growth in the period after 1990. In Europe, the TFP share has diminished over time, but has historically accounted for between one-third and one-half of growth in output per worker.

By and large, Solow's results regarding the importance of the unexplained residual have stood the test of time reasonably well. Thus a key puzzle in economic growth remains: under reasonable assumptions, a substantial portion of economic growth is not the result of capital and labour inputs, and not even human capital, but of something else. In the neo-classical growth model this something else is knowledge in the form of a pure public good. But as we mentioned earlier, not all knowledge is a pure public good. To the extent that at least some knowledge has private good properties, we can reduce the Solow residual even further by explicitly accounting for this in the production function.

3.2 Treating knowledge as fixed capital: Investment in “intangible” capital

Efforts to widen the definition of productive fixed capital in neo-classical growth accounting have focused on “intangible capital”. This includes firm-specific human and organisational capital, R&D capital, computer software, brands, and the development of new designs.

Intangible assets were excluded from the narrow definition of fixed capital in early growth accounting, partly because of measurement difficulties. Unlike physical assets, intangible assets are often embedded in the skilled staff of a firm and in its organisational structure and not always directly observable. In growth accounting, their contribution to growth was therefore captured by the Solow residual. But treating intangible capital just like any other form of fixed capital is consistent with its inherent properties, since it too increases potential future output. Focusing on the private business sector, researchers have typically limited estimates of intangible capital to that which can be appropriated by the investing firm. A large portion of knowledge, for instance that generated as a result of publicly funded scientific research, or arising from knowledge spillovers, remains beyond the reach of intangible capital estimates. Its impact on the economy thus continues to be captured by the residual.

The rationale for broadening the concept of fixed capital to include intangibles has strengthened with the post-industrial transformation of modern economies. The wealth and incomes of firms in developed economies are increasingly based on intangible assets. The shift towards post-industrial societies has caused the ratio of tangible fixed capital – such as buildings, machinery and equipment – to fall over time as a ratio to GDP, especially in the US. This was a source of concern for some observers, fearing that future growth prospects were being short-changed by a culture of excessive consumption. But when the concept of productive capital is broadened to include a growing stock of intangible capital, this decline is no longer visible. Because of this gradual shift towards intangibles in the composition of fixed capital, growth accounting that relies exclusively on tangible fixed capital tends to become increasingly misleading over time.

Growth accounting that relies exclusively on tangible fixed capital tends to become increasingly misleading over time.

One of the most influential contributions to this literature came with two papers by Corrado, Hulten, and Sichel (2005, 2009), henceforth referred to as CHS. With the aim of including a more complete measure of productive capital when accounting for growth, they broaden the concept of capital to include three types of intangible assets:

- Computerised information (software and databases);
- Scientific and creative property (R&D, mineral exploration, copyright and license costs, other product development, design, and other research expenses);
- Economic competencies (brand equity, firm-specific human capital and organisational structure costs).

While some of the data used by CHS comes from official government sources, the System of National Accounts (SNA) of most countries still treats spending on intangible assets as a current business expense, not as fixed investment. This includes for instance expenditures on advertising to maintain brand equity and employee time and additional costs for training, even though such spending contributes to the accumulation of human capital. The only widespread inclusion so far of intangibles in the SNA occurred a decade ago, with the treatment of software expenditures as investment. Also in the pipeline is the capitalisation of R&D expenditures, but progress on this has been slow due to measurement difficulties. Given these limitations, CHS rely on a combination of public and private data, as well as estimates.

On this basis, they estimate that total annual investment in intellectual assets by US businesses in the late 1990s amounted to some USD 1.1 trillion, or 12 percent of GDP. This is a substantial figure, broadly similar to that of tangible investment.

The data also suggest a dramatic increase in intangible business investment over time. The gradual rise in intangible investment has been of the same order of magnitude as the decline in tangible investment, thus keeping the ratio of total investment to GDP relatively stable over time. Not all segments of intangible investment have contributed equally to this expansion however. Comparing the time period 1973–1995 with 1995–2003, CHS find that overall intangible investment grew from 9.4 percent of total national income to 13.9 percent. Computerised information rose the most, from 0.8 to 2.3 percent. Interestingly, while traditional scientific R&D remained flat (increasing its share from 2.4 to 2.5 percent), “non-scientific R&D” rose from 1 percent to 2.2 percent. Non-scientific R&D includes innovative and artistic content in the form of commercial copyrights, licenses, and designs, which are not counted in traditional R&D statistics. Brand equity rose from 1.7 to 2 percent, while firm-specific resources increased from 3.5 to 5 percent. In other words, while scientific R&D is traditionally seen as the key element in knowledge creation, it has made a negligible contribution to the ascent of US intangible capital investment in recent decades.

The inclusion of intangibles into the capital stock has the effect that capital deepening becomes the dominant source of growth.

Based on the estimates of intangible investment, CHS estimate the size of the intangible capital stock, which is then added to the standard growth accounting framework. As illustrated by Figure 2, the rate of change of output per worker increases more rapidly in the presence of intangible capital. Also, the inclusion of intangible capital dramatically changes the observed sources of economic growth. Capital deepening – increases in the stock of capital per hour worked – now becomes the dominant source of growth. For the period 1995–2003, intangible and tangible capital investment account for broadly equal shares of growth in output per worker. Though not visible in the chart, another key conclusion from this exercise is that scientific R&D accounts for only a small part of intangible capital deepening, notably less than that of software. The non-traditional types of intangibles highlighted by CHS – non-scientific R&D, brand equity, and firm-specific resources – together account for nearly 60% of total intangible capital deepening in the post-1995 period.

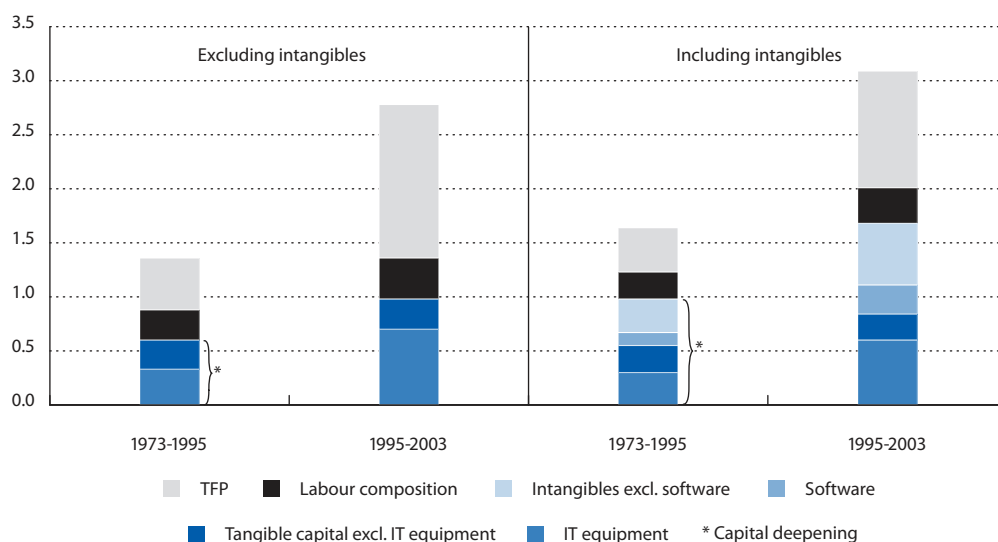
With capital deepening explaining a larger share of growth, the contribution from the TFP residual becomes correspondingly smaller, falling from around half to one-third for the post-1995 period when intangibles are included. The Solow residual also accounts for a smaller portion of the post-1995 *acceleration* in growth. When intangibles are excluded, some two-thirds of the increase in growth is accounted for by TFP. Its share drops to just over one-third when intangibles are included.

The CHS methodology was consequently applied by Giorgio Marrano and Haskel (2007) for the UK, by Fukao *et al.* (2009) for Japan, by Jalava *et al.* (2007) for Finland and by Edquist (2009) for Sweden. In all of these cases, total investment in intangible capital stood at around 10 percent of GDP, *i.e.* a similar order of magnitude as in the US. However, when this methodology has been applied to a larger number of continental European countries, a wider range of results has emerged. As shown by van Ark *et al.* (this volume), outside the Anglo-Saxon and Nordic countries, both the resources devoted to intangible investment and their contribution to productivity growth have typically been of a smaller magnitude.

This brings our discussion on growth accounting to a close. Broadening the concept of capital to include R&D and human capital has clearly improved the ability of the neo-classical production function to *account* for economic growth. But growth accounting by necessity rests on simplifying assumptions that limit its usefulness in understanding the underlying *drivers* of economic growth. Much of the modern growth literature, empirical as well as theoretical, aims at coming to terms with this issue. This

is essential if countries are to succeed in putting in place the institutions and policies needed to foster high growth in output and incomes.

Figure 2: Contributions to US output growth per hour worked (percentage points)



Source: Corrado et al. (2009)

4. Beyond growth accounting: Cross-sectional evidence on growth

The empirical literature on growth is not confined to growth accounting. There is also a large cross-sectional literature which, rather than imposing parameter values, estimates these on the basis of evidence across firms, sectors or countries. In this respect, the cross-sectional growth regression literature is a valuable complement to single country growth accounting. Cross-sectional evidence is particularly valuable in light of the limitations of time series analysis in the context of long-term economic growth. For many countries the availability of long time series data is limited, and many key determinants of growth display too little variability across time to allow for reliable conclusions from time series analysis regarding their impact on growth. Having said that, some argue that single country regressions may be the only way to go in light of parameter heterogeneity, which is to say that the fundamental drivers of growth are so different across countries that cross-country regressions may yield unreliable results. See Brock and Durlauf (2001) and Temple (1999) for further discussion on these issues.

Cross-sectional evidence is valuable in light of the limitations of time series analysis in the context of long-term economic growth.

The growth regression literature is enormous. It addresses many different issues, including the relative importance of institutional and policy drivers in the income convergence of countries, and the empirical validity of the neo-classical model (Barro 1991, 1995, 1997). Rather than discussing this literature in its entirety, however, we focus in this section on two issues: Empirical evidence for the link between investment in R&D and growth, and the importance of cross-border knowledge spillovers.

4.1 Empirical evidence on the importance of R&D for growth

Although the process of knowledge formation is highly complex, it is widely perceived that investment in R&D is a key input in its creation. Similar to human capital, there is strong microeconomic evidence for the importance of R&D. The link between R&D and economic performance has been demonstrated

Empirical studies have generally found that the rate of return is somewhat higher on R&D than on tangible capital.

in numerous firm- and industry-level studies. The rate of return on R&D can be estimated on the basis of either profits or output. A majority of studies using these approaches have found that the rate of return on R&D is somewhat higher than that of tangible fixed capital. This may reflect the relative riskiness of R&D investment, which warrants a higher return. It could also be, however, that greater barriers to entry in R&D generate excess returns. Investment in R&D at the sectoral level also seems strongly influenced by its private rate of return. Relatively research-intensive sectors, on average, have higher returns from R&D.

The presence of knowledge spillovers from R&D, however, make it difficult to draw strong macroeconomic conclusions on the basis of microeconomic evidence alone. Macroeconomic studies have typically found that social rates of return on R&D are higher than private returns, which in turn is viewed as evidence of positive spillovers (Griliches 1992, 1995; Hall 1996; Fraumeni and Okubo 2005; OECD 2000; CBO 2005; see also Mc Morrow and Röger, this volume, for a comprehensive overview of private and social rates of return to R&D). Many empirical studies have furthermore found a relatively strong link between R&D, related spillovers, and productivity growth (see Cincera and van Pottelsberghe 2001; Mohnen 2001; and Los and Verspagen 2007 for recent reviews of the empirical spillover literature). The presence of positive spillovers from R&D at the national level, combined with evidence of international knowledge spillovers, suggests that there is probably collective underinvestment in R&D (Griffith *et al.* 2004). This presents a case for public intervention in support of R&D, for instance in the form of intellectual property protection or R&D subsidies.

Similar to many institutional determinants of growth, R&D spending displays relatively little variability over time, which makes time series analysis difficult in many countries. Some time-series evidence exists for the US, however, and it poses some challenges to the notion of knowledge-driven growth. Griliches (1988) found that although R&D has a measurable effect on growth, the slowdown in R&D investment in the 1970s can account for only a small portion of the growth slowdown during this period. More generally, the post-1970 productivity growth slowdown has been particularly difficult to reconcile with the notion that the expansion of knowledge is a major engine of growth. Jones (1995a,b) observes that investment in knowledge has continuously risen in OECD countries during the post-war period, both in terms of years of schooling and in terms of R&D. Institutional factors that are known to foster knowledge spillovers have also shifted in a favourable way. Trade openness, for instance, has increased steadily over time. If growth in the stock of knowledge is key to economic growth, then the increased pace at which knowledge accumulates should cause productivity growth to speed up. But post-war growth rates in OECD countries have remained relatively impervious to such changes. Jones interprets this as knowledge having large level effects. If the level of output is affected by a continuous process of many small increases in knowledge, then the steady state path of long-term growth becomes very difficult to observe. What may seem like a growth acceleration caused by revolutionary innovations may thus be nothing more than a transitory adjustment in the *level* of productivity.

Recent experience has, on the other hand, strengthened the link between the development and application of new technologies and productivity growth. Specifically, since the mid-1990s, the US economy has experienced an acceleration in both. But this relationship has at the same time proven complex and multidirectional. Investment in new technologies contributes to aggregate productivity growth primarily by facilitating a more efficient organisation of production. New knowledge thus typically only has a substantial impact on the economy once commercially implemented on a large scale. For years, substantial investment in ICT seemed to have little impact on aggregate productivity, as first observed by Solow (1987): "You can see the computer age everywhere but in the productivity statistics." But the application of new technologies for the purpose of organisational innovation entails substantial learning, which means that the productivity gains from major innovations can emerge with long lags. Brynjolfsson and Hitt (2003) estimate that the longer term productivity and output contributions

of computerisation at the firm-level are up to five times greater than those in the short run (also see Baily 2004, and Brynjolfsson and Saunders 2009, for comprehensive discussions on these issues). It is now widely believed that such long lags in the application of new technologies explain why high US productivity growth continued for years after the ICT investment wave cooled off.

On balance, the lags and the interaction between R&D, investment in new technologies and organisational innovation tend to blur the distinction between capital deepening and knowledge as the key drivers of growth, as well as the relationship between each of these components and growth. What is in the end more important for policymakers is to understand which policies and institutions are the most conducive to high productivity growth, regardless of the exact mechanisms through which they operate.

4.2 International knowledge spillovers and the absorptive capacity of countries

While it may be the case that the bulk of US productivity gains stem from its own investment in R&D and homegrown innovation efforts, for most other countries the adoption of knowledge generated abroad plays an equally, if not more, important role. The cross-country literature has helped shed valuable light on the importance of such international knowledge spillovers, an area where single-country growth accounting has little to say.

One of the key observations made in the growth regression literature is that it is TFP, and not the stocks of capital and labour, that accounts for the bulk of income differences across countries (Easterly and Levine 2001). Similarly, those countries that have succeeded in converging towards high income countries have done so primarily on the back of a convergence in TFP and the stock of knowledge, not factor inputs. But while many countries have benefited from such knowledge-driven convergence, industrialised countries account for the bulk of the world's investment in R&D and other intangibles. This suggests that the flow of knowledge across national borders is an important driver of economic growth and income convergence. Such international spillovers have become increasingly important over time, as the world economy has become more integrated. But knowledge spillovers are neither automatic nor costless, and they depend on many institutional factors. Those countries that have put in place the policies and institutions needed to benefit from knowledge spillovers have tended to grow rapidly, while many others have been left behind.

It is TFP, and not the stocks of capital and labour, that accounts for the bulk of income differences across countries.

One of the most powerful conduits of cross-border knowledge transfer is international trade and its role has grown over time². The ratio of world imports to world gross output has more than doubled since 1970, to 28 percent in 2005. The role of trade as a vehicle for knowledge transfers has been demonstrated by Coe and Helpman (1995). They investigate the influence of domestic and foreign R&D capital on a given country's level of TFP under the assumption that trade helps to channel knowledge spillovers. Drawing on data from 22 developed countries over the period 1971 to 1990, they find that the positive impact on TFP from the foreign R&D stock is larger for countries that are more open to trade.

In the wake of Coe and Helpman, several studies have aimed to identify other domestic conditions that may also facilitate knowledge spillovers. Largely refuting the early predictions of Gerschenkron (1962) and Kuznets (1973), that poorer countries would gain more from foreign technology than richer countries, later research has shown that more developed countries tend to have more of those institutions and policies needed to benefit from foreign knowledge spillovers. Specifically, this literature

² Another important conduit for international knowledge transfers is foreign direct investment. See Glass and Saggi (2008) for a recent review of this literature.

shows that countries that invest in human capital and R&D tend to be better placed to absorb knowledge generated in other countries (Cohen and Levinthal 1989; Griffith *et al.* 2004; Guellec and Van Pottelsberghe 2004; Khan and Luintel 2006). There is also evidence that the most effective policies to promote knowledge spillovers differ depending on the “receiving” country’s distance from the knowledge frontier. Benhabib and Spiegel (1994) and Engelbrecht (1997, 2000) find that human capital formation is relatively more important for developing countries far from the technological frontier, whereas investing in R&D grows in importance for countries closer to the frontier. This is consistent with the view that it is increasingly difficult for countries to sustain high growth through adoption and imitation alone as they approach the technological frontier.

Also the functioning of labour and product markets affects a country’s ability to absorb knowledge from abroad.

Also the functioning of labour and product markets affects a country’s ability to absorb knowledge from abroad. Parente and Prescott (2000) argue that absorptive capacity is influenced by institutional aspects that give rise to adjustment costs in adopting new technologies. Incumbents can for instance resist the adoption of better production techniques when they have monopoly rights to the current technology. The greater the market power of incumbents, the greater the amount of resources that potential entrants with superior technology have to spend in order to enter the industry.

There is also a crucial geographic constraint to cross-border knowledge spillovers. Because some knowledge is tacit, *i.e.* embedded in individual researchers and organisational structures, knowledge spillovers tend to diminish with geographic distance (Bottazzi and Peri, 2003). Finding ways to benefit from such “localised” spillovers is therefore an important complement to building up the absorptive capacity at home. Griffith *et al.* (2006) illustrate this point using data on R&D in UK and US manufacturing firms. They find evidence of substantial R&D spillovers from US manufacturing to UK firms, but UK firms that also undertake R&D in the US benefit the most. This suggests that policies promoting R&D in the home country alone may be counterproductive, since this fails to take into account the importance of proximity to fully benefit from foreign knowledge spillovers. While many governments have expressed fear of losing business R&D activities to foreign innovative clusters, they may have no choice but to allow some global repositioning of business R&D if their innovative sectors are to stay competitive.

5. Endogenous growth theory: Explaining innovation-led growth

The neo-classical model has provided the benchmark for empirical growth research ever since first conjured up by Solow and Swan. As a result of improved data availability covering a larger number of countries, the validity of the model has been continually tested. This has both led to the reconfirmation of the model’s key qualities but has also brought out some major shortcomings. In particular, the neo-classical growth model cannot theoretically explain the underlying drivers of growth, insofar as growth is propelled by an exogenous expansion of the knowledge stock. Over the past quarter-century, a new strand of “endogenous” growth theory has evolved to address these shortcomings. This literature has been essential for our deeper understanding of the incentives of individual firms to invest in knowledge, and how institutions and policies may influence these incentives.

5.1 The shortcomings of the neo-classical model paved the way for endogenous growth theory

There are two features of the neo-classical model that fail to reflect what we know about the role of knowledge in economic growth. Ignoring for now knowledge that has private good properties, *i.e.* private intangible capital, the first is that shared knowledge does not arise as a consequence of the actions of economic agents, but exogenously. The second is that the exogenous expansion of this knowledge stock is the sole engine of economic growth in the long run.

That knowledge grows exogenously in the neo-classical growth model follows from two of its underlying assumptions: that knowledge is a pure public good and that the economy operates under conditions of perfect competition. As we mentioned earlier, while fixed capital is rival, knowledge is not. Once knowledge exists, its use by one firm does not preclude others from using it. With the same amount of labour and capital inputs, another firm can use the existing stock of knowledge and still achieve exactly the same output as the first one. This characteristic of knowledge implies that the concept of constant returns to scale can only apply to capital and labour. Meanwhile, the assumption of perfect competition means that firms pay rental prices for capital and labour that are equal to their respective marginal products, and that the total output of the firm equals what the firm pays for these inputs. Perfect competition ensures that any profit is competed away, which means that there are no resources left for investment in knowledge with pure public good properties. Not that the firm would have any reason to invest in such knowledge if it could. Doing so gives the investing firm no advantage over competing firms that simply free-ride on the knowledge created by others. In Solow's world, if knowledge exists, it must therefore be exogenous to the model. It cannot arise as a resource-using output in a competitive equilibrium, *i.e.* the model itself cannot explain how it comes into existence. This is consistent with a world-view where the inventors exist entirely in the confines of a scientific community separate from the market economy. But this property does not fit comfortably with what we know about knowledge. Inventors and researchers draw extensively on the resources of the rest of the economy and a large portion of R&D is conducted inside the business sector.

The second weakness of the neo-classical growth model is that long-term growth is entirely driven by the exogenous expansion of knowledge, which makes long-term growth impervious to the actions of economic agents and to government policies and institutions. This result follows the assumption of diminishing marginal returns to capital. If a country raises its investment rate, growth temporarily speeds up since the productive capital stock expands. But as a result of diminishing returns, the acceleration in output slows down as the capital stock rises. Meanwhile, depreciation of the fixed capital stock rises proportionally to the capital stock. At some point, the marginal output increase from higher investment is again only enough to offset the now higher level of capital depreciation. Higher investment has succeeded in permanently raising the level of output, but not its growth rate. The only source of steady-state growth is therefore exogenous growth in knowledge.

The shortcomings of the neo-classical growth model encouraged a number of prominent economists to approach the issue of growth from a new perspective in the 1980s. In the models of "endogenous" growth, as the name suggests, knowledge-driven long-term growth is the outcome of the actions of the various players in the economy. Designing such models with realistic properties has not been entirely straightforward, however. In essence, the literature has come up with two solutions for how knowledge can grow endogenously. Knowledge can arise as a spillover from fixed investment, which allows it to arise without the use of additional resources. Alternatively, resources for investment in knowledge are made available by deviating from the perfect competition assumption, which creates a surplus that firms can use to invest in knowledge.

In the models of 'endogenous' growth, knowledge-driven long-term growth is the outcome of the actions of the players in the economy.

5.2 Knowledge as an unintended spillover effect of investment

Early forerunners of modern endogenous growth models of the spillover type are the "AK-models", by Harrod (1939) and Domar (1946). Unlike the Solow-Swan framework, the AK model made output strictly proportional to capital. With no diminishing marginal returns to capital, steady-state growth simply depended on the rate of saving. Frankel (1962) provided an early modification of this model, with substitutable factors similar to the Solow-Swan model.

The most influential modern AK-model is that by Romer (1986). This model is typically regarded as the starting point of modern endogenous growth theory. In Romer's model, individual firms face diminishing returns to investing in knowledge. This means that the model can still be described as competitive. But because of knowledge spillovers, the economy-level rate of return to knowledge can be constant or increasing. While Romer's model has many attractive properties derived from utility maximising behaviour, its core ideas mirror those of Arrow (1962a). For simplicity, we use this to illustrate the main points.

A key feature of Arrow's model is that technological progress is the unintended and unremunerated side-effect of producing new capital goods. Such "learning by doing" is external to the firms doing it. In an economy with many small firms, each firm takes the knowledge as given, even though each of them contributes to its creation. The stock of knowledge is assumed to be a non-linear function of the aggregate capital stock: $A=K^\varphi$, where $\varphi>0$. This expression can be substituted for A in the neo-classical production function:

$$(2) \quad Y = AK^\alpha L^{1-\alpha} = K^\varphi K^\alpha L^{1-\alpha} = K^{\alpha+\varphi} L^{1-\alpha}$$

In the case where $\alpha+\varphi=1$, there is now constant returns to capital as a result of knowledge spillovers. So long as there is an incentive to invest, long run growth is positive in this model, without any requirement for exogenous knowledge expansion. A key policy implication of Arrow's and Romer's models is that the competitive equilibrium growth rate is below what would be socially optimal, since firms do not take into account the positive external effects that their investment has on the rest of the economy. This provides a strong theoretical argument for subsidising R&D, which is common practice in many countries.

The competitive-equilibrium growth rate is socially sub-optimal when investing firms do not take positive external effects into account.

5.3 Knowledge creation under imperfect competition: Horizontal innovation

While the AK model succeeds in explaining knowledge as an outcome of the investments of economic agents, it suffers from some shortcomings with respect to empirical observation. One is that knowledge occurs merely as the *unintended* side-effect of investment. No firm deliberately devotes resources to its creation, contrary to what we observe in reality. Also, despite knowledge spillovers, the primary driver of growth in this model is capital accumulation. Hence, it does not really succeed in explaining growth as the outcome of knowledge, which we have observed in the large role that TFP has played in growth, historically.

The ensuing branches of endogenous growth theory aimed at coming to terms with these shortcomings. A key challenge was to design a model where knowledge is the deliberate aim of those contributing to its formation. In order to achieve this, the assumption of perfect competition had to be dropped.

One influential contribution to this literature is that of Romer (1990). Romer defines productivity growth as the outcome of an expanding *variety* of specialised intermediate products, also referred to as "horizontal" product innovation. In this model, R&D aimed at the creation of new product varieties incurs a fixed up-front cost. Unlike the AK model, this fixed cost makes product markets monopolistically competitive rather than perfectly competitive, with the resulting monopoly profits used exclusively to finance innovation. The monopoly rents from innovation are also what give firms the incentive to invest in innovation and develop new product varieties.

While taking a step in the right direction, also this approach to endogenous growth has been challenged by empirical evidence. As observed by Jones (1995a), endogenous models of the product variety type

give rise to strong scale effects, where larger economies should grow faster than small economies³. This prediction enjoys little support in empirical observation. A perhaps even greater challenge to the product variety models is that firm exit, which reduces product variety, also reduces productivity. This runs counter to the notion of creative destruction introduced by Schumpeter (1942), whereby new innovations destroy the results of earlier innovations by making them obsolete.

5.4 Knowledge creation under imperfect competition: Schumpeterian theory and vertical innovation

Schumpeterian growth theory confronts head-on some of the most serious empirical challenges to early endogenous growth models. It does so by turning the innovative process discussed so far on its head. Rather than leading to a horizontal expansion of product varieties, innovation here replaces obsolete with new and improved technology. This is known as “vertical” innovation. The Schumpeterian growth model emphasises the exit and entry of firms as a key element in growth, and its modern descendants provide a framework for analysing the relationship between product market competition and innovation (Aghion and Howitt 2009).

The relationship between competition and innovation was first introduced by Schumpeter (1942), who argued that large, monopolistic firms have a greater incentive to innovate than small competitive ones. Schumpeter’s hypothesis suggests that innovation may be hampered by too strong competition and that mergers should be tolerated even when reducing competition.

Schumpeter argued that large monopolistic firms have a greater incentive to innovate than small competitive ones.

Schumpeter’s predictions have been tested in numerous empirical studies. While the overall result is mixed, there is some evidence in support of Schumpeter’s conclusions. More competition is not always good for innovation. A number of studies have found that market power (*i.e.* less competition) raises the rate of return on R&D for the investing firm (Hall and Vopel 1996; Blundell *et al.* 1999; Greenhalgh and Rogers 2006). To the extent that a higher rate of return encourages spending on R&D, these studies seem to suggest that more competition may actually harm innovation.

Evidence based on the profitability of R&D is, however, not providing a convincing picture of the macroeconomic effects of competition. A casual comparison between the degree of product market competition in Europe and the US shows that it is the more competitive of the two that also invests more in R&D. The US economy is also the one where TFP growth has been sustained as the main engine of productivity growth. But reconciling the two facts requires some tricky modelling. How can one show that more competition fosters more innovation, even as it squeezes profit margins?

Arrow (1962b) made a valuable early contribution to this discussion by showing how cost-reducing innovation can give monopolistic market power to the innovator even when initially operating in a perfectly competitive market. In sharp contrast to Schumpeter, Arrow thus demonstrated that competition can encourage innovation as a means of protecting monopoly profits. This view stands at the core of modern “neo-Schumpeterian” growth theory, which has helped frame modern thinking on the interaction between competition and innovation.

Building on these insights, Aghion and Howitt (1992, 1998) have become the modern standard-bearers of the neo-Schumpeterian school of growth. In their framework, which was further developed and

³ Since product variety has a positive impact on productivity growth, it also follows that market integration leading to greater variety has a positive impact on productivity. This is demonstrated by Grossman and Helpman (1991), who use the product variety framework in an international context.

tested empirically in Aghion *et al.* (2005), firms invest in R&D to improve the quality of existing products, rendering the previous generation of products obsolete. Firms on the technology frontier invest in innovation in order to obtain temporary monopoly rents. Firms that are behind the technology frontier also invest in R&D, as a means to learn and to improve their productivity, but without pushing out the technology frontier itself.

In the model by Aghion and his collaborators, the incentive to invest in R&D is generated not by the absolute post-innovation rents, but by the *difference* between post- and pre-innovation rents, *i.e.* between the profits a firm stands to make when it chooses to innovate, compared to when it doesn't. Thanks to a minor modification to the Schumpeterian model, where also the incumbent firms earn a profit, more competition can now encourage innovation. Even though competition squeezes the rents that a firm stands to make from innovating (*i.e.* post-innovation rents), the rents of non-innovation (*i.e.* the pre-innovation rents) diminish even more. In essence, in a competitive environment, continuous innovation becomes necessary to retain at least some rents.

In 'neck-and-neck' industries, innovation is the means by which the firm can escape competition from its close technological rivals.

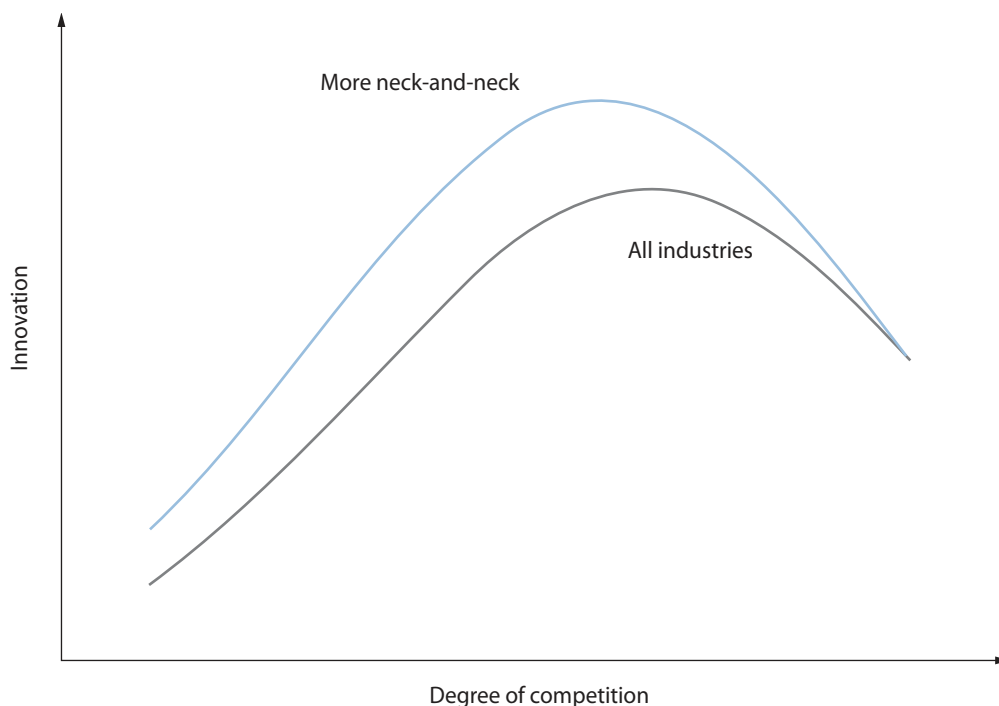
More competition does not boost innovation under all circumstances in this model, however. There is a difference between industries where firms are operating on a similar technological level – so-called “neck-and-neck” industries – and those where firms are more technologically uneven. In neck-and-neck industries, innovation becomes a means by which the firm can break away from the constraints of intense competition with a close technological rival. Aghion *et al.* call this the “escape competition” effect. When industries compete “neck-and-neck”, more competition tends to encourage innovation.

On the other hand, in industries where firms are technologically diverse, more competition can actually reduce innovation. If the technological leader feels sufficiently unthreatened by the follower, it will feel no need to innovate more regardless of the competition policy. The follower, on the other hand, will have less incentive to catch up with the leader through more intense innovation if stiffer competition reduces the post-innovation rents that it can earn from catching up. This the authors refer to as the “Schumpeterian effect”. Adding up the innovation of the two firms, the sum total is less innovation than before.

Thus, one important prediction of the neo-Schumpeterian model is that product market competition should have a greater positive effect on innovation and productivity growth in industries where firms are more neck-and-neck, where the “escape competition” dominates over the “Schumpeterian effect”. Another prediction is that the relationship between competition and innovation is non-linear. At lower levels of competition, the “escape competition” effect dominates, so that more competition leads to more innovation. But at some point, competition becomes so fierce that the Schumpeterian effect becomes the dominant one, and the relationship turns negative. The result is an inverted-U shaped relationship between competition and innovation.

These are testable predictions. As illustrated by the chart below, Aghion *et al.* (2005) find evidence of the predicted inverted-U relationship when using data on patenting rates for UK manufacturing firms as a proxy for innovation. Also in line with the model they find that the shape of this relationship is different for firms that are close to the technological frontier and those that are not. The upward sloping section of the competition-innovation relationship is steeper for firms that are closer to the frontier than for the full sample. In other words, at moderate levels of competition, more competition has a stronger positive effect on innovation for firms engaging in more “neck-in-neck” competition with each other than for those further from the technological frontier.

Figure 3: Relationship between competition and innovation intensity



Source: Simplified chart based on Aghion *et al.* (2005)

5.5 Neo-Schumpeterian growth theory: Implications for Europe, part 1

Aghion *et al.*'s distinction between firms that are on the technology frontier and those that are behind it is particularly useful in order to understand Europe's continuing innovative and productive gap *vis-à-vis* the US and the role that competition may play as a driver of this gap.

Europe was for a long time successful in narrowing its productivity gap with the US. In 1945, Europe's stock of physical capital was partially destroyed and its technological knowledge was well behind that of the US. At that time, what Europe needed to grow was essentially to accumulate capital and adapt existing technologies by means of a high investment rate. The economic institutions and policies needed to foster economic convergence in this environment was limited product market competition, expansion of secondary education and an economy dominated by large bank-financed firms. Labour market flexibility and firm turnover were of secondary importance, since productivity depended on the accumulation of experience within existing firms.

For decades, Europe's convergence towards US productivity was impressive, but the catching-up process stumbled before it was completed. As Europe's technology gap to the global leader narrowed, its imitation-driven growth model became less and less capable of sustaining high growth. By the late-1980s, the advanced European countries had largely caught up with the world's leaders in terms of capital intensity and productivity. They were closing in on the world technology frontier and it became increasingly important to innovate rather than imitate or adopt to achieve productivity gains. But for this, the European economic model was not well-tailored (Aghion 2006).

Europe's productivity growth has become increasingly dependent on innovation rather than the adoption of existing technologies.

Empirical evidence is supportive of this story. Acemoglu *et al.* (2006) draw on sectoral evidence to show that R&D intensity tends to be higher for countries that are closer to the technological frontier. An interesting observation is that R&D intensity increases in all industries when an economy gets closer to the technological frontier. This is not surprising, since all industries have to compete for the same

scarce resources, such as skilled labour. In a high-cost, high-productivity economy, the survival of all industries – and not just the most R&D intensive ones – depends on innovation. For each country and industry, distance to the frontier is here measured as the TFP gap *vis-à-vis* the global leader in that industry.

If there is sufficient competition we should also expect European countries to invest more in R&D, as they have over time moved closer to the world technological frontier. Also, within the EU we would expect the most advanced countries to invest more in R&D. But while the latter is true, the former is less so. Aggregate business spending on R&D remains remarkably constant over time. On average, the EU-15 countries spent around 1.9 percent of GDP on R&D in 1998-2007, compared with 3.2 percent in Japan and 2.6 percent in the US. Most of these differences are accounted for by business R&D, not by government or education sectors. R&D spending by the EU-15 business sector averaged 1.2 percent of GDP over the ten-year period, compared with 1.9 percent in the US and 2.4 percent in Japan.

One likely explanation for Europe's persistently lower level of R&D spending relative to the US is its less intense product market competition.

On the basis of the previous discussion, one likely explanation for such non-convergence in business R&D spending is a lack of product market competition. As observed by the OECD (2009), product-market competition is less intense in Europe than in the US. This represented no impediment to growth so long as European firms were predominantly technological laggards. More intense competition would only have reduced European innovation rates during this period, by squeezing post-innovation rents that firms would earn from innovation. As Europe converged towards the global technological frontier, more industries became characterised by neck-and-neck competition between European firms and their US counterparts. In this situation, Europe's less competitive environment began to weigh down on innovation (Aghion 2006).

5.6 Neo-Schumpeterian growth theory: Implications for Europe, part 2

Schumpeterian theory allows for a unique effect on innovation from the entry and exit of firms. The idea here is that increased entry, and increased threat of entry, enhance innovation and productivity growth because the threat of being driven out by a potential entrant gives incumbent firms an incentive to innovate in order to escape entry, through an effect that works much like the escape-competition effect discussed earlier. For this result to hold, it is necessary that new entrants replace incumbent firms, in other words that entry be associated with firm turnover.

The entry-threat effect is not equal for all firms, however. An increased threat of entry discourages innovation by incumbents that lie initially far behind the frontier. Under the assumption that new entrants come with a high level of technological sophistication, there is no way for relatively backward incumbents to match the entrant even if they do innovate. Firms close to the frontier, on the other hand, may be able to beat or scare off the potential entrant if they successfully innovate.

Aghion *et al.* (2005) test this hypothesis empirically on the basis of UK manufacturing data for the 1980-93 period. They find that a higher entry-rate at the industry level indeed boosts average productivity growth of incumbent firms. They also confirm the model's prediction that increased firm entry has a more positive effect on productivity (which here stands in as a proxy for innovation) in industries where the incumbents are close to the technological frontier.

As European firms are now closer to the global technology frontier, the positive effect on incumbent innovation and productivity from the threat of entry is greater than it used to be. By the same token, neglect of entry considerations has over time had an increasingly depressing effect on European growth. Evidence of firm turnover in Europe and the US suggests that there is room for improvement. For example, 12 percent of the largest US firms by market capitalisation at the end of the 1990s had been founded less than twenty years before, against only 4 percent in Europe (Aghion, 2006).

There is a wealth of empirical evidence that good management and productivity benefit from higher firm entry and exit (Bloom and Van Reenen 2005; Scarpetta *et al.* 2002; Brandt 2004). Existing firms are burdened by organisational rigidities that hamper their adoption of superior technologies. New firms seem particularly adept at exploiting new technological opportunities and responding to changing market needs. The beneficial role played by young innovative companies has been particularly notable in the ICT sector. Empirical evidence also shows that entry and exit of firms made a sizeable contribution to multifactor productivity growth in many OECD countries. Carree and Thurik (1998) found that a higher share of SMEs in the economy (proxying for young innovative companies even though the overlap is far from perfect) is robustly associated with higher growth in subsequent years. But the ease and speed with which new firms are created and grow varies substantially across OECD countries. While firm turnover plays an important part in US productivity growth, most productivity gains in Europe take place within existing firms (Nicoletti and Scarpetta 2003). This difference likely weighs down on Europe's overall productivity growth.

5.7 Fostering innovation: the interaction between competition policy and intellectual property rights

Schumpeter pointed to the inherent conflict between competition and the need to make firms willing to invest in R&D. The goal of competition policy is to limit the market power and monopolistic profits of firms, yet some of the empirical evidence suggests that those profits are needed to encourage firms to invest in R&D. The solution to this conflict has essentially been to encourage competition in product markets while giving innovators proprietary rights to their inventions through patents and other intellectual property (IP) rights. In effect, market power that derives from IP is partly exempt from competition law. As stated in a recent US Supreme Court ruling: "[t]o safeguard the incentive to innovate, the possession of monopoly power will not be found unlawful unless it is accompanied by an element of anti-competitive conduct."⁴

This illustrates the complementary nature of competition policy and IP. Without competition policy, IP protection would give innovators free rein to sustain monopolistic positions, using R&D to create impenetrable barriers to entry. Competition without IP rights, on the other hand, would allow copying to undermine profits from innovation to the point where firms may have little reason to innovate. It should be said, however, that IP is not the only way to protect the rents from innovation. Lead time and secrecy can sometimes be more effective, depending on the nature of the industry and the innovation. Some have even argued that today's patent laws survive primarily because of strong vested interests and a strong historical legacy, while their true economic value is unproven. The problem is that the long history and pervasiveness of IP has deprived the world of examples of the counterfactual. We do not really know how much innovation would occur in a world completely without IP.

Competition without intellectual property rights would allow copying to undermine the incentives of firms to innovate.

6. National innovation systems

Much of the theoretical and empirical literature discussed up to this point has taken the macroeconomic perspective. Also the policy prescriptions that emerge from this literature have to do with getting the big picture right. Innovation is stimulated in competitive, flexible and open economies with sound macroeconomic policies and a high level of human capital. But this is not necessarily enough. The process of innovation entails a highly complex interaction between a number of different elements. One important link in this process is the interaction between academic research and product market innovation. While many productivity-enhancing innovations have their origins in academic research,

⁴ Verizon Communications Inc. v. Law Offices of Curtis V. Trinko, US Supreme Court 2004.

it is only through commercial application that this research has been able to affect the wider economy. Even with the broad macroeconomic frameworks in place, economies may still fail to reach their full innovation potential unless there are institutions in place that facilitate technology transfer from academic research to commercial innovation. Here there is a role for well-tailored IP rights protection that encourages the creation of new scientific knowledge and its commercialisation.

The literature on “national innovation systems” looks at this complex set of issues, with a particular focus on the character and intensity of the interactions between the different elements of the system (Freeman 1987; Cohen and Levinthal 1989; Lundvall 1992; Nelson 1993; Edquist and Chaminade 2006). According to this view, innovation depends crucially on the ability to combine new knowledge produced elsewhere with existing knowledge. New and commercially useful knowledge is not only the result of the conscious action of creative individuals but also of the interaction and learning processes among various actors in innovation systems, *i.e.* producers, users, suppliers, public authorities and scientific institutions, which David and Foray (1995) term the “knowledge distribution power” of the innovation system. These interactions represent the process through which knowledge spillovers influence economic growth, as detailed in the endogenous growth theory literature.

Country differences with respect to innovation and growth might reflect differences in the efficiency of innovation systems.

From the national innovation systems perspective, country differences with respect to innovation and growth might reflect not just different endowments in terms of labour, capital and the stock of knowledge, but also the efficiency of the innovation system. This is not that easy to measure empirically, however. Indicators may include measures of interactions, such as cooperative R&D agreements among firms, between firms and universities or the availability of venture-backed financing (see for example, Stern *et al.* 2000). The OECD (2004) has also made some attempts at linking economy-wide growth to policy and institutional variables.

7. Concluding remarks

This paper set out to answer two key questions: How important is R&D and innovation for economic growth and what are the mechanisms that make firms invest in the accumulation of new knowledge? The empirical growth literature has confirmed that growth of the knowledge stock accounts for a large portion of growth in output per worker. Treating some of the knowledge stock as intangible capital that is proprietary to the investing firms does not fundamentally change this conclusion. At the same time the mechanisms that lead to the generation of this knowledge stock are complex. Policymakers in Europe recognise that sustained growth has become increasingly dependent on innovation as the economy has converged towards the global technological frontier. But efforts to boost Europe’s R&D have so far met with limited success and a substantial gap remains *vis-à-vis* Japan and the US. Even though the macroeconomic literature has acknowledged that R&D subsidies are justified to compensate for knowledge externalities, such incentives are likely of second order importance for the innovative business sector.

It is becoming increasingly clear that the pace of innovation and the rate of productivity growth in Europe are unlikely to budge unless the incentives for innovation change fundamentally in the business sector. Such changes would have to take into account the role played by competition, the exit and entry of firms, and the ability of new innovative firms to expand quickly when successful. Innovation generates productivity gains primarily by allowing for a more efficient organisation of the economy, often combined with a reallocation of resources towards industries with higher growth prospects. An inflexible economy thus stands to squander many of the potential economic benefits stemming from the creation of new knowledge and innovation.

8. An overview of this year's EIB Papers

The contributions to this year's volume of the EIB Papers reflect on key elements in the role of R&D and innovation in economic growth. These fit into three broad groups. The first looks at macroeconomic issues: investment in intangible capital and its impact on economic growth. The second analyses the microeconomics of innovation and the role of public policy. The third group, finally, focuses on the financing of innovation.

Starting off the macroeconomic discussion on the role of intangible capital and innovation in economic growth, **Christian Helmers, Christian Schulte** and **Hubert Strauss**, provide a review of R&D capital stock estimates in Europe, including new estimates for seven countries. While much of the policy debate on R&D has focused on the ratio of R&D expenditures to GDP, as with other types of productive capital it is the stock of knowledge that is an input in production. The R&D capital stock is the result of many years of R&D investment. Japan and the US have notably larger R&D capital stocks than the EU, relative to GDP, as a result of their consistently higher levels of R&D investment over many years. It would thus take many years of R&D expenditures on par with the Lisbon target before the bulk of the EU/US gap in R&D capital stocks was closed. The authors point to a dispersion in R&D capital stocks across individual European countries that is wider than for other factors of production. There is also little evidence of convergence in these R&D capital stocks over time. At the industry level, the authors highlight the positive correlation between R&D capital intensity and conventionally-measured TFP.

While R&D capital is a non-negligible component in total intangible capital, the latter is a broader concept. **Bart van Ark, Charles Hulten, Janet Hao** and **Carol Corrado** present a comprehensive perspective on the state of the art in the measurement of intangible capital and its contribution to economic growth. Building on earlier estimates of intangible capital for the US and several European countries, they extend the estimates of intangible investment and capital to five additional European countries: Austria, the Czech Republic, Denmark, Greece and Slovakia. In addition to R&D, intangible investment here includes architectural designs, brand equity, organisational capital and firm-specific human capital. A key finding of this exercise is that the level of total intangible investment to GDP varies markedly across countries. In the US and some of the most advanced EU countries, investment in intangible capital in the business sector is broadly on par with investment in conventional tangible capital. Intangible investment is the highest in the US, at 11 percent of GDP, followed closely by the UK. In many European economies, however, investment in intangible capital remains far below investment in tangible capital. Properly accounting for intangible investment allows for a more accurate portrayal and understanding of the drivers of economic growth. Through its impact on the productive capital stock, intangible investment has made a substantial contribution to productivity growth in the US and a few other leading economies, though less so in many others.

Kieran Mc Morrow and **Werner Röger** take as their starting point the existing empirical literature on rates of return on R&D. These estimates are then used to interpret the economic significance of R&D in a calibrated semi-endogenous growth model. The main question addressed is to what extent different policy options could help narrow Europe's productivity gap *vis-à-vis* the US. They find that stimulating R&D investment directly through subsidies is not nearly enough to achieve this goal, due to declining marginal efficiency in knowledge investment. Additional "framework policies" are therefore needed. Specifically, raising R&D subsidies and the supply of high skilled labour, and lowering entry barriers for start-ups, would reduce the EU-US productivity gap by around half. Additional measures to further narrow the transatlantic productivity gap would include improvements in the quality of higher education and liberalising Europe's non-manufacturing sectors, such as services and agriculture.

Turning to microeconomic issues and public policy support for innovation, **Dirk Czarnitzki** shows how cooperative R&D agreements can help foster more investment in R&D in the presence of knowledge spillovers. Cooperation in R&D allows the investing firms to internalise such spillovers, while also exploiting the economies of scale and scope of R&D. A pooling of risk and fixed costs can also broaden the research horizon of cooperating firms. This is particularly true for research that is closer to basic science, where the rents are typically harder to appropriate. On the basis of the existing empirical literature and new original results for Belgium and Germany, Czarnitzki finds that private firms collaborating with academia invest more in R&D than firms collaborating with other firms – even in the absence of subsidies – and that subsidies of such science-industry collaborations would boost R&D investment even further. However, Czarnitzki also points to the opportunity cost of these vertical collaborations and the subsidies that are used to foster them. To the extent that government funding is reallocated from basic research to subsidising science-industry collaborations, this could steer academic research in a more applied direction, thus undermining the complementarity between science and industry that made such collaboration valuable in the first place.

Continuing the policy discussion, **Damien Ientile** and **Jacques Mairese** review the effectiveness of the R&D tax credit, whereby a company deducts part of its R&D expenditure from its tax bill. A number of studies estimating the direct effects of the tax credit on R&D investment point to mixed effects of such policies. While business R&D investment increases in all cases reviewed, one euro of taxpayer money sometimes leads to less than one euro of additional R&D. Specifically, there is notable variability across countries. The survey article also shows that the R&D tax credit increases the likelihood of firms starting own R&D activities and that it is conducive to higher innovation output such as the number of new products or their share in a beneficiary firm's total sales. They point out that the best evaluation of the R&D tax credit would take into account the additional GDP generated by the additional R&D as well as all direct and opportunity costs of the measure.

The third type of policy support for R&D is through intellectual property rights. Patents have for a long time been used to strengthen the ability of innovative firms to appropriate the rents from their R&D investments. Since patents aim at the protection of existing scientific discoveries, they can and are often used as a proxy for the output of R&D.

Jérôme Danguy, **Gaétan de Rassenfosse** and **Bruno van Pottelsberghe** investigate the relationship between R&D expenditures and patent applications at the industry level. This relationship reflects both a productivity channel – *i.e.* R&D leads to inventions – and a “propensity-to-patent” channel, whereby firms in different countries and industries differ in their eagerness to protect their inventions. Firms seek patent protection either as a means (among others) to appropriate income from their IP or to make life difficult for competitors (“strategic propensity”). Danguy *et al.* find that more R&D does lead to more patents, but this relationship is not very strong. This suggests that the propensity to file for patent protection, as expressed by the stringency of IP rights protection and exposure to international markets, matters more than the productivity of R&D. Countries with strong IP rights rely more on the patent system, as do industries with high international exposure. Yet, a significant part of the dramatic increase in patent filings worldwide remains unaccounted for. The authors disentangle which countries and industries contribute most to this surge. They also demonstrate that the “global patent warming” reflects firms’ growing desire to extend national patents to the world market rather than an increase in national patent filings.

In addition to knowledge spillovers, public intervention to support R&D may also be justified by market failure in finance. **Bronwyn Hall** discusses the main theories and empirical evidence regarding the financing of innovation. Key questions addressed are whether new and/or innovative firms are

fundamentally different from established firms and whether they therefore require a different form of financing. She points to a large literature suggesting that this is indeed the case. First, intangible assets typically account for a larger portion of total assets in innovative firms. Such assets are less easily used as collateral when seeking external finance. Second, in the case of young innovative firms, these tend to be inherently riskier and have less of a track record. The particularly severe asymmetric information and agency problems that characterise such firms tend to make external finance costlier and more difficult to obtain. By addressing the information and incentive issues directly through better monitoring and risk sharing, equity financing in general – and venture capital in particular – tends to be the preferred form of external financing for such firms.

Laura Bottazzi expands the discussion on financing innovation with a review of the role of venture capital in financing new dynamic firms in Europe. Bottazzi finds that venture capital in Europe is not associated with particularly dynamic or successful companies, whether one looks at sales growth or employment. This stands in contrast to US experience, where venture capital has tended to accompany the formation and growth of dynamic companies. A key factor in the effectiveness of venture capital appears to be its own human capital. Human capital affects the level of activism of venture capitalists and thus the value added that they bring to the firms they invest in. This points to the importance of postgraduate education for the level of professionalism in the European venture capital industry. In the last decade, however, Europe has experienced new entrants in the industry, which seem to operate in a manner closer to the US investment style.

It is only through commercial application that most technological discoveries can affect the productivity of the wider economy. To the extent that scientific research is conducted in universities and specialised research institutions, successful commercialisation of technological discoveries requires linking scientific research to the wider business sector. This is what is commonly known as technology transfer. **Jacques Darcy, Helmut Krämer-Eis, Dominique Guellec** and **Olivier Debande** provide a mapping of the specific financial constraints, risks and asymmetric information problems that may impede such technology transfer. The scaling up of scientific research for commercial application requires large amounts of capital typically not available in the research community itself. But similar to venture capital, the financing of technology transfer entails more than just the provision of funds. If technology transfer is to take off in Europe, there is a need to tailor both intellectual property rights and financial instruments in such a way that the incentives, risks and rewards are optimally aligned between universities, inventors, entrepreneurs and investors.

The commercialisation of new technological discoveries in part suffers from a shortage of financing because intangible capital is more difficult to use as collateral. These problems would be alleviated with the development of a better market for technology. If patented knowledge could be bought and sold in a marketplace, then it would also become more attractive as collateral when seeking external finance. **Dietmar Harhoff** focuses on this issue. A key condition for patents to serve not only as intellectual property protection, but also as collateral, is that they have a residual market value outside the investing firm. European experience in this area has so far been mixed. Some intermediaries have attempted to provide external finance to innovative firms based on their patent portfolios. Patents have been used either as collateral, or as assets in patent funds seeking to commercialize the patent rights. Patent auctions are indicative of a nascent market for patented technology. Supported by changes in valuation techniques and accounting regulation, it seems likely that patent rights will increasingly be used as collateral in debt finance. The development of a liquid market for technology and the use of patents as collateral are complementary, but they depend crucially on an appropriate design of patent systems. Uncertain and questionable patent rights tend to hamper the development of markets for technology and the use of patents as collateral, which in turn drives up the cost of innovation finance.

References

- Acemoglu, D., Aghion, P. and Zilibotti, F. (2006). "Distance to frontier, selection, and economic growth". *Journal of the European Economic Association*, (4:1), pp. 37–74.
- Aghion, P. (2006). "A primer on innovation and growth". *Bruegel Policy Brief*, Issue October 2006/06, pp. 1-8.
- Aghion, P., Bloom, N., Blundell, R., Griffith, R. and Howitt, P. (2005). "Competition and innovation: An inverted-U relationship". *Quarterly Journal of Economics*, (120:2), pp. 701-728.
- Aghion, P. and Howitt, P. (1992). "A model of growth through creative destruction". *Econometrica*, (LX), pp. 323-351.
- Aghion, P. and Howitt, P. (1998). *Endogenous growth theory*. MIT Press, Cambridge, Massachusetts, USA.
- Aghion, P. and Howitt, P. (2009). *The economics of growth*. MIT Press, Cambridge, Massachusetts, USA.
- Arrow, K.J. (1962a). "The economic consequences of learning by doing". *Review of Economic Studies*, (29:80), pp. 155-173.
- Arrow, K.J. (1962b). "Economic welfare and the allocation of resources for invention", in Nelson, R.R. (ed.), *The rate and direction of inventive activity*. Princeton University Press, Princeton, New Jersey, USA.
- Baily, M.N. (2004). "Recent productivity growth: the role of information technology and other innovations", *Federal Reserve Bank of San Francisco Economic Review*, pp. 35-41.
- Barro, R.J. (1991). "Economic growth in a cross section of countries". *Quarterly Journal of Economics* (CVI:2), pp. 407-443.
- Barro, R.J. (1995). *Economic growth*. McGraw-Hill, Boston, Massachusetts, USA.
- Barro, R.J. (1997). *Determinants of economic growth: A cross-country empirical study*. MIT Press, Cambridge, Massachusetts, USA.
- Benhabib, J. and Spiegel, M.M. (1994). "The role of human capital in economic development. Evidence from aggregate cross-country data". *Journal of Monetary Economics* (34), pp. 143–173.
- Bloom, N. and van Reenen, J. (2005). *Management Matters*. Centre for Economic Performance, London School of Economics.
- Blundell, R., Griffith, R. and van Reenen, J. (1999). "Market share, market value and innovation in a panel of British manufacturing firms". *Review of Economic Studies*, (66) pp. 529-554.
- Bottazzi, L. and Peri, G. (2003). "Innovation and spillovers in regions: Evidence from European patent data". *European Economic Review*, (47:4), pp. 687–710.
- Brandt, N. (2004). "Business dynamics in Europe". *OECD STI Working Paper* 2004/1.
- Brock, W.A. and Durlauf, S.N. (2001). "Growth empirics and reality". *World Bank Economic Review*, (15:2), pp. 229-272.
- Brynjolfsson, E. and Hitt, L.M. (2003). "Computing productivity: Firm-level evidence". *Quarterly Journal of Economics*, (84:4), pp. 793-808.
- Brynjolfsson, E. and Saunders, A. (2009). *Wired for innovation: How information technology is reshaping the economy*. MIT Press, Cambridge, Massachusetts, USA.
- Carree, M.A. and Thurik, A.R. (1998). "Small firms and economic growth in Europe". *Atlantic Economic Journal*, (26:2), pp. 137-146.
- Cincera, M. and van Pottelsberghe de la Potterie, B. (2001). "International R&D spillovers: a survey". *Brussels Economic Review*, (169), pp. 3-32.
- Coe, D. and Helpman, E. (1995). "International R&D spillovers". *European Economic Review*, (39), pp. 859–887.

- Cohen, W. and Levinthal, D. (1989). "Innovation and learning: The two faces of R&D". *Economic Journal*, (99), pp. 569–596.
- Congressional Budget Office (CBO) (2005). "R&D and productivity growth". Background Paper, Congress of the United States, June.
- Corrado, C.A., Hulten, C.R. and Sichel, D.E. (2005). "Measuring capital and technology: An expanded framework", in Corrado, C.A., Haltiwanger, J. and Sichel, D.E. (eds.), *Measuring capital in the new economy*. NBER Studies in Income and Wealth, (65), University of Chicago Press, Chicago, USA.
- Corrado, C.A., Hulten, C.R. and Sichel, D.E. (2009). "Intangible capital and US economic growth". *The Review of Income and Wealth*, (55:3), pp. 661-685.
- Crafts, N. and Tonioli, G. (2008). "European economic growth, 1950-2005: an overview". *CEPR Discussion Paper No. 6863*.
- David, P. and Foray, D. (1995). "Accessing and expanding the science and technology knowledge base". *STI Review*, (16), OECD, Paris, France.
- Denison, E.F. (1967). *Why growth rates differ*. The Brookings Institution, Washington, D.C., USA.
- Domar, E. (1946). "Capital expansion, rate of growth, and employment". *Econometrica*, (14), pp. 137-147.
- Easterly, W. and Levine, R. (2001). "It's not factor accumulation: Stylized facts and growth models". *World Bank Economic Review*, (15:2), pp. 221-224.
- Edquist, C. and Chaminade, C. (2006). "Industrial policy from a systems-of-innovation perspective". *EIB Papers*, (11), pp. 108-132.
- Edquist, H. (2009). "How much does Sweden invest in intangible assets?" *Research Institute of Industrial Economics Working Paper No. 785*.
- Engelbrecht, H.J. (1997). "International R&D spillovers, human capital and productivity in OECD economies: an empirical investigation". *European Economic Review*, (41), pp. 1479–1488.
- Engelbrecht, H.J. (2000). "Human capital and international knowledge spillovers in TFP growth of a sample of developing countries: An exploration of alternative approaches". *Applied Economics*, (34), pp. 831–841.
- Frankel, M. (1962). "The production function in allocation and growth: A synthesis". *American Economic Review*, (52), pp. 995-1022.
- Fraumeni, B.M. and Okubo, S. (2005). "R&D in the national income and product accounts: A first look at its effect on GDP", in Corrado, C.A., Haltiwanger, J. and Sichel, D.E. (eds.), *Measuring capital in the new economy*. NBER Studies in Income and Wealth, (65), University of Chicago Press, Chicago, USA.
- Freeman, C. (1987). "Technology and economic performance, lessons from Japan". Frances Printer Publishers, London, UK.
- Fukao, K., Hamagata, S., Miyagawa, T. and Tonogi, K. (2009). "Intangible investment in Japan: Measurement and contribution to economic growth". *The Review of Income and Wealth*, (55:3), pp. 717-736.
- Gerschenkron, A. (1962). *Economic backwardness in historical perspective*. Harvard University Press, Cambridge, Massachusetts, USA.
- Giorgio Marrano, M. and Haskel, J. (2007). "How much does the UK invest in intangible assets?". CEPR Discussion Paper No. 6287.
- Glass, A.J. and Saggi, K. (2008). "The role of foreign direct investment in international technology transfer", in Dutt, A. and Ros, J. (eds.), *International handbook of development economics*, Edward Elgar, Cheltenham, UK.

- Greenhalgh, C. and Rogers, M. (2006). "The value of innovation: The interaction of competition, R&D and IP". *Research Policy*, (35), pp. 562-580.
- Griffith, R., Harrison, R. and van Reenen, J. (2006). "How special is the special relationship? Using the impact of US R&D spillovers on UK firms as a test of technology sourcing". *American Economic Review*, (96:5), pp. 1859-1875.
- Griffith, R., Redding, S. and van Reenen, J. (2004). "Mapping the two faces of R&D: productivity growth in a panel of OECD industries". *Review of Economics and Statistics*, (86:4), pp.883-895..
- Griliches, Z. (1979). "Issues in assessing the contribution of research and development to productivity growth". *Bell Journal of Economics*, (10:1), pp. 92-116.
- Griliches, Z. (1988). "Productivity puzzles and R&D: another nonexplanation". *Journal of Economic Perspectives*, (2:4), pp. 9-21.
- Griliches, Z. (1992). "The search for R&D spillovers," *Scandinavian Journal of Economics*, (94) pp. 29-47.
- Griliches, Z. (1995). "R&D and productivity: econometric results and measures", in Stoneman, P. (ed.), *Handbook of the Economics of Innovation and Technological Change*, Blackwell Publishers Ltd, Oxford, UK.
- Grossman, G. and Helpman, E. (1991). *Innovation and Growth in the Global Economy*. MIT Press, Cambridge, Massachusetts, USA.
- Guellec, D. and van Pottelsberghe de la Potterie, B. (2004). "From R&D to productivity growth: do the institutional settings and the source of funds of R&D matter?". *Oxford Bulletin of Economics and Statistics*, (66:3), pp. 353-378.
- Hall, B.H. (1996). "The private and social returns to research and development: what have we learned?", in Smith, B.L.R. and Barfield, C.E. (eds.), *Technology, R&D, and the economy*, pp. 140-183. The Brookings Institution and American Enterprise Institute, Washington, D.C., USA.
- Hall, B.H. and Vopel, K. (1996). "Innovation, market share and market value". Working Paper, University of California at Berkeley, USA.
- Harrod, R.F. (1939). "An essay in dynamic theory". *Economic Journal*, (49), pp.14-33.
- Jalava, J., Aulin-Ahmavaara, P. and Alanen, A. (2007). "Intangible capital in the Finnish business sector 1975-2005". Discussion Papers 1103, The Research Institute of the Finnish Economy.
- Jones, C.I. (1995a). "Time series tests of endogenous growth models". *Quarterly Journal of Economics*, (110:2), pp. 495-525.
- Jones, C.I. (1995b). "R&D-based models of economic growth". *Journal of Political Economy*, (103:4), pp. 759-784.
- Jorgenson, D.W. (1995). *Productivity*. MIT Press, Cambridge, Massachusetts, USA.
- Khan, M. and Luintel, K.B. (2006). "Sources of knowledge and productivity: how robust is the relationship?". OECD Science, Technology and Industry Working Papers 2006/6, OECD, Paris, France.
- Kuznets, S. (1973). "Modern economic growth: findings and reflections". *American Economic Review*, (68), pp. 247-258.
- Los, B. and Verspagen, B. (2007). "Technology spillovers and their impact on productivity", in Hanusch, H. and Pyka, A. (eds.), *Elgar companion to neo-schumpeterian economics*, pp. 574-593, Edward Elgar, Cheltenham, UK.
- Lundvall, B-A. (ed.), (1992). "National systems of innovation: Towards a theory of innovation and interactive learning". Pinter, London, UK.
- Mc Morrow, K. and Röger, W. (2009). "R&D capital and economic growth: The empirical evidence". *EIB Papers*, (14:1), in this issue.

- Mohnen, P. (2001). "International R&D spillovers and economic growth", in Pohjola, M. (ed.), *Information technology, productivity, and economic growth: International evidence and implications for economic development*, pp. 50-71, Oxford University Press, Oxford, UK.
- Nelson, R. (ed.), (1993). "National innovation systems: A comparative analysis". Oxford University Press, Oxford, UK.
- Nicoletti, G. and Scarpetta, S. (2003). "Regulation, productivity and growth: OECD evidence". *Economic Policy*, (18), pp. 36-39.
- OECD (2000). "Innovation and economic performance", chapter 3 in *OECD science, technology and industry outlook 2000*, OECD, Paris, France.
- OECD (2004). *OECD science, technology and industry outlook 2004*. OECD, Paris, France.
- OECD (2006). *Creating value from intellectual assets*. Meeting of the OECD council at ministerial level, DSTI/IND/STP/ICCP(2006)1, OECD, Paris, France.
- OECD (2009). *Economic Policy Reforms: Going for Growth 2009*. OECD, Paris, France.
- Oesterreichische Nationalbank (OeNB) (2004). *Current issues of economic growth*. Proceedings of OeNB Workshops, No. 2, March.
- Parente, S.L. and Prescott, E.C. (2000). *Barriers to Riches*, MIT Press: Cambridge, MA.
- Romer, P. (1986). "Increasing returns and long-run growth". *Journal of Political Economy*, (94:5), pp. 1002-1037.
- Romer, P. (1990). "Endogenous technical change". *Journal of political economy*, (98:5), pp. S71-S102.
- Sala-i-Martin, X. (2002). "15 years of growth economics: What have we learnt?", in *The Challenges of Economic Growth*, Loaiza, N. (ed.), Central Bank of Chile.
- Scarpetta, S., Hemmings, P., Tressel, T. and Woo, J. (2002). "The role of policy and institutions for productivity and firm dynamics: Evidence from micro and industry data". OECD Economics Department Working Paper No. 329.
- Schumpeter, J.A. (1942). *Capitalism, socialism and democracy*. Harper & Row, New York, New York, USA.
- Scotchmer, S. (2004). *Innovation and Incentives*. MIT Press, Cambridge, Massachusetts, USA.
- Solow, R.M. (1956). "A contribution to the theory of economic growth". *Quarterly Journal of Economics*, (70), pp. 65-94.
- Solow, R.M. (1957). "Technical change and the aggregate production function". *Review of Economics and Statistics*, (39), pp. 312-320.
- Solow, R.M. (1987). "We'd better watch out". *New York Times Book Review*, July 12.
- Stern, S., Porter, M.E. and Furman, J. (2000). "The determinants of national innovative capacity". NBER Working Paper No 7876.
- Swan, T.W. (1956). "Economic growth and capital accumulation". *Economic Record*, (32:2), p.334-61.
- Temple, J. (1999) "The new growth evidence". *Journal of Economic Literature*, (37), pp. 112-156.
- van Ark, B., Hao, J., Corrado, C. and Hulten, C. (2009). "Measuring intangible capital and its contribution to economic growth in Europe". *EIB Papers*, (14:1), in this issue.
- van Ark, B., O'Mahony, M. and Timmer, M. (2008). "The productivity gap between Europe and the U.S.: Trends and causes", *Journal of Economic Perspectives*, (22:1), pp. 25-44.

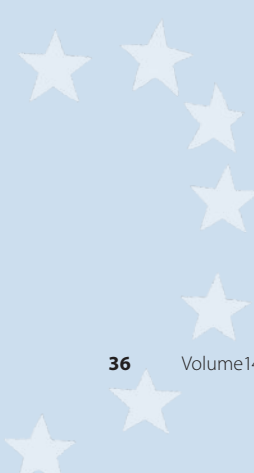
ABSTRACT

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.

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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

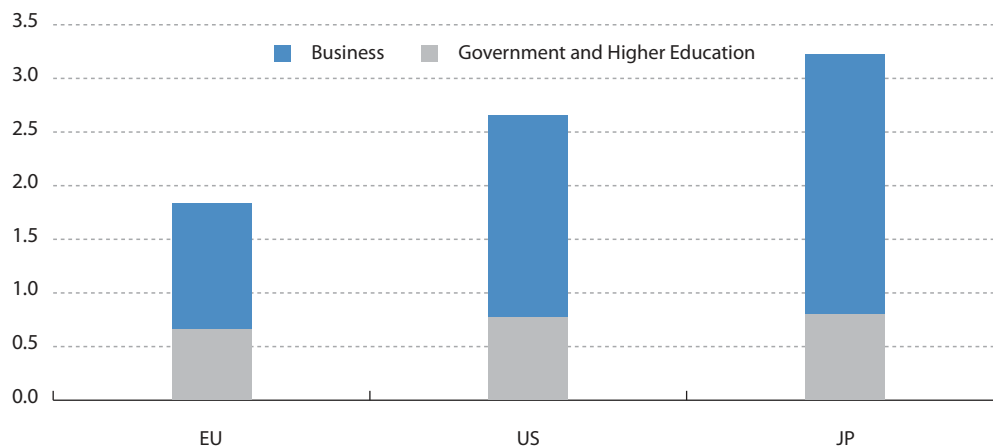
2.1 Total and business R&D: Stable over time and below target

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

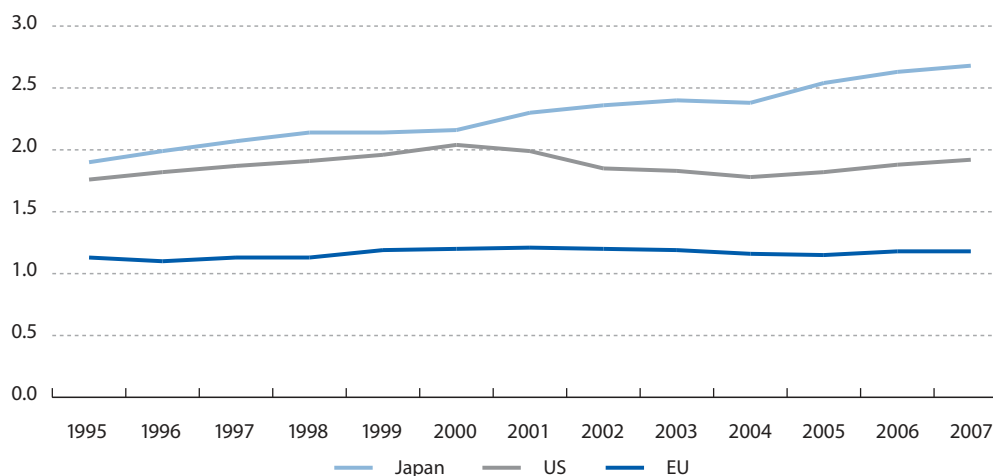


Source: Eurostat, own calculations

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

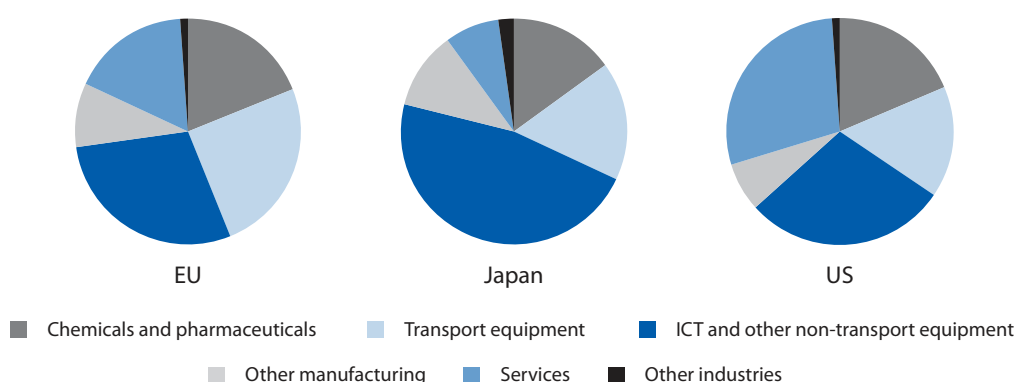
³ This section draws on and updates Uppenberg (2009b).

– 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).

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

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

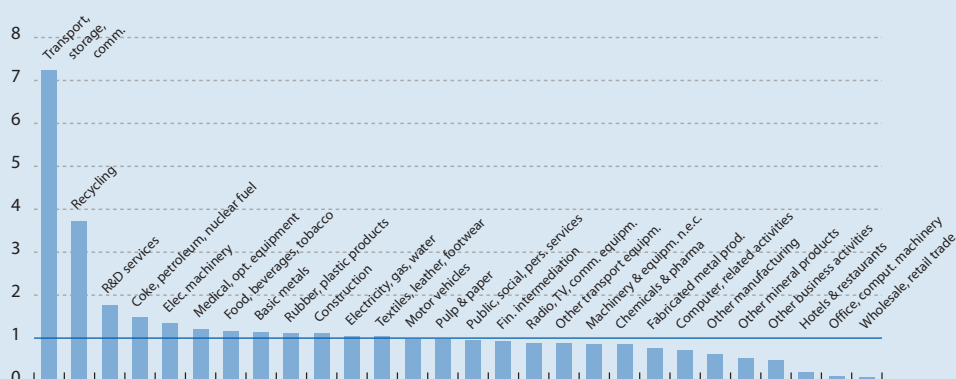
As stated in the main text, the comparability of industry-level R&D data is limited across countries because countries differ as to whether they follow the main-activity or the product-field approach in collecting R&D data from companies and compiling BERD at the industry level.

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

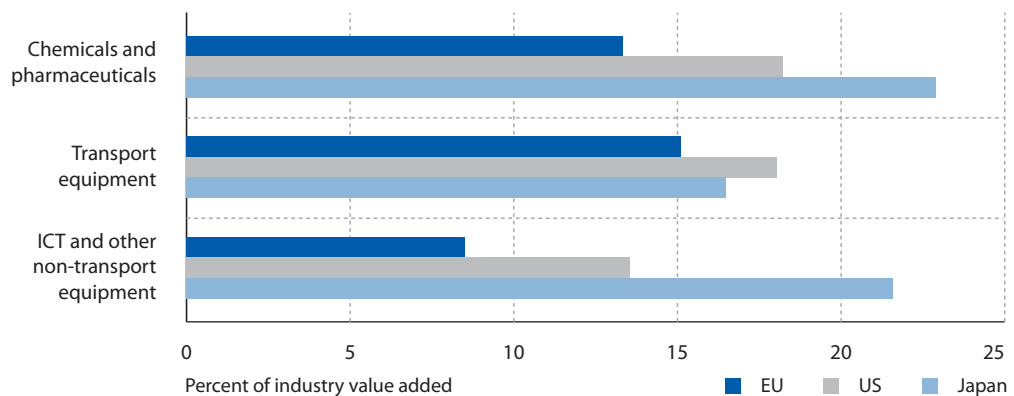


Source: OECD ANBERD, own calculations

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



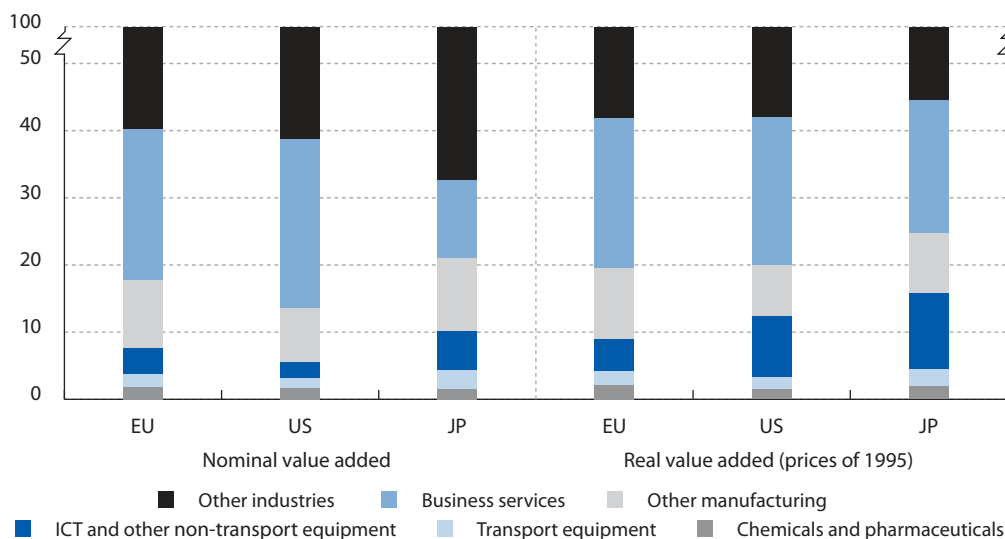
Source: OECD ANBERD, Eurostat, own calculations

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.

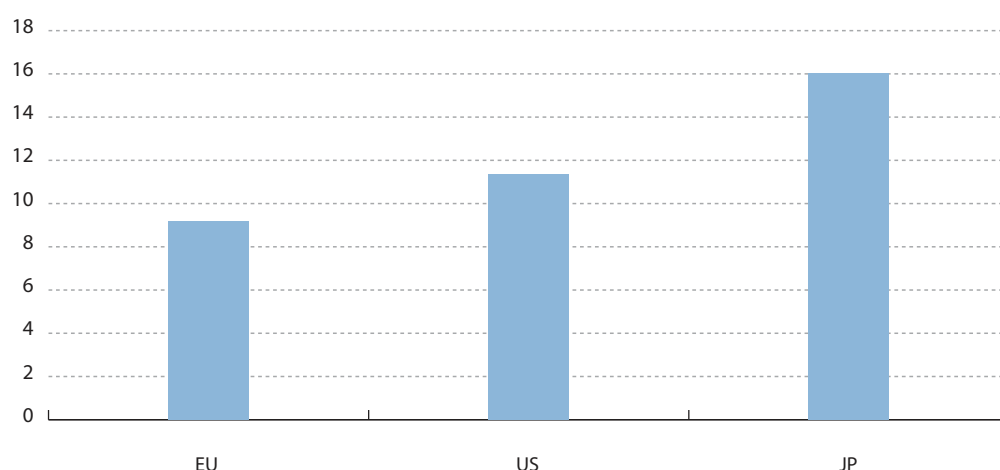
Deflator of R&D expenditure. As EUKLEMS, we use the GDP deflator. Alternatively, one could combine labour costs and output price indices of relevant industries in order to account for extraordinary productivity gains in “producing” R&D. For an overview and practical problems, see Fraumeni and Okubo (2005).

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



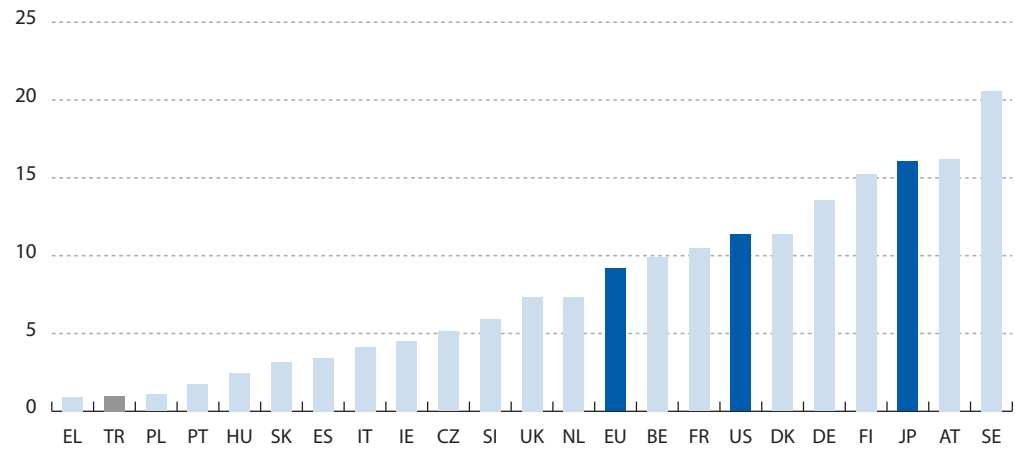
Source: EUKLEMS, OECD ANBERD, own calculations

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

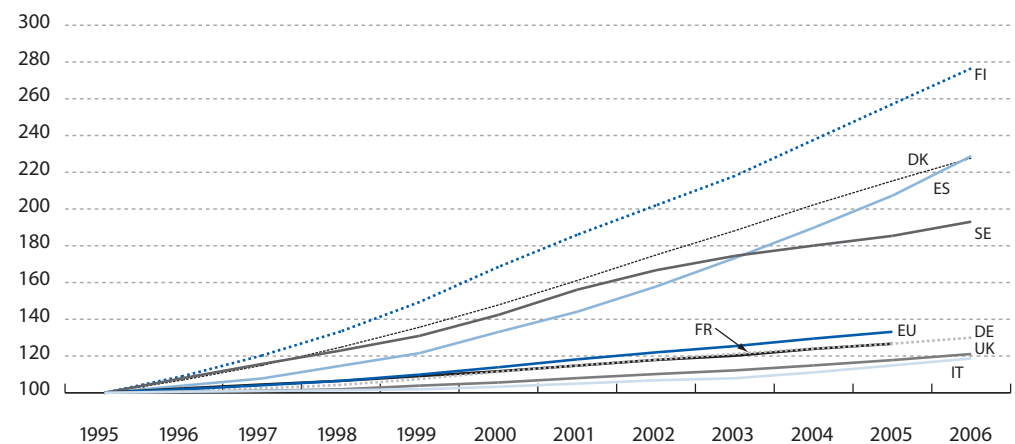


Source: EUKLEMS, OECD ANBERD, own calculations

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.

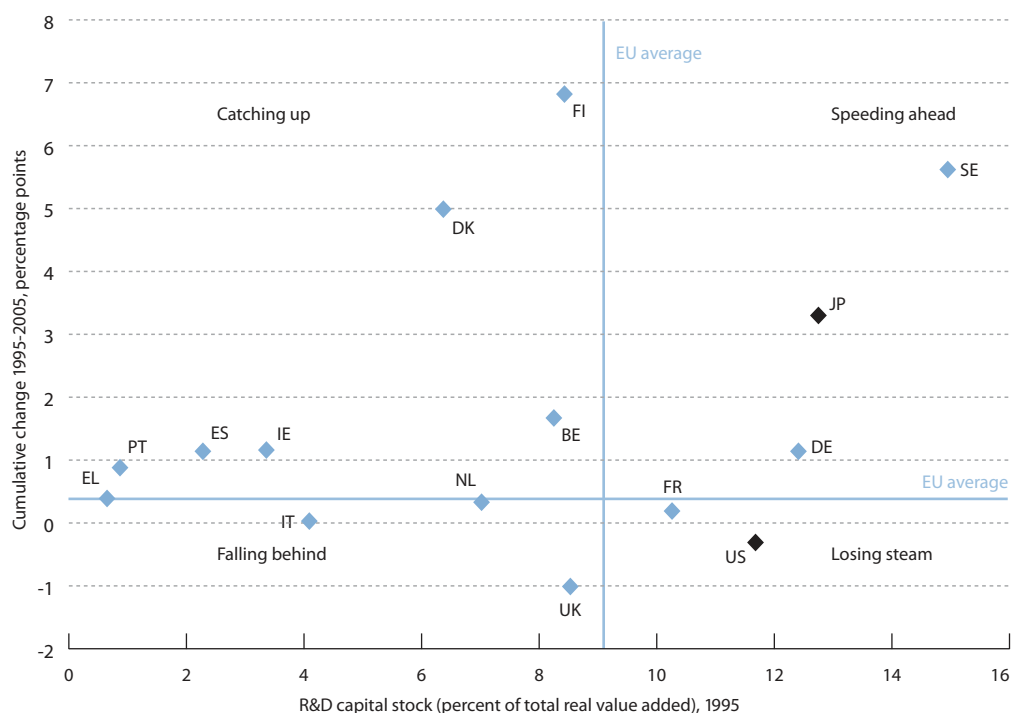
It takes a combination of the two views presented above – the size of the R&D capital stock relative to the economy and the evolution of R&D capital stocks over time – to make statements about whether EU countries converge or diverge in terms of R&D capital intensity. This is done in Figure 9, which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

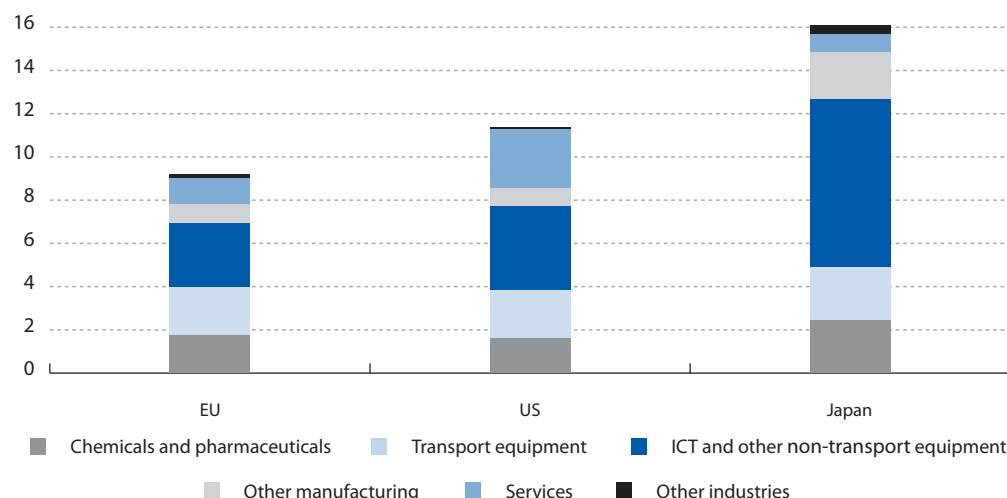
A comprehensive policy discussion on whether it is sensible to design policies that speed up convergence in national R&D capital stocks and whether governments in lagging EU countries are doing enough to that end is beyond the scope of this paper. Suffice it here to note that full convergence is unlikely 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



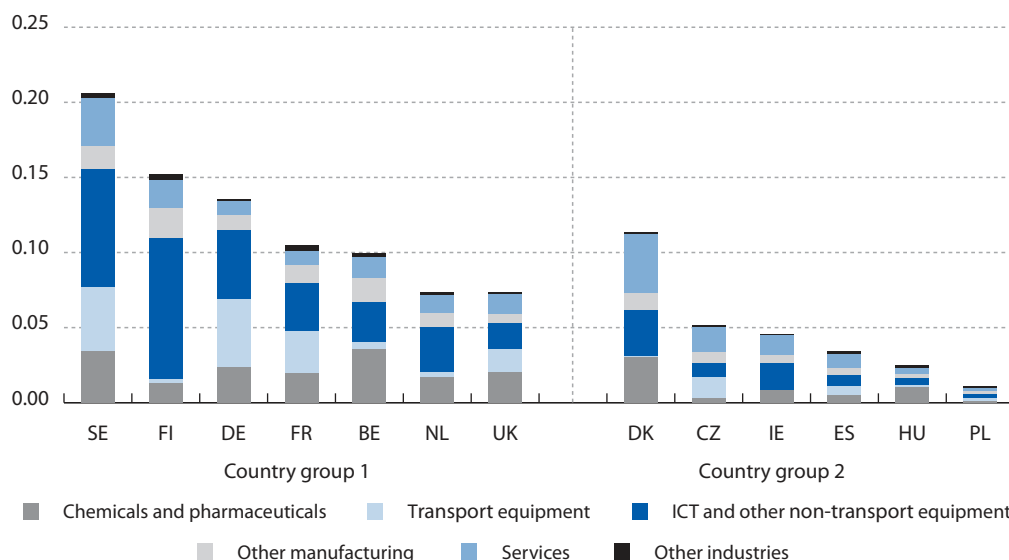
Source: EUKLEMS, OECD ANBERD, own calculations

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.

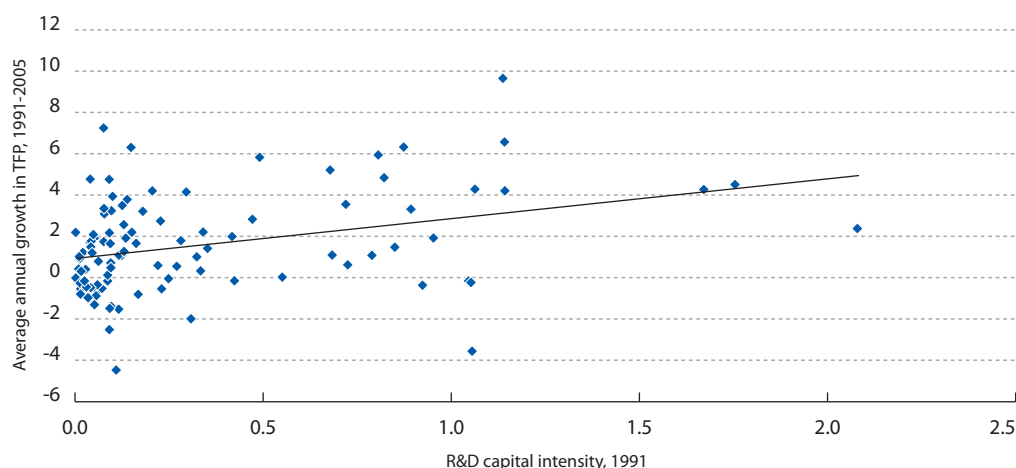
Figure 12 illustrates that there is indeed a positive link between R&D capital and conventional TFP at the industry level. It plots average annual TFP growth over the 15-year period 1991-2005 (vertical axis) against R&D capital intensity (horizontal axis) at the beginning of that period for 13 manufacturing 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

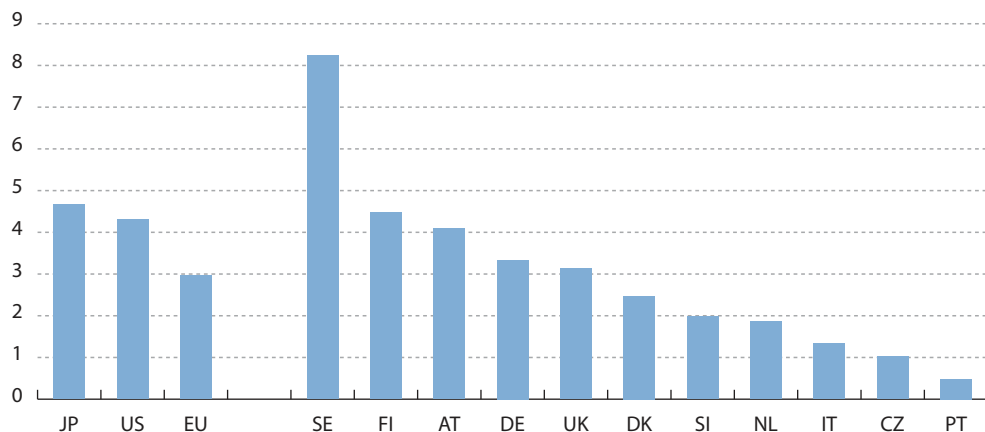
We now change the perspective and analyze the R&D capital ratio, which we define as the ratio of the R&D capital stock to the stock of tangible capital. By tangible capital, we refer to all asset types for which gross fixed capital formation is reported in the national accounts. It includes transport 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.

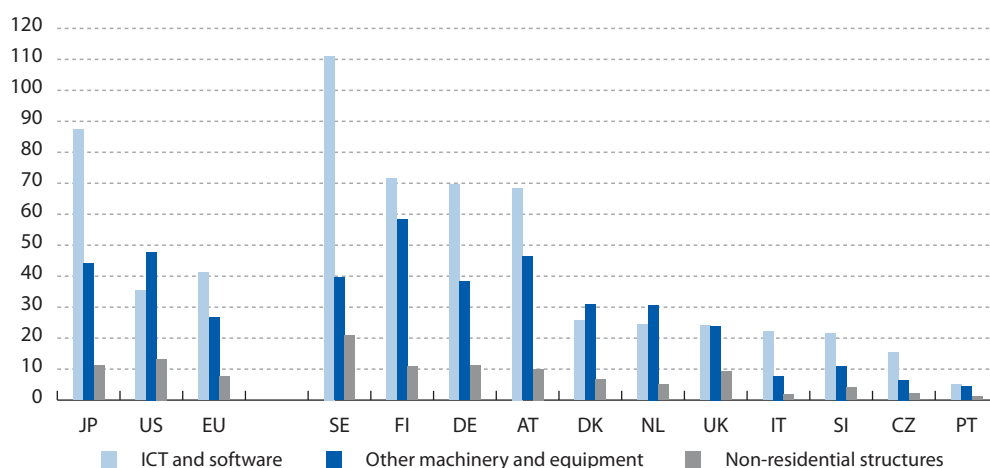
Again, there are considerable cross-country differences within the EU, too. The range of R&D capital ratios spans from 0.5 percent in Portugal to 8.2 percent in Sweden and, hence, broadly matches that of R&D capital intensities. Nevertheless, there are notable differences in the ranking of countries 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

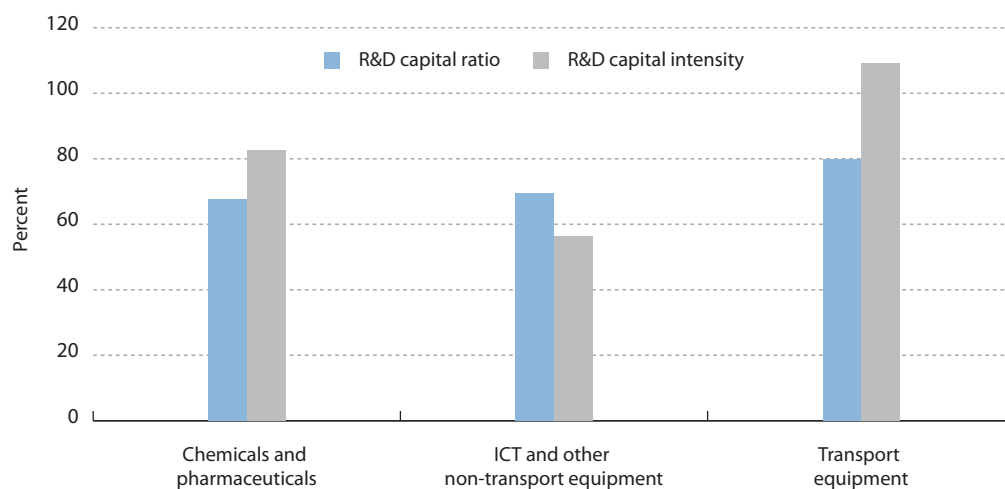
We conclude this section by illustrating R&D capital ratios with respect to total tangible capital¹³ in the EU for selected groups of industries. In addition, we show how these ratios compare with the pattern of R&D capital intensities. This is done in Figures 15a and b. Figure 15a presents the results 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

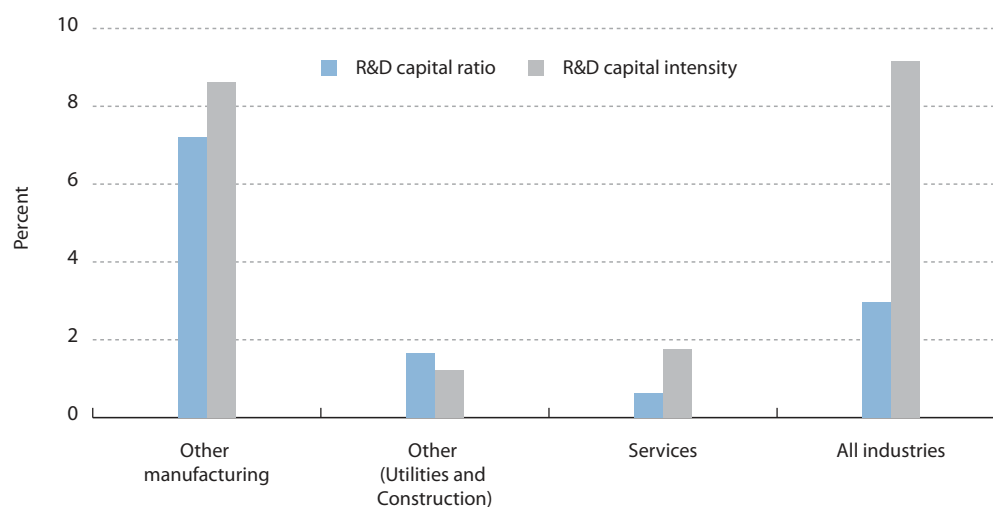


Compared to the overall economy, technology-intensive manufacturing is ten times as R&D intensive and has 25 times the R&D capital ratio.

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 ANEBRD 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.

References

- Acemoglu, D., Zilibotti, F. and Aghion, P. (2006). "Distance to Frontier, Selection, and Economic Growth". *Journal of the European Economic Association*, (4:1), pp. 37-74.
- Arrow, K. (1962). "Economic Welfare and the Allocation of Resources for Inventions", in Nelson, R. (ed.), *The Rate and Direction of Inventive Activity*, Princeton University Press, Princeton, USA.
- Cameron, G., Proudman, J. and Redding, S. (2005). "Technological Convergence, R&D, Trade and Productivity Growth". *European Economic Review*, (49:3), pp. 775-807.
- Bontempi, M.E. and Mairesse, J. (2008). "Intangible capital and productivity: An exploration on a panel of Italian manufacturing firms". NBER Working Paper No. 14108. National Bureau of Economic Research.
- Cohen, W.M. and Levinthal, D.A. (1989). "Innovation and learning: the two faces of R&D". *The Economic Journal*, (99), pp. 569-596.
- Corrado, C., Hulten, C. and Sichel, D. (2005). "Measuring Capital and Technology – An Expanded Framework", in Corrado, C., Haltiwanger, J. and Sichel, D. (eds.), *Measuring Capital in the New Economy*, NBER Studies in Income and Wealth Volume 65, Chapter 1, University of Chicago Press, Chicago, USA.
- Danguy, J., de Rassenfosse, G. and van Pottelsberghe de la Potterie, B. (2009). "The R&D-patent relationship: An industry perspective". *EIB Papers*, (14:1), in this issue.
- D'Auria, F., Pagano, A., Ratto, M. and Varga, J. (2009). "A comparison of structural reform scenarios across the EU member states – Simulation-based analysis using the QUEST model with endogenous growth". European Economy Economic Papers No. 392, European Commission, DG ECFIN.
- Eberhardt, M., Helmers, C. and Strauss, H. (2010). "Do spillovers matter when estimating private returns to R&D?" Economic and Financial Report, European Investment Bank (forthcoming).
- EUKLEMS (2008). "EUKLEMS release March 2008". <http://www.euklems.net/index.html>
- European Commission, International Monetary Fund (IMF), Organisation for Economic Co-operation and Development (OECD) United Nations (UN) and World Bank (2009). *The System of National Accounts 2008*, <http://unstats.un.org/unsd/nationalaccount/sna2008.asp>
- Fraumeni, B.M. and Okubo, S. (2005), "R&D in the National Income and Product Accounts – A first look at its effects on GDP", in Corrado, C., Haltiwanger, J. and Sichel, D. (eds.), *Measuring Capital in the New Economy*, NBER Studies in Income and Wealth Volume 65, Chapter 8, University of Chicago Press, Chicago, USA.
- Griffith, R., Redding, S. and van Reenen, J. (2003). "R&D and Absorptive Capacity: Theory and Empirical Evidence". *Scandinavian Journal of Economics*, (105:1), pp. 99-118.
- Griffith, R., Redding, S. and van Reenen, J. (2004). "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Countries". *Review of Economics and Statistics*, (86:4), pp. 883-895.
- Griliches, Z. (1979). "Issues in assessing the contribution of research and development to Productivity Growth". *The Bell Journal of Economics*, (10:1), pp. 92-116.
- Griliches, Z. and Lichtenberg, F. (1984). "R&D and Productivity Growth at the Industry Level: Is there Still a Relationship?", in Griliches, Z. (ed.), *R&D, Patents and Productivity*, University of Chicago Press, Chicago, USA.
- Grossman, G. and Helpman, E. (1991). *Innovation and Growth in the Global Economy*, MIT Press, Cambridge, MA, USA.

- Guellec, D. and van Pottelsberghe de la Potterie, B. (2004). "From R&D to Productivity Growth: Do Institutional Settings and the Source of Funds Matter?" *Oxford Bulletin of Economics and Statistics*, (66:3), pp. 353-378.
- Mead, C.I. (2007). "R&D Depreciation Rates in the 2007 Satellite Account". Bureau of Economic Analysis and National Science Foundation, Washington, D.C., USA.
- OECD (2009a). *Measuring Capital. OECD Manual, Second edition*, Organisation for Economic Co-operation and Development, Paris.
- OECD (2009b). "ANBERD (Analytical Business Enterprise Research and Development) database 2009". Organisation for Economic Co-operation and Development, Paris. www.oecd.org/sti/anberd – Data available at: http://stats.oecd.org/Index.aspx?DataSetCode=ANBERD_REV3
- O'Mahony, M., Castaldi, C., Los, B., Bartelsmann, E., Maimaiti, Y. and Peng, F. (2008). "EUKLEMS – Linked Data: Sources and Methods", University of Birmingham, <http://www.euklems.net/linked.shtml>
- O'Mahony, M. and Timmer, M. (2009). "Output, Input and Productivity Measures at the Industry Level: The EUKLEMS Database". *The Economic Journal*, (119:538), pp. F374-F403.
- Romer, D. (1990). "Endogenous Technological Change". *Journal of Political Economy*, (98:5), pp. 71-101.
- Solow, R.M. (1956). "A contribution to the theory of economic growth". *Quarterly Journal of Economics*, (70), pp. 65-94.
- Uppenberg, K. (2009a). "Innovation and growth". *EIB Papers*, (14:1), in this issue.
- Uppenberg, K. (2009b). *R&D in Europe: Expenditures across Sectors, Regions and Firm Sizes*, Centre for European Policy Research, Brussels, Belgium.
- van Ark, B., Hao, J., Corrado, C. and Hulten, C. (2009). "Measuring intangible capital and its contribution to economic growth in Europe". *EIB Papers*, (14:1), in this issue.

ABSTRACT

This study describes the state of the art in the measurement of intangible capital and its contribution to economic growth, with a focus on an international comparison of intangible investment intensity and intangible capital deepening among eleven advanced economies. By employing a broad measure of intangibles, including computerized information, innovative property and economic competencies, we find a relatively large impact on growth. Intangible capital explains about a quarter of labour-productivity growth in the US and larger countries of the EU. The continental West-European countries show a distinction between countries with significant contributions from intangible capital deepening and a group of laggards. Catching-up countries such as the Czech Republic, Greece and Slovakia show much larger contributions from tangible capital deepening than from intangibles, and also larger multi-factor productivity (MFP) growth rates related to the restructuring of those economies.

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Measuring intangible capital and its contribution to economic growth in Europe

1. Introduction

The recent economic downturn has changed the current debate on economic growth from one that emphasizes the long-run need for productivity and innovation to one that stresses economic recovery, particularly in employment. The focus on job growth is an inevitable aspect of any recession, and the deeper the recession, the greater the concern. This recession, however, is somewhat different because it has unfolded against the backdrop of the job losses and labour force restructuring brought about by the globalization of the world economy. One way to accomplish both short- and long-term objectives is to promote investment where the high-wage economies of Europe and the US have their greatest comparative advantage – the creation of knowledge. As the knowledge-content of the products and services that economies produce gradually increases, investment in knowledge production becomes the key source of economic growth. Moreover, the creation of knowledge both raises investment opportunities in the short run while creating the rewards of higher income and productivity growth in the future.

Knowledge creation is part of a wide-ranging process of investment in intangible capital. This investment includes expenditures for human capital, in the form of education and training, public and private scientific research, and business expenditures for product research and development, market development, and organizational and management efficiency. These are strategic investments in the long-run growth path of individual companies and of the economy as a whole. They are increasingly seen by policy makers as essential for the sustained economic health of the economy as witnessed, for example, by the European Lisbon Strategy to revitalize growth, competitiveness and sustainable development and the America Competes Act in the United States.

In order to manage intangibles both as a source of growth at the macroeconomic level, and as a driver of value creation for individual firms, it is important to measure them well. While nobody would disagree with their long-lasting benefits, the costs of most intangibles are still expensed in company financial statements and in national income and product accounts, implying that they detract from value-added growth rather than increasing it. To paraphrase Solow's quip about the computer revolution, one could say that today "the knowledge economy is all around us, but where can we see it in the official statistics?"¹ One answer is that much of the activity we associate with knowledge creation, especially by businesses, isn't there. Conventional measures of investment in the accounts consist primarily of tangible assets such as plant and equipment, vehicles, office buildings and other commercial structures. In reality, as the reported estimates in this article show, investment in intangibles in many advanced economies approaches the value of investment in tangible assets, and in some cases (such as in the United Kingdom and the United States) it even exceeds tangible investment.

In recent decades, the accounting treatment of intangibles has begun to change, with the decision to capitalize software expenditures and treat the result as a contribution to GDP. Software is a major category of intangibles and a primary means of transforming knowledge (or "blueprints") into computerized information. More recently, it has been proposed to extend the capitalization of intangibles to expenditure on research and development (R&D). For example, the US Bureau of Economic



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¹ The Solow productivity paradox states that "you can see the computer age everywhere but in the productivity statistics" (Solow 1987), which subsequently led to a surge of studies to improve the measurement of ICT and their contribution to economic growth.

Analysis will count R&D as investment in its headline GDP measure in 2013, and in a satellite account until then. These moves are supported by recent decisions by the United Nations to do likewise in its System of National Accounts.

The full range of spending on intangibles is not likely to get treated as investment in the national accounts.

Still, the full range of value-building intangible assets is not likely to be accorded the same treatment as software and R&D in the national accounts, even though economic research and surveys show that assets such as management capability, marketing and employee-training expenditures are important co-investments with R&D and information and communication technologies (ICT). The challenges concerning the conceptualization of intangible capital, its measurement on the input and output sides, and their integration into a production function or growth accounting framework are substantial indeed (van Ark 2002; van Ark and Hulten 2007).

In this study we discuss the state of the art in the measurement of intangible capital and its contribution to economic growth, with a focus on international comparisons currently available. In Section 2, we discuss some of the conceptual and theoretical issues in relation to the capitalization of intangible capital. Section 3 provides a brief overview of the methodology used to obtain measures of intangibles, and reports estimates for a wide range of European countries and the United States. We combine estimates from a new study by Corrado and Hulten (2009) that updates previous studies by Corrado, Hulten and Sichel (CHS 2005; 2009) for the United States with updated figures from Marrano, Haskel and Wallis (MHW 2007; 2009) for the United Kingdom, estimates from The Conference Board's previous empirical study for Germany, France, Italy and Spain (Hao *et al.* 2009) and new estimates for five additional European countries (Austria, Czech Republic, Denmark, Greece and Slovakia). In Section 4 we integrate these measures in a growth accounting framework. Finally, as we gradually grow the number of countries for which intangible capital can be measured and integrated in growth analysis, Section 5 provides a first attempt to study the role of intangibles from a broader perspective of economic growth and development using the results for our eleven countries in combination with estimates for five other countries from alternative studies, including Jalava *et al.* (2007) for Finland, van Rooijen-Horsten *et al.* 2008) for the Netherlands, Edquist (2009) for Sweden, Barnes and McClure (2009) for Australia and Fukao *et al.* (2007 and 2009) for Japan. In the concluding section we identify some key issues for further reflection and research.

2. Why capitalize intangibles?

Empirical studies of economic growth have traditionally focused on the contribution of capital in terms of plant and equipment, vehicles, and buildings. These are tangible assets that can be seen and touched, and their historical role as sources of economic growth is beyond dispute. Their status as capital is indisputable because they are created using current resources in order to increase future production and consumption. However, CHS (2005; 2009) point out that this criterion applies equally to all expenditures on product and market development (that is, including, but not limited to, R&D), worker training, and organizational development, which also aim to increase future output and consumption.

CHS (2009) formalize how intangible may be incorporated into the conventional GDP/GDI national accounting identity. The key to this extension is that the flow of new intangibles must be included *both* on the product side of the accounts and on the input/income side via the flow of services from the intangible stock (a point sometimes missed in the literature on R&D):

$$(1) \quad P^Q(t)Q(t) = P^C(t)C(t) + P^I(t)I(t) + P^N(t)N(t) = P^L(t)L(t) + P^K(t)K(t) + P^R(t)R(t)$$

Here, aggregate output is denoted by Q , consumption by C , tangible investment goods by I , intangibles by N , and their respective prices by P with the appropriate superscript. On the input side labour L , tangible capital K , and intangible capital R represent the inputs that are allocated to the production of all three output components. This formulation is distinctly different from the current national accounts' definition of GDP, which treats N as an intermediate input to the production of C and I .

Treating intangible expenditures as investment also makes economic sense from a business strategy point of view. Outlays on software, R&D, advertising, training, organizational capital *etc.*, are critical investments that sustain a firm's market presence in future years by reducing cost and raising profits beyond the current accounting period. For example, the development of software for on-line banking has provided customers with 24/7 financial services and hence massively reduced labour cost in retail banking. Similarly, R&D is carried out with the expectation that it will increase the future profit of a firm, an expectation that is validated on average by the positive correlation between R&D and patents, on the one hand, and stock prices, on the other (Hall 1999). Moreover, marketing intangibles (brand equity, customer satisfaction) determine whether or not a firm is competitive in the long run.² The value of these intangibles is reflected in the market value of a company. In a sample of 617 companies drawn from the COMPUSTAT data base for the year 2006, Hulten and Hao (2008) find that the book value of conventionally reported equity explains only a small fraction of its market value (around 30 percent), but this fraction increases to 75 percent when the capitalized cost of intangibles is added to the balance sheets of these companies.

Taking intangible assets into account eliminates most of the large discrepancy between market- and book values of listed companies.

Capitalizing intangibles is thus an important step in its own right. It is also an important step towards measuring its contribution to economic growth. CHS (2009) expand the conventional Solow-Jorgenson-Griliches sources-of-growth (SOG) model to include intangible input and output. The expanded model leads to the following equations:

$$(2) \quad g_Q(t) = s_C(t)g_C(t) + s_I(t)g_I(t) + s_N(t)g_N(t) \\ = s_L(t)g_L(t) + s_K(t)g_K(t) + s_R(t)g_R(t) + g_A(t)$$

This formulation links the growth rate of output $g_Q(t)$ first to the weighted contributions of the growth of consumption ($g_C(t)$), tangible investment ($g_I(t)$) and intangible investment ($g_N(t)$), and second, to the supply-side of the economy where $g_Q(t)$ equals the weighted contributions from the growth in labour ($g_L(t)$), tangible capital ($g_K(t)$) and intangible capital ($g_R(t)$) and multifactor productivity ($g_A(t)$). In both cases the weights sum up to one.

The inclusion of intangibles in the $g_Q(t)$ framework means that the labour share is smaller than in the traditional growth accounting equation because of the expanded capital base. CHS also note that when intangible investments are increasing as a share of output, the measured multifactor productivity residual will tend to be smaller than the corresponding MFP estimate calculated without intangibles.³

2 A survey of manufacturing firms in the UK identifies eight marketing practices that determine long-run competitiveness, including the use of the experience curve-concepts in marketing and the ability to offer superior quality products (Brooksbank *et al.* 2003). Training has reduced the cost of introducing flexible production systems in automobile firms across the world (McDuffie and Krafcik 1992). And apprentice training contributes to the productivity of a firm during and beyond the apprentice period, according to a survey of Swiss firms (Wolter *et al.* 2006). Management practices also appear highly correlated with firm-productivity. For example, Bloom and Van Reenen (2007) link the intangible of corporate management practices to productivity and show significant cross-country differences, with US firms on average better managed and more productive than European firms. In particular, it is suggested that US multinationals are organized in a way that allows them to use new technologies such as ICT more efficiently than non-US firms (Bloom *et al.* 2009)

3 However, the smaller MFP residual is not an inevitable consequence of adding intangibles. See the recent survey of growth accounting by Hulten (2009a) for further discussion.

The need to capitalize intangibles is evident but there are formidable measurement challenges.

Despite the evident need to capitalize intangible assets, estimating the magnitude of the investment flows (the $P_N N$), separating these flows into price (P_N) and quantity (N) components, and determining the service lives of the assets to enable the compilation of net asset stocks (R), are formidable measurement challenges. Moreover, all relevant assets must be identified and measured. The literature has discussed these measurement and identification challenges from alternative points of view: some regard the challenges as a wall that is virtually impossible to scale (perhaps even fraught by theoretical impossibility), while others stress the importance and policy-relevance of updating empirical growth accounts to reflect modern business realities.⁴ All told, and as indicated by CHS (2009), “the real issue of whether intangibles should be classified as intermediates or as capital depends on the economic character of the good ... and not on the ease with which it can be measured” (p. 667). In the remainder of this section we discuss these challenges – both measurement and theoretical – as they pertain to the growth accounting framework and its implementation.

First, with regard to the scale and scope of intangible investment ($P_N N$) their presence is primarily recognized by the resources the firm spends to acquire the knowledge-based assets through, for example, R&D, licenses, patenting, *etc.*, as well as their spending on co-investments to R&D and ICT (including those related to changes in business models and practices). There are various ways of getting at these investments. For example, measures of organizational capital used in this article are based on estimating managers’ time devoted to organizational innovation tasks and expenses on external management consultancy contracts. A more precise measurement would translate firms’ documentation in performance tracking, target time horizon, human-capital management, and the rewarding of high performance, *etc.*, into dollar values. From a practical point of view, the emerging survey work on measuring intangible investment in the United Kingdom (Clayton *et al.* 2009) and business activity by business function in the United States (Sturgeon and Gereffi 2009; Brown 2008) offers promising methods for greatly improving the measurement of intangible investment.

Second, intangible investment and capital in real terms – the measurement of N – is the most vexing challenge: Units of knowledge cannot be defined *per se*, a problem akin to defining prices for business or medical services and for which no consensus solution exists.⁵ Other than for software and some other small items already included in the national accounts, CHS (2005; 2009) used the overall output price as the price for intangible investment. The Bureau of Economic Analysis (BEA) has offered an R&D-specific output price in its preliminary R&D satellite account. In this study we maintain the CHS assumptions, but note, as they did, its “place-holder” nature until a more satisfactory solution emerges (see also Annex 1).

Third, both the measurement and conceptualization of net stocks of intangibles (R) is complicated by the fact that intangibles are largely non-rival and returns on investment are not fully appropriable. Patent protection and business secrecy may give the innovator a degree of protection, but the value of the investment to the innovator is limited to the returns on the investment that can be captured, which in turn provides the conceptual basis for measuring depreciation and calculating net stocks (Pakes and Schankerman 1984). The decision to invest a dollar in an innovation is presumably based on the expectation that, on average, at least a dollar’s worth of value can be appropriated. This is not, however, a precise calculation. In fact, the return on a specific intangible dollar may be zero or a multitude of output dollars. Innovation usually involves experimentation and uncertainty, in which

4 For discussions of these issues, see for example, Howitt (1996), Lev (2001), Nakamura (2001), van Ark (2002), van Ark and Hulten (2007) and CHS (2005; 2009).

5 Corrado and Lane (2009) consider the measurement of innovation within firms and suggest that the “project” be the unit of analysis and measurement. Notwithstanding practical issues, such an approach opens potential for measuring productivity of a business function, much as Diewert (2008) suggests that productivity for certain medical services can be measured by isolating “procedures” as a unit of analysis.

winners and losers are sorted out over time in a Schumpeterian process of “creative destruction”. Ultimately, the benefits from an innovation diffuse to other users. This process of knowledge diffusion is the source of at least a part of MFP growth at the aggregate level. Indeed, MFP measures the costless gains in the efficiency of production. The diffusion of knowledge from the original investor/innovator is one way the costless gains are achieved. For example, estimates of the Bureau of Labor Statistics suggest that somewhere between a fifth and a quarter of the growth rate of MFP in the US non-farm business sector is due to R&D spillovers.

MFP measures the costless gains in the efficiency of production, notably through the diffusion of knowledge from innovators.

Fourth, several theoretical considerations are central when using available measures to obtain estimates of the contribution of intangibles to economic growth. Intangibles are often not a direct or continuous input to current production but represent an upfront cost to the production process with substantial uncertainty whether or not they will actually produce an output in terms of a new product or service delivery. Uncertainty does not only apply to the R&D going into a new product (which may or may not lead to an actual decision to manufacture the product) but also to the marketing of, in particular, a service output.⁶ Adding these indirect inputs to the SOG model shifts it away from a purely production-function model of growth in which technology improves the processes of production to a more Schumpeterian approach that puts emphasis on the actual product or service output created. Hulten (2009b) develops a model that reconciles the technology-oriented nature of the Solow residual with the broader innovation-based nature of intangible inputs at the firm level. This research also highlights the fact that measured MFP growth may come through improvements in quality of products and services, which can be integrated in the accounting framework by linking the intangible investment to prices on the output side. Thus, while intangibles may not necessarily refer to technology-oriented processes, they can be handled in the current SOG accounting framework, provided data are available to develop adequate measures of quality change in inputs and outputs.

Finally, the assumptions behind the version of the Solow residual in Equation (2) are not necessarily applicable to a world in which intangibles are important. The assumptions of perfect competition and foresight do not easily apply to the situation in which a firm’s intangible assets create market share and in which control over the property rights is associated with an innovation. One result is that the factor shares in Equation (2) do not necessarily equal the output-elasticity as required by the Solow framework. However, Hulten (2009b) shows that this is not necessarily a disabling problem when passing from the micro to the macroeconomic level of activity. Deviations in capital and labour compensation shares from their required theoretical values may cancel out when passing from the micro to the macroeconomic level of analysis. In any event, van Ark and Hulten (2007) note that growth accounting remains essentially the only game in town as far as a comprehensive empirical growth analysis involving all inputs and output in production is concerned, and that the inclusion of intangibles does not diminish that claim.

3. Measures of intangible investment

Various definitions of intangible capital are possible, but most definitions are offshoots of Schumpeter’s classification, which includes product and process development, organizational change, management, marketing and finance (Schumpeter 1934). Some studies focus on structural characteristics of particular types of intangibles related to innovation, human resources or organizations (Lev 2001) or to the

⁶ For example, Campbell-Kelly (1995) describes the example of Lotus 1-2-3 which was the dominant spreadsheet program in the 1980s, developed by Mitch Kapor in 1982. The biggest challenge was the marketing of Lotus 1-2-3. Kapor spent USD 1 million developing the software and USD 2.5 million marketing it. With the successful launch, 850,000 copies of Lotus 1-2-3 were sold, making it the most popular spreadsheet software. The price of Lotus 1-2-3 was USD 495, and 40% of that price covered marketing.

We distinguish between computerized information, innovative property and economic competencies, valuing them at investment cost.

investment characteristics of intangibles (Nakamura 2001). Other studies use functional characteristics on the output side, such as the measurement of the stock market value of output (Hall, 2001) or the projected future value of output (van Bakkum 2009). The approach adopted here follows the work of CHS (2005; 2009), which uses a combination of structural characteristics combined with functional (investment-related) characteristics on the input side, *i.e.* the value of investment at cost and distinguishing between business investment in three categories, *i.e.* (1) computerized information, (2) innovative property, and (3) economic competencies:

(1) Computerized information is already largely included in the national accounts, as computer software for both purchased and own-account components. However, this category also includes databases which are often not included in the national accounts today.

(2) Innovative property includes both scientific property and “non-scientific” R&D.⁷ Until recently, neither scientific nor non-scientific R&D has been included in national accounts, although this will change in 2013 with the implementation of the 2008 System of National Accounts in most countries, which recommends the inclusion of (mainly) scientific R&D. Non-scientific R&D is a somewhat “under-defined” category in the R&D statistics because it is unclear whether it belongs to R&D and what is actually included in this category.⁸ The estimates of this study follow CHS (2005; 2009) and include the cost of developing new motion picture films and other forms of entertainment, investments in new designs, and a crude estimate of the spending for new product development by financial services and insurance firms. CHS report that, by the late 1990s, investment in non-scientific R&D was as large as investment in scientific R&D.

(3) Economic competencies are the largest category and include two sub-categories, brand equity and firm-specific competencies. Investment in brand names is measured as a fraction of advertising spending to reflect that not all advertising may be seen contributing to the building of brands. We adopt the estimate by CHS (2005; 2009) that about 60 percent of total advertising expenditures has long-lasting effects rather than short-term expenditure focused on, say, “this week’s sale”. Investment in firm-specific capital and human resources includes the costs of employer-provided worker training and an estimate of management time and expenditure on external consultants devoted to enhancing the productivity of the firm. The estimates for firm-level training are based on a mix of data from statistics on vocational training and cost data from employment statistics. Expenditure on organizational changes is derived from revenues for the management consultant industry in combination with trends in the cost and number of persons employed in executive occupations. It is assumed that managers spend 20 percent of their time on improving organizational structures. While these numbers are imprecise, even on the basis of this modest assumption they represent the largest type of business intangible investment.

We use the same methodology as CHS (2005; 2009) for the United States and MHW (2007; 2009) for the United Kingdom to examine intangible investment in continental European countries. In Hao *et al.* (2009), we estimate intangible investment for France, Germany, Italy and Spain. For the purpose of the current article, we develop five additional estimates for other European countries, including Austria, Denmark, Greece, Czech Republic and Slovakia. Those countries include both old and new member

7 Innovative property should not to be confused with intellectual property which refers to creations of the mind, including inventions, literary and artistic works, symbols, names, images, and designs used in commerce. There is a significant overlap between the two concepts, but the innovative property exclusively focuses on the investment and output characteristics. The labelling of “non-scientific” R&D is somewhat misleading because the development of new financial products and architectural modelling is mostly conducted by personnel with scientific degrees.

8 The Frascati Manual on the collection and use of R&D data explicitly includes social science R&D and Eurostat explicitly includes it. The United States launched a new R&D survey in which data on social science R&D will be collected for 2008 for the first time. Previously, social science R&D was explicitly excluded from US R&D.

states of the European Union (EU), so we can learn the patterns of intangible investment in economies at different stages of development.⁹

Table 1 shows the investment in the market sector of the economy as a percentage of total GDP in the US and the UK as well as for the four large continental European countries. In the continental European countries the market sector results were obtained by excluding the entire government, health and education sector. Real estate activities are also excluded due to the problems in measuring their productivity (EU KLEMS 2008). In the US, the private non-farm business sector invested 11.5 percent of conventionally measured GDP in intangible assets in 2006. In the same year, the private sector invested 10.5 percent of GDP in intangibles in the UK, 7.2 percent in Germany, 7.9 percent in France, 5.0 percent in Italy and 5.5 percent in Spain.

Intangible investment exceeds 10 percent of GDP in the US and the UK, is below that mark in France and Germany and hovers around 5 percent in Italy and Spain.

Table 1. Intangible investment in the market sector in Germany, France, Italy, Spain, UK and US (percent of GDP, 2006)

Type of Investment	Germany 2006	France 2006	Italy 2006	Spain 2006	UK 2006	US 2006
1. Computerized information	0.73	1.42	0.64	0.79	1.55	1.61
a) Software	0.71	1.37	0.63	0.76	0.00	
b) Databases	0.02	0.05	0.01	0.03	0.00	
2. Innovative property	3.59	3.18	2.21	2.78	3.16	4.37
a) R&D, including social sciences and humanities	1.72	1.30	0.58	0.63	1.07	} 2.25
b) Mineral exploration and evaluation	0.01	0.04	0.09	0.04	0.04	
c) Copyright and license costs	0.21	0.31	0.10	0.18	0.22	} 2.12
d) Development costs in financial industry	0.75	0.60	0.58	0.52	0.07	
e) New architectural and engineering designs	0.90	0.93	0.86	1.41	1.74	
3. Economic competencies	2.84	3.30	2.19	1.90	5.84	5.50
a) Brand equity	0.56	0.99	0.71	0.42	1.15	1.47
Advertising expenditure	0.41	0.73	0.47	0.19	0.91	
Market research	0.15	0.26	0.24	0.23	0.24	
b) Firm-specific human capital	1.29	1.51	1.02	0.81	2.54	} 4.03
Continuing vocational training	0.65	1.25	0.71	0.71		
Apprentice training	0.64	0.26	0.32	0.10		
c) Organizational structure	1.00	0.81	0.45	0.68	2.14	
Purchased	0.54	0.32	0.15	0.27	0.51	
Own account	0.46	0.49	0.3	0.41	1.63	
Total Investment	7.16	7.90	5.04	5.47	10.54	11.48
<i>pro memoria</i>						
Total Spending	7.55	8.51	5.43	5.70	11.56	

Sources: Hao *et al.* (2009) for Germany, France, Italy and Spain; CHS (2009) for the US and MHW (2009) for the UK. They all have updated their results to 2006.

Notes: 60 percent of expenditure on advertisement, 80 percent of expenditure on own-account organizational structure and 100 percent of all the other expenditure are considered as investment (CHS 2005). GDP here is conventionally-measured GDP (including software and mineral exploration but excluding other intangibles). MHW (2009) estimate item 2(d) using the wages of research occupations of financial industry, and estimate item 2(e) using the wages of designers and engineers.

⁹ Other recent studies include intangible intensity measure for Finland (9.1 percent of GDP according to Jalava *et al.* 2007), the Netherlands (8.3 percent of GDP between 2001 and 2004; van Rooijen-Horsten *et al.* 2008), Sweden (10.6 percent of GDP according to Edquist 2009), Australia (9.6 percent of market-sector value added in 2005-2006; Barnes and McClure 2009) and Japan invested 7.5 percent of GDP from 1995 to 2002 (Fukao *et al.* 2007; 2009).

We present new estimates for Austria, Czech Republic, Denmark, Greece and Slovakia.

Table 2 shows the new results for five smaller European economies in 2006. The estimate for Denmark (7.9 percent) is comparable to that of Germany and France but considerably lower than in three other small countries, Finland, Sweden and the Netherlands. The estimates for Austria are lower than for France and Germany, but still above those for Italy and Spain. The Czech Republic and Slovakia are also closer to the lower end, with the former more intensive in intangibles than the latter. The big outlier is Greece, which suggests intangible investment is only 1.6 percent of GDP, much lower than in any other country. While the results for Greece require more research, the outcome is surprisingly close to the estimate from Jona-Lasinio *et al.* (2009), which also shows Greece as extraordinarily low in terms of intangible investment intensity. The difference between Greece and the other countries is largest in all areas of economic competencies.

Table 2. Intangible investment in the market sector in Austria, the Czech Republic, Denmark, Greece and Slovakia (percent of GDP, 2006)

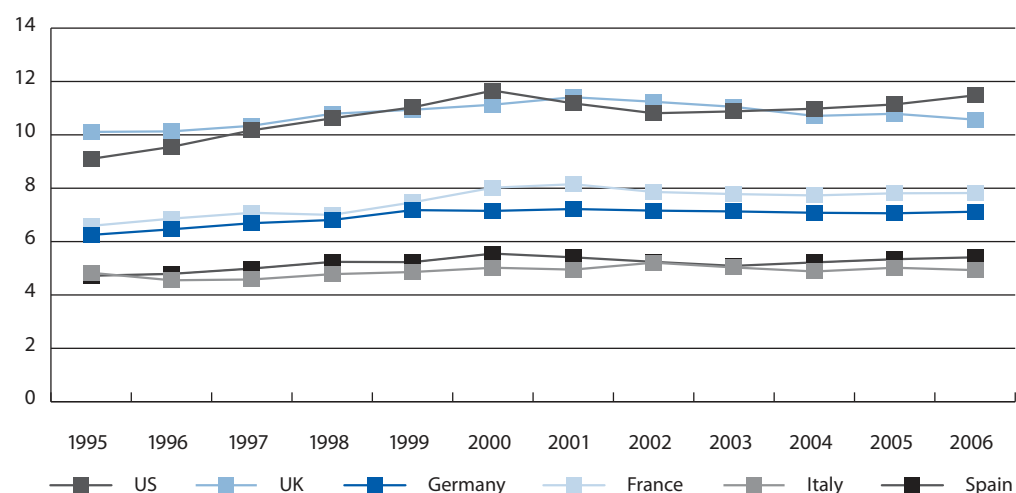
Type of Investment	Austria 2006	Czech Republic 2006	Denmark 2006	Greece 2006	Slovakia 2006
1. Computerized information	0.89	0.71	1.87	0.34	0.37
a) Software	0.85	0.71	1.85	0.33	0.37
b) Databases	0.04	0.01	0.03	0.01	0.00
2. Innovative property	3.14	2.8	3.06	0.62	1.76
a) R&D, including social sciences and humanities	1.74	1.03	1.68	0.18	0.21
b) Mineral exploration and evaluation	-	-	-	-	-
c) Copyright and license costs	0.10	0.04	0.16	0.02	0.04
d) Development costs in financial industry	0.63	0.55	0.54	0.16	0.37
e) New architectural and engineering designs	0.66	1.18	0.69	0.27	1.15
3. Economic competencies	2.42	2.93	2.93	0.63	2.39
a) Brand equity	0.25	1.37	0.63	0.15	1.04
Advertising expenditure	0.15	0.94	0.36	0.08	0.46
Market research	0.11	0.43	0.27	0.06	0.59
b) Firm-specific human capital	0.79	0.63	1.49	0.19	0.51
Continuing vocational training	0.46	0.63	1.07	0.17	0.51
Apprentice training	0.33	0.00	0.42	0.02	0.00
c) Organizational structure	1.38	0.93	0.81	0.29	0.83
Purchased	0.93	0.26	0.45	0.06	0.25
Own account	0.44	0.67	0.36	0.23	0.58
Total Investment	6.46	6.45	7.86	1.59	4.53
<i>pro memoria</i>					
Total Spending	6.67	7.24	8.19	1.70	4.98

Sources: See Annex 1

Notes: 60 percent of expenditure on advertisement, 80 percent of expenditure on own-account organizational structure and 100 percent of all the other expenditure are considered as investment (CHS 2005). GDP is conventionally measured (including software and mineral exploration but excluding other intangibles).

The results of Table 2 are portrayed graphically in Figure 1b along with the updated time series for the countries from previous studies (Figure 1a). Interestingly, while we generally find a slowdown or stabilization in the intensification of intangibles in the countries included in previous studies (notably in the US, but also in the UK, France and Germany), we find a continuation or even a slight pickup in the trends for Austria and Denmark, though less so in the other countries.

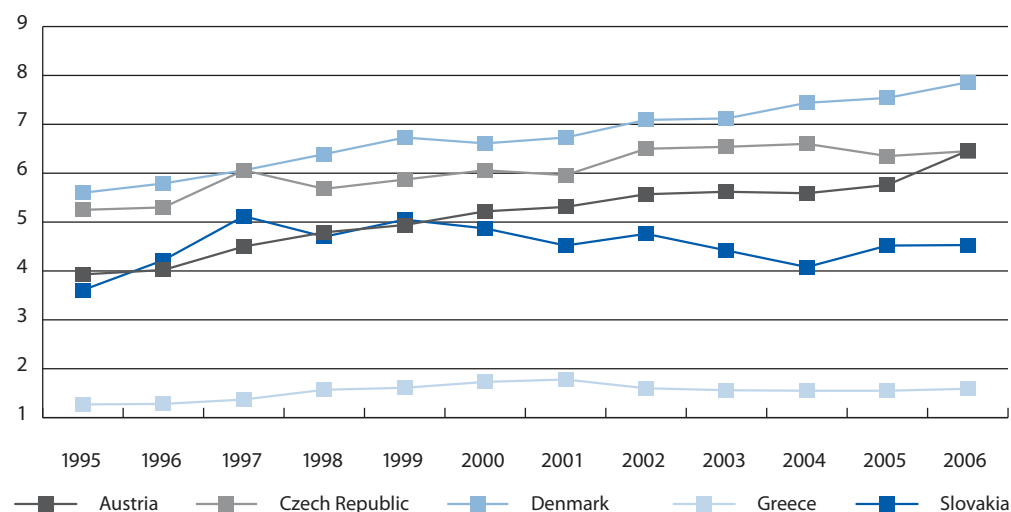
Figure 1a. Intangible investment in France, Germany, Italy, Spain, the UK and the US (percent of GDP)



Source: See Table 1

Note: GDP is conventionally measured (including software and mineral exploration but excluding other intangibles).

Figure 1b. Intangible investment in Austria, Czech Republic, Denmark, Greece, and Slovakia (percent of GDP)



Source: See Table 2 and Annex 1

Note: GDP is conventionally measured (including software and mineral exploration but excluding other intangibles).

Table 3 provides the time series dimension associated with Table 2. It shows that the shares of economic competencies in the Central European countries have in fact been relatively high for the whole period 1995-2006, which might also reflect the legacy of a less-technology intensive economy leading to lower shares of computerized information and innovation property.

Table 3. Composition of intangible investment (percent of total intangible investment)

year	Austria			Czech Republic			Denmark			Greece			Slovakia		
	Comp Info	Innov Prop	Econ Comp	Comp Info	Innov Prop	Econ Comp	Comp Info	Innov Prop	Econ Comp	Comp Info	Innov Prop	Econ Comp	Comp Info	Innov Prop	Econ Comp
1995	8	49	44	10	47	44	16	39	45	10	44	46	8	43	50
1996	8	46	46	10	45	45	18	38	44	15	40	45	9	48	42
1997	10	51	40	7	40	52	21	37	42	18	39	43	8	50	41
1998	12	49	38	9	43	48	22	38	40	20	40	40	9	44	48
1999	13	50	37	13	40	48	24	37	39	20	41	39	8	41	52
2000	14	49	36	14	40	47	22	39	38	24	38	37	8	40	53
2001	17	48	36	14	40	46	20	42	38	25	39	37	10	39	52
2002	16	51	33	14	40	46	23	41	36	19	40	41	8	40	53
2003	16	52	32	12	41	47	22	42	36	18	41	41	10	39	51
2004	15	52	32	13	41	47	25	39	36	19	41	40	9	41	50
2005	14	54	32	11	43	46	23	40	38	19	40	40	9	40	51
2006	14	49	37	11	43	45	24	39	37	22	39	39	8	39	53
Average	13	50	37	12	42	47	22	39	39	19	40	41	9	42	50

Sources: See Annex 1

Note: The average is the simple average of percentages from 1995 to 2006.

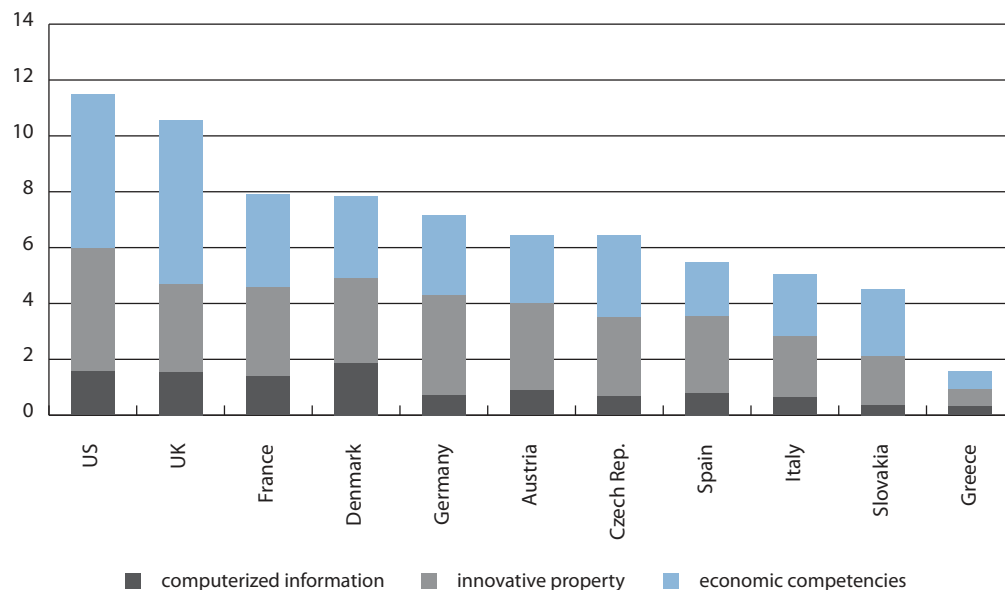
The bottom-line results of Tables 1 and 2 are shown graphically in Figure 2. The US and UK are the clear leaders by this metric, with intangible investment of the US almost double that of the median country in the comparison (Austria). There is also substantial variation in the composition of intangible assets. The differences in GDP shares are smallest for computerized equipment, where the US and Germany have a relatively high share (perhaps related to a relatively large contribution of high and medium-tech manufacturing industries). The UK shows a particularly strong result for economic competencies, which may be related to the large share of business services in the UK.

The US and the UK spend more on intangible than on tangible capital.

Perhaps the most striking result is shown in Figure 3, which compares the ratio of intangible investment (including software and other intangibles already included in the current national accounts) as percentage of GDP relative to tangible capital (excluding software and other intangibles already included in the current national accounts). Two countries, the United States and the United Kingdom, show a higher GDP intensity for intangibles than for tangibles. In the lower-income countries (Czech Republic, Spain, Italy, Slovakia and Greece) where intangible investment is still relatively low, the ratio of tangible capital to GDP is the highest.

Finally, it should be stressed that the capitalization of intangibles not only creates more capital input, but also leads to more output. After adjustment for intangibles, the size of GDP is larger by the intangibles investment rates, which range from 1.59 to 11.69 percent of GDP conventionally measured. The inclusion of intangible investment also increases the growth rate of GDP when intangible investment is expanding rapidly, and decreases it when intangible investment is slowing down. From 1995 to 2006 – a period during which intangible investment was expanding rapidly in most countries – GDP growth rates were about 0.1-0.2 percentage points higher due to the inclusion of intangibles for all countries in our sample.

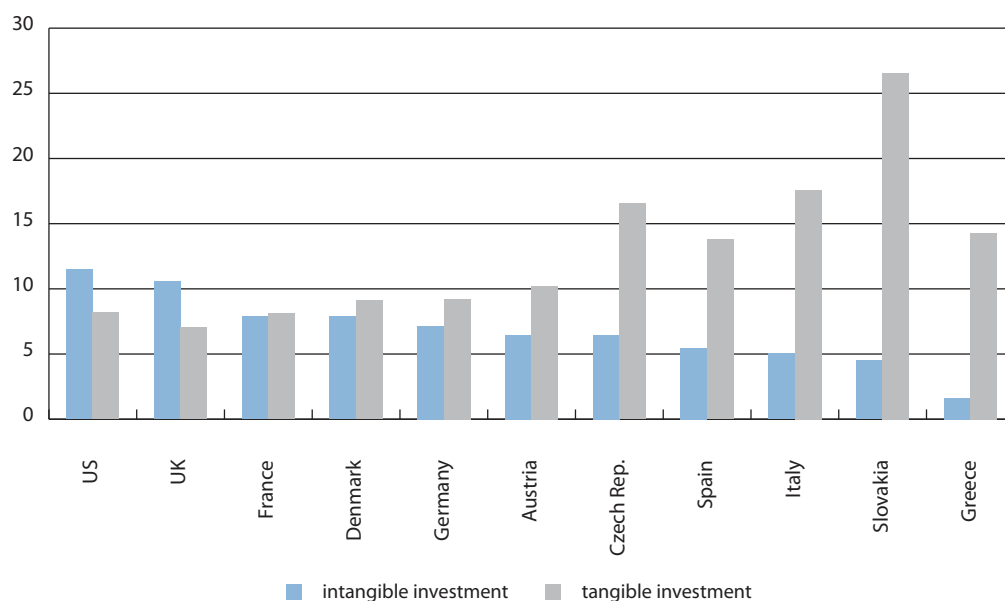
Figure 2. Intangible investment in the market sector (percent of GDP), 2006



Source: See Table 1

Note: GDP is conventionally measured (including software and mineral exploration but excluding other intangibles).

Figure 3: Intangible and tangible investment in the market sector (percent of GDP), 2006



Source: See Table 1

Note: GDP is conventionally measured (including software and mineral exploration but excluding other intangibles).

Before looking at the effects of intangible capital on growth, we stress that the investment measures in the tables and figures presented in this section are still relatively unrefined, and that there is much room for further improvements. Since this is a relatively new research field, statistical offices and other agencies often do not have comprehensive data on various intangible assets, and research is still scarce in most areas. For example, it is because of limited evidence that CHS (2005) assume that the financial industry spends 20 percent of their intermediate costs on developing new products and that managers

The estimates are partly based on assumptions, leaving room for future improvements.

spent 20 percent of their time improving organizational structure.¹⁰ At this point we have no corroborating evidence that those percentages would hold in other countries, and once more detailed sources become available for individual countries we may see adjustments to these measures. Our estimates also lack information on imports and exports of intangible assets. Jalava *et al.* (2007) use imports and exports of R&D to adjust the business expenditure on R&D for Finland in 2005. They estimate that Finland invested EUR 4,275 million in R&D in 2005, which was EUR 399 million more than their unadjusted estimation. The updated estimates for the United States included here use the R&D investment estimates developed by the US Bureau of Economic Analysis, which defines R&D investment as domestic R&D investment plus imports minus exports.

We use a wide range of data sources including national accounts and surveys from statistical offices and trade associations.

It is also important to note that some of the national studies summarized in Tables 1 and 2 use more details from nationally available sources than others. Another distinction is the intensity by which use is made of national accounts-related sources. For example, Marrano and Haskel (2006) and Van Rooijen *et al.* (2008) rely heavily on the data from national accounts for the UK and the Netherlands, respectively. In contrast, the US estimates rely more strongly on survey data from the Census Bureau (for services industries), the Bureau of Labour Statistics (for training), as well as on trends in managerial and professional employment.¹¹ In this comparative study we use the widest possible range of data sources including national accounts and other surveys from national or international statistical offices (*e.g.* Eurostat). But we also intensively use data from trade associations which are often more broadly available across countries and for which no equivalents can be directly obtained from national accounts.

Our results can also be compared with those from a preliminary study by Jona-Lasinio *et al.* (2009) which provides a comparison of intangible investment for all EU-27 member states. While that study applies similar principles as the current one (exhaustiveness, international comparability, *etc.*), it creates more or less “point-in-time” estimates that rely very heavily on national accounts sources, and aim (as much as possible) to create maximum consistency with current national accounts measures. Then, intangibles are expressed in *per-capita* terms (per worker or per employee) or as a percentage of a national accounts variable (*e.g.* as a share of output or as a share of labour costs), and subsequently “worked back” using their employment, output and cost shares. A tentative comparison suggests that this approach leads to overall somewhat lower measures of intangible investment by about 1.5 percentage points of GDP on average.¹²

4. Intangible assets contributed to labour productivity

Our results suggest that intangibles are an important component of output, and that their omission biases the GDP estimates that are important for the formulation of economic policy. In this section, we show that they are also an important source of economic growth. Using the investment estimates developed in the preceding sections, we now proceed to implement the modified Solow sources-of-growth model set out in Equation (2) of Section 2.

¹⁰ See Annex 1 for further details. Currently, with support from the National Science Foundation, The Conference Board is conducting research and designing a survey to determine the validity of these assumptions for the finance and insurance industry.

¹¹ At the time the US estimates were developed, the industry accounts were undergoing a shift in classification systems and sufficient and up-to-date information was not available.

¹² With thanks to Mary O'Mahony for sharing this comparison with us.

A number of steps are needed to transform the data on intangible investment into the capital stocks and capital service prices needed for Equation (2). First, we use a perpetual-inventory method to measure the stocks of intangible capital (a proxy for the flow of capital services). This step involves adding each year's investment in each type of intangible to the depreciated amount of the preceding year's capital stock. Unfortunately, relatively little is known about depreciation for intangibles, so we follow the assumptions by CHS (2005; 2009), which use an annual rate of 33 percent for computerized information, 15 percent for R&D, 60 percent for advertising and 40 percent for firm specific resources (see Table A.2 in Annex 2). In each case, we create initial capital stocks in the beginning year, which in our case is 1995, by cumulating investments over previous years.¹³ Given the relatively high depreciation rates, most of each investment is depreciated away within five years, so it is sufficient to extrapolate the investment series back to 1990.

A number of steps are needed to make the intangible investment series usable in growth accounting.

The next step is to calculate the user cost of each asset type, including intangibles. The user cost is made up of the rate of return, the depreciation rate and a capital gains term. For the rate of return we may assume the same rate for intangible capital as for tangible capital, assuming that businesses arbitrage their investments across all types of capital, investing in each type until the rate of return for all assets is equal (CHS 2009, p. 677). The income accruing to each type of capital in each year is then found by multiplying the quantity of stock by the corresponding user cost, and the cost shares can then be calculated.

Table 4 summarizes the contributions of intangibles to the growth rate of labour productivity growth in the market sector for the eleven countries included in this study. The updated US estimates show that the growth in intangible capital per unit of labour ("intangible capital deepening") contributed an average 0.8 percentage points to the annual growth of US labour productivity from 1995 to 2006.¹⁴ In the UK, intangible-asset deepening increased labour productivity by an average of 0.7 percentage points per year, from 1995 to 2006 (MHW 2009). In Germany, intangible assets contributed to labour productivity growth by 0.4 percentage points per year on average from 1995 to 2006, in France by 0.5 percentage points, in Italy and in Spain by 0.1 percentage points.

Table 4 also shows the estimates for the contribution of intangible assets to labour productivity growth in the market sectors of Austria, the Czech Republic, Denmark and Greece. In Denmark and the Czech Republic intangible assets contributed to 0.7 percentage points to labour productivity growth, compared to 0.6 percentage points in Austria and only 0.2 percentage points in Greece.¹⁵

13 The starting year is 1995 for most countries, but 1997 is the first year for the Czech Republic given available estimates on capital gains, and 2000 is the first year for which a stock of tangible capital could be produced for Slovakia.

14 Unlike the original CHS (2009) estimates and official MFP estimates for the United States, the estimates in Table 4 do not include contributions from land and inventory capital. We do this to strengthen the international comparisons made in this paper, as estimates of multi-factor productivity for most countries generally do not account for land and inventory capital.

15 For Slovakia, the growth accounts estimates start only in 2006, showing a contribution of about 0.2-0.3 percentage points to labour productivity growth

Table 4. Average annual change in labour productivity in the market sector and contribution of tangible and intangible capital deepening, labour quality and MFP growth, 1995-2006

	Germany 95-06	France 95-06	Italy 95-06	Spain 95-06	Austria 95-06	Denmark 95-06	Average 95-06	Czech Rep 97-06	Slovakia 00-06	Greece 95-06	UK 95-06	USA 95-06
Labour productivity growth	1.61	1.83	0.26	0.36	1.99	1.54	1.18	4.50	6.30	3.21	2.90	2.75
Contributions				<i>Excluding Intangible Capital (percent)</i>								
ICT cap. deep. (ex. software)	0.23	0.14	0.12	0.21	0.29	0.50	0.20	0.38	} 2.85	0.46	0.74	0.47
Non-ICT cap deep.	0.57	0.37	0.31	0.56	-0.03	0.28	0.39	1.76		1.52	0.36	0.30
Labour quality	-0.16	0.44	0.24	0.68	0.24	0.19	0.23	0.34	0.49	0.73	0.26	0.20
MFP	0.98	0.88	-0.41	-1.10	1.49	0.57	0.37	2.02	2.97	0.51	1.54	1.78
Labour productivity growth	1.79	2.00	0.29	0.47	2.36	2.11	1.32	4.60	6.17	3.27	3.06	2.96
Contributions				<i>Including Intangible Capital (percent)</i>								
ICT-capital deepening	0.20	0.12	0.11	0.19	0.26	0.44	0.17	0.35	} 2.72	0.45	0.63	0.40
Non-ICT-cap deepening	0.48	0.31	0.29	0.49	-0.02	0.24	0.34	1.62		1.48	0.28	0.28
Intangible-cap. deepening	0.38	0.48	0.12	0.12	0.55	0.72	0.30	0.68	0.21	0.24	0.69	0.83
Computerized information	0.07	0.15	0.03	0.05	0.13	0.29	0.08	0.06	0.04	0.06	0.16	0.18
Innovative property	0.23	0.18	0.05	0.15	0.29	0.27	0.16	0.35	0.07	0.11	0.17	0.35
Economic competency	0.07	0.15	0.04	-0.08	0.13	0.17	0.06	0.27	0.10	0.07	0.36	0.29
Labour quality	-0.15	0.40	0.22	0.64	0.22	0.17	0.21	0.31	0.46	0.71	0.22	0.18
MFP	0.88	0.69	-0.45	-0.96	1.35	0.53	0.29	1.64	2.78	0.40	1.23	1.33

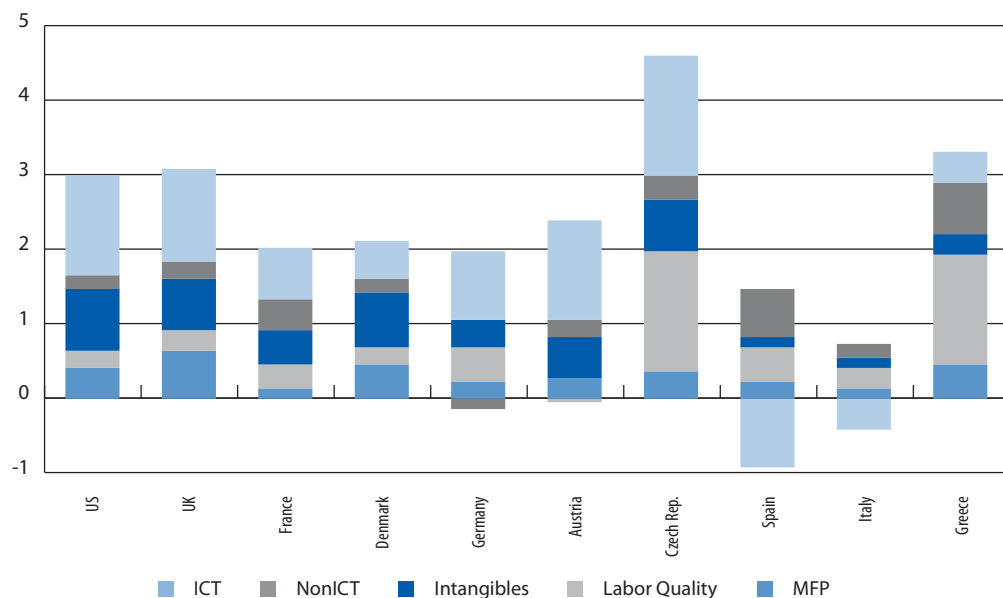
Sources: Employment, value added, and the stock of tangible capital for all countries from 1997 to 2005 from EUKLEMS, version March 2008 (www.euklems.net). EU KLEMS provides the deflators and depreciation rates of tangible assets and the depreciation rates of software and databases. CHS (2005) provides the deflators of all intangible assets and the depreciation rates of intangible assets excluding software and databases. For intangible investment in Austria, the Czech Republic, Denmark, Greece and Slovakia, see Annex 1; for Germany, France, Italy Spain, the UK and the US, see Table 1.

Notes: We follow the EUKLEMS definition of market sector by excluding the following industries: public administration, health, education and real estate. Measures of tangible capital exclude land and inventories.

Figures 4a and 4b reproduce the results from Table 4 graphically. In Figure 4a, we show that the average contribution of intangibles ranges from less than 10 percent of labour productivity growth in the case of Greece to 40 percent in Italy. However, overall labour productivity growth has been very low in Italy (as well as in Spain) due to a strong negative contribution from a decline in MFP. In Denmark, intangible-capital deepening accounts for 34 percent of labour productivity growth.

The contribution of intangibles to labour productivity growth ranges from about 10 to 40 percent.

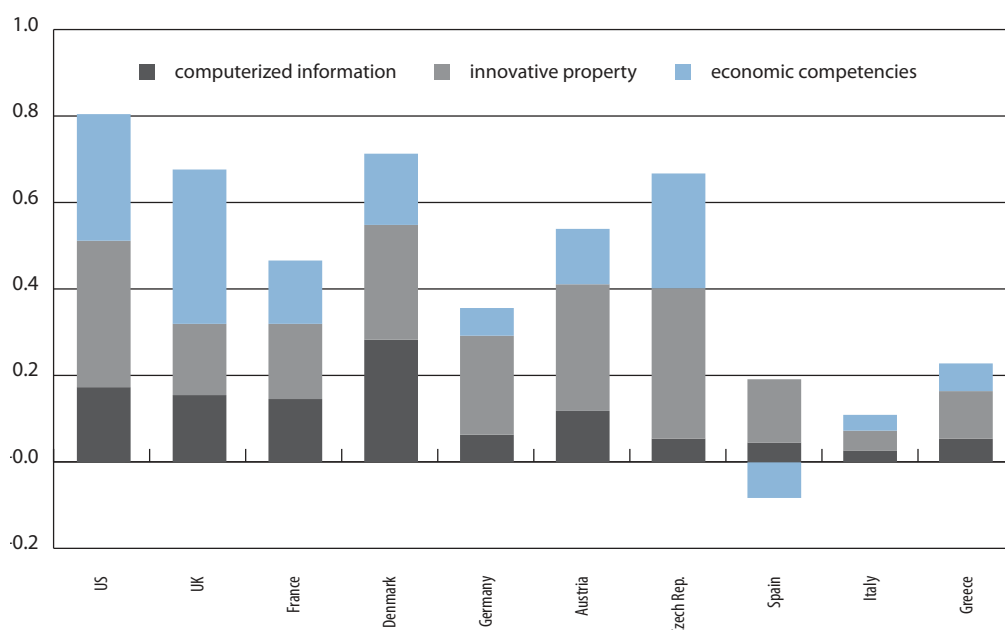
Figure 4a. Contribution of inputs to labour productivity growth, annual average (percent), 1995-2006



Source: See Table 4

Note: GDP is conventionally measured (including software and mineral exploration but excluding other intangibles).

Figure 4b. Contribution of sub-components of intangibles to labour productivity growth, annual average (percent), 1995-2006



Source: See Table 4

Note: GDP is conventionally measured (including software and mineral exploration but excluding other intangibles).

Figure 4a also shows that in most European countries the growth contributions from intangible capital deepening are smaller or at best close to the growth contribution of tangible capital (which includes ICT capital excluding software, and non-ICT capital which are mainly equipment and structures). Except for the United States, only one other European country (Denmark) is showing a much larger contribution from intangible capital deepening. Non-ICT capital tends to be dominated by traditional types of “brick and mortar” capital used in the manufacturing sector, suggesting the importance of structural differences in the economies in the comparison, although some of the brick-and-mortar capital may in fact be rather high in technology (e.g. advanced machine tools).

Figure 4b compares the absolute contributions of intangible capital to labour productivity as well as the breakdown into contributions from computerized information, innovative property and economic competency. The figure reveals that the largest differences in contributions are due to economic competencies. The countries are ranked in the same way as in Figure 2, that is, according to the share of intangible investment in GDP (“intangible intensity”) in 2006. The comparison suggests that there is no perfect relationship between intangible intensity (as in Figure 2) and the growth contribution from intangible capital deepening (as in Figure 4). In particular, Denmark (showing a relatively high contribution from computerized information) and the Czech Republic (showing a large impact from innovative property) are among the most important outliers.

All in all, one may distinguish between four groups of countries in terms of their intangibles contribution to output and productivity growth: (1) the US and the UK, which show rapid labour productivity growth and high contributions of intangibles; (2) France, Denmark, Germany and Austria, which still show significant contributions against the backdrop of smaller growth rates of labour productivity; (3) catching-up countries such as the Czech Republic and Greece (and also Slovakia) which show much larger contributions from non-ICT-capital deepening than from intangibles, and – in some cases – also larger MFP growth rates related to the restructuring of those economies; and (4) laggard economies, such as Italy and Spain, which show small absolute contributions of intangibles coupled with slow growth of labour productivity and even negative contributions from MFP growth.

5. Intangible investment and levels of economic development

Intangible investment is concentrated on the world's richest countries, arguably because...

A look at international data on R&D spending and brand equity, as well as the location of the largest non-financial non-resource companies, suggests a high concentration of intangible capital in the richest countries of the world. For example, today five countries – the US, Japan, Germany, France and the UK – account for 75 percent of R&D spending in the world in 2005 (OECD 2008). One reason for this concentration may be that high-income countries tend to have more of everything that is economically valuable, including this particular kind of capital. However, there are other reasons for intangibles to be concentrated in these countries.

First, less-developed countries may be less likely to invest in intangibles because of their industrial structure. To the extent that they specialize in sectors where low wages provide a competitive advantage, they may be able to make do with technology developed elsewhere. Technology transfer and diffusion is less costly for them than domestic development programmes in R&D, knowledge creation and other intangibles. However, this tends to change as their production moves up the supply chain to higher-value-added activities. For example, Howitt and Mayer-Foulkes (2002) distinguish three groups of countries, of which only the first small group develops leading-edge R&D which accounts for most of the R&D spending in combination with the highest growth rates

of output. The second group of countries primarily uses technology developed elsewhere, using a pool of skilled workers to absorb it. The third group is unable to develop their own technologies or even use other countries' technologies as they lack absorption capacity. Another factor is the larger share of service industries, which tend to rely more strongly on intangibles (van Ark *et al.* 2003).

A second reason for a concentration of intangibles and a strong intangible effect on growth is that lower-income countries may not be able to afford risky upfront investment in activities with an uncertain outcome, such as R&D or huge advertising expenses with uncertain results in the longer term. In a Schumpeterian competition environment (which has been identified earlier as relevant to the discussion on intangibles), there is often a "winner takes all" outcome (e.g. in packaged consumer software) or a few major rivals (e.g. in pharmaceuticals). In such an environment, small or under-resourced economies may lack the incentives to invest in intangible capital.

...they can afford risky upfront investment and have large high-skilled labour markets, deep stock markets and ample venture capital.

Third, innovations often require a mature and sizeable stock market and ample venture capital. Stock markets and venture capital are key financial sources of innovation. While traditional financial instruments, such as regular loans, often favour long-term tangible investment, using building and machines as collaterals, they tend not to finance risky R&D. In contrast, stock markets and venture capital are typically friendlier toward intangible investment. Investors in stock markets value R&D and other intangible investment. Hall (1999) shows that R&D and patents are strongly related to stock prices. Venture capital is seeking investment with high risk and high return.

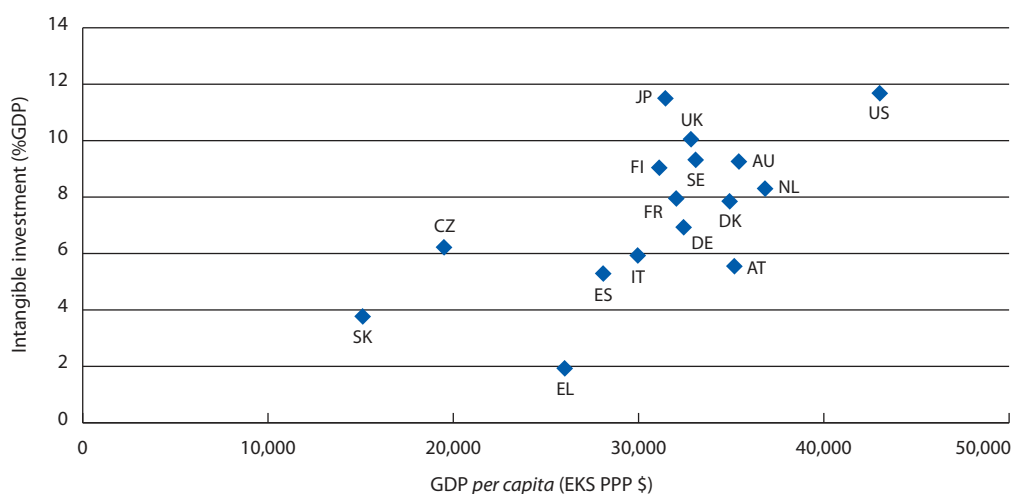
Finally, innovations driven by intangible investment might require a flexible labour market. Innovation projects are risky, and innovation programs are often discontinued because of a competitor's success or the programme's failure. In such cases, researchers may face layoffs, and require wage premiums or job guarantees in order to accept employment. These premiums and guarantees are less important when the market for researchers is relatively thick and flexible, giving an advantage to larger, richer, countries with bigger pools of highly-educated people and a tradition of job switching.¹⁶

Unfortunately, our sample is at this point not large or broad enough to fully address this issue. Despite important differences, the eleven countries we have dealt with so far are among the richest in the world. Nevertheless, we can have a look at our sample to see if there is evidence of a correlation between intangible investment and the level of income *per capita* and labour productivity. To do this, we combine our estimates for the eleven countries included in this study with the results on intangible investment analysis for five other countries, including Australia (Barnes and McClure 2009), Finland (Jalava *et al.* 2007), Japan (Fukao *et al.* 2007; 2009), the Netherlands (van Rooijen-Horsten *et al.* 2008), and Sweden (Edquist 2009). Figure 5a shows the relation between the relative levels of income *per capita* converted into purchasing power parities (PPP) and intangible investment as a percentage of GDP, for the period from 2001 to 2004. The figure shows a positive association between the two variables. As an additional control, Figure 5b shows the link between relative levels of income *per capita* (PPP-converted) and the ratio of intangible to tangible investment as a percentage of GDP, revealing a positive correlation, too. The latter confirms that the positive association appears to be limited to intangibles and does not apply to income and capital more broadly. However, the correlations are far from perfect, as the cases of Japan, Finland, and the UK show.

16 If a firm has to offer employees long-term employment contracts, it may be more likely to develop incremental technology than high technology. For example, it has been argued that the relatively rigid labour market in Germany has led to more success in traditional chemical industries rather than high-technology industries (Streeck 1992 and Katzenstein 1989).

Intangible-investment intensity is correlated with the level of economic development, whether measured by per-capita income...

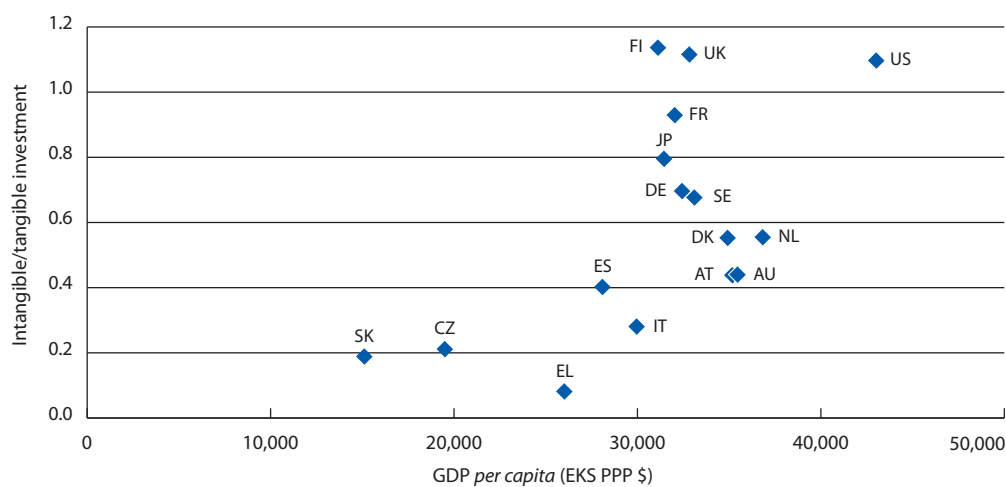
Figure 5a. Intangible investment and GDP per capita (2001-04)



Source: See Figure 5b

Notes: See Figure 5b.

Figure 5b. Intangible investment and GDP per capita (2001-04)

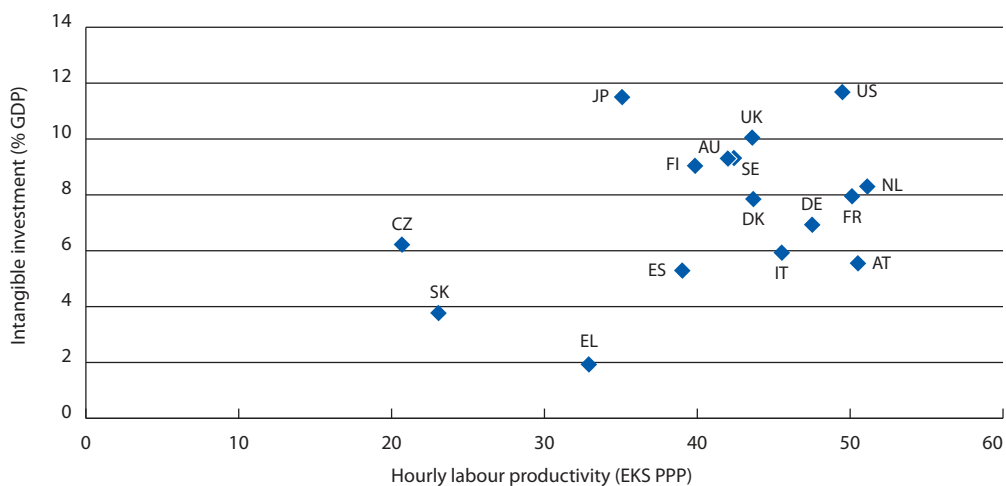


Source: GDP per capita is from the The Conference Board, Total Economy Database, version June 2009. For intangible investment, sources are Jalava *et al.* (2007) for Finland, Fukao *et al.* (2009) for Japan, Edquist (2009) for Sweden, Van Rooijen-Horsten *et al.* (2008) for the Netherlands and Barnes and McClure (2009) for Australia. For the other countries see Figures 1a and 1b.

Notes: The 16 countries are Australia (AU), Austria (AT), Czech Republic (CZ), Denmark (DK), Finland (FI), France (FR), Germany (DE), Greece (EL), Italy (IT), Japan (JP), the Netherlands (NL), Slovakia (SK), Spain (ES), Sweden (SE), the UK and the US. Intangible investment is the average investment from 2001 to 2004 for all countries, except the US (2000-2003), Finland (2000 and 2005) and Sweden (2004).

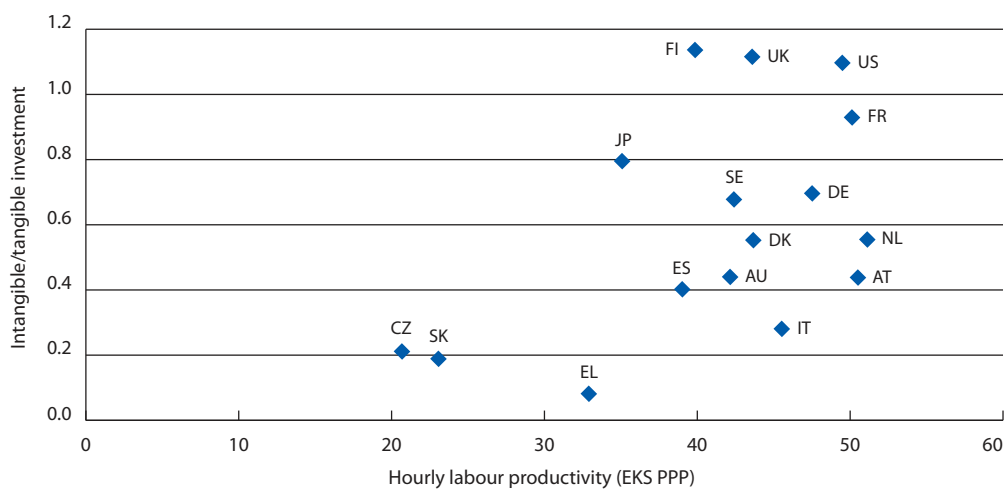
Figures 6a and 6b show that the correlation is weaker when the per-capita-income variable is replaced with the level of labour productivity. However, if the relationship between the ratio of intangible to tangible investment and a living-standards variable is fit with an exponential trend, the strength of the relationship does not vary substantially according to which measure of living standards is used.

Figure 6a. Intangible investment and labor productivity (2001-04)



Source: See Figure 5b
Notes: See Figure 5b.

Figure 6b. Intangible/tangible investment and labour productivity (2001-04)



Source: See Figure 5b
Notes: See Figure 5b.

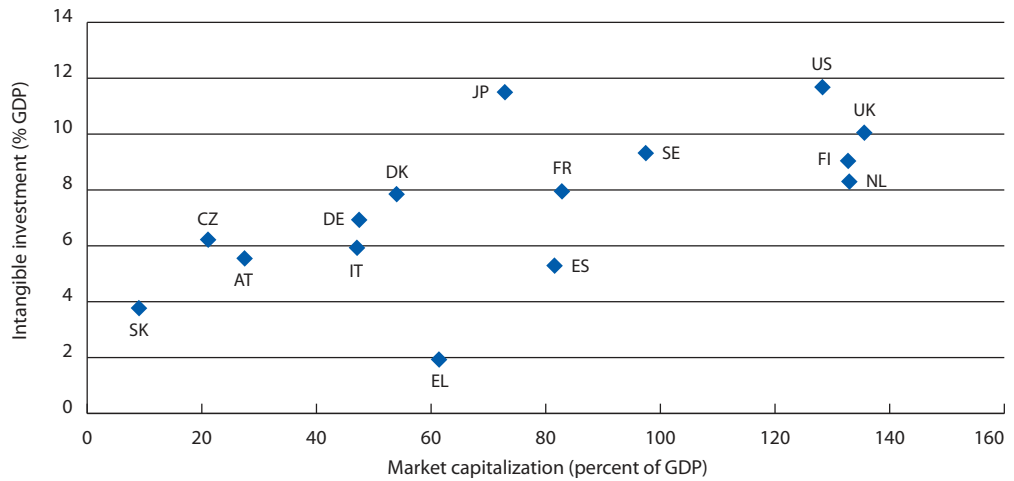
Figures 7a and 7b examine the link between stock market capitalization and venture capital, on the one hand, and investment in intangible assets on the other. Figure 7a shows that the size of stock markets as a percentage of GDP is strongly related to the level of intangible investment over the period 2001-2004. Figure 7b shows that venture capital (early stage and expansion and replacement stage) as a percentage of GDP is also strongly related to the level of intangible investment.

Finally, we have already noted that the non-rival nature of knowledge capital implies a theoretical link to MFP growth *via* the diffusion of knowledge. For example, in the case of R&D, US estimates suggest that between a fifth and a quarter of business sector MFP may be due to R&D spillovers.

Intangible investment is strongly related to the size of stock- and venture capital markets.

If this spillover result can be generalized, there should be a positive association between the importance of intangibles as a source of labour-productivity growth and the size of MFP growth. This positive association is evident in Figure 8. Even though additional research is needed to establish their importance, these results suggest that spillovers from intangibles may exist beyond the well-researched effects from R&D.

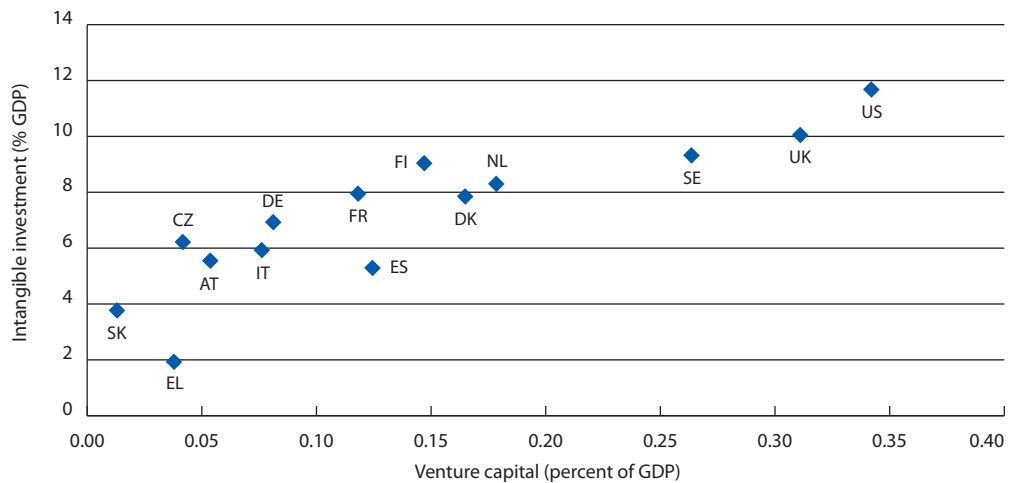
Figure 7a. Intangible investment and market capitalization (2001-04)



Source: See Figure 5b

Note: Market capitalization is the value of the stock market as a percentage of GDP. We use the average percentage from 2000 to 2006.

Figure 7b. Intangible investment and venture capital (2001-04)

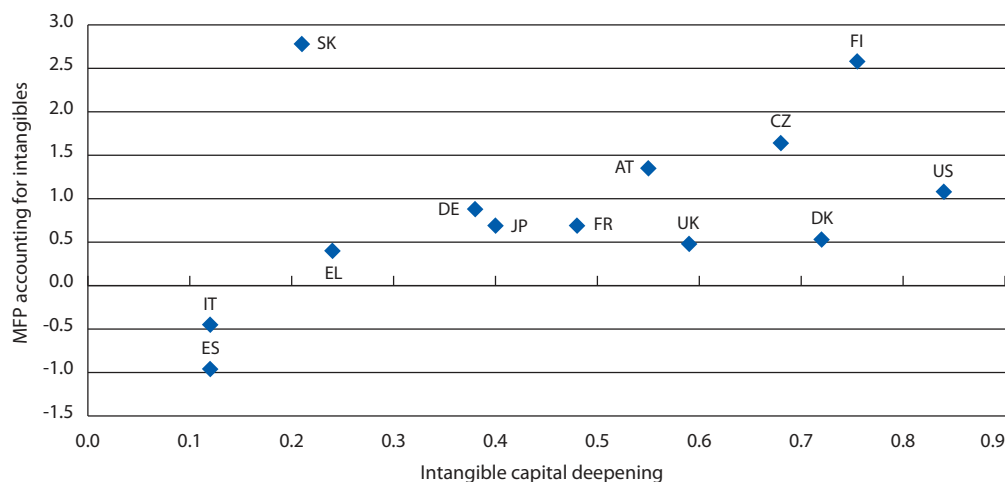


Source: See Figure 5b

Note: We include venture capital for the early stage, expansion and replacement, and average the values from 2000 to 2006.

While the link between intangibles and economic development may be blurred by conditional factors and endogeneity issues, there are theoretical reasons to believe that it exists and that it is important. Our sample is too small to pin down the size of the effect, but the various pieces of evidence we have presented suggest that the importance of intangible capital as a source of growth is large and it increases with the level of economic development.

Figure 8. Intangible capital and spillover effects



Source: See Figure 5b

Note: The 13 countries are Austria, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Japan, Slovakia, Spain, the UK and the US.

6. Conclusion

The current economic downturn has distracted attention away from long-term value-building investments in intangibles, which are the ultimate key to recharging our knowledge economy, to providing higher rewards to labour and capital and to raising productivity in a sustainable manner. Investments in intangibles are also the “foundation” on which short-term stimulation measures are anchored. Companies will not commit resources to significant near-term expansion unless it is consistent with their overall business model – a model that is supported by intangible capital.

In this article we have discussed the state of the art in the measurement of intangible capital and its contribution to economic growth, with a focus on international comparisons currently available. Our core group of eleven countries for which we have been able to build measures of intangible investment intensity and of intangible capital deepening shows that intangibles have a large impact on growth. To omit intangibles from the analysis of growth is therefore to present a biased picture of the growth process.

Intangible capital explains about a quarter of labour-productivity growth in the US and larger countries of the EU. However, the growth patterns of individual countries in the EU vary considerably. Notably the continental West-European countries show a distinction between countries with significant contributions from intangible capital deepening (although less than in the US and the UK, the lead countries) and a group of laggards (Italy and Spain) that show small absolute contributions of intangibles, slow growth of labour productivity and even negative contributions from MFP growth. Catching-up countries such as the Czech Republic, Greece and Slovakia show much larger contributions from non-ICT capital deepening than from intangibles, and – in some cases – also larger MFP growth rates related to the restructuring of those economies.

Our analysis suggests that higher rates of investment in intangibles (as a share of GDP) are often associated with higher growth rates of GDP *per capita*, which might be attributed to a higher propensity to invest in higher-income (and productivity) countries. Returns to scale in innovation and possibly

Intangible capital explains about a quarter of labour-productivity growth in the US and in the larger EU countries.

the tendency for smaller economies to compete in established market niches may also be other factors. Moreover, the non-rivalry in the use of knowledge capital may make across-the-board competition for the development of new technology non-optimal, since new technology in the follower countries can more often be obtained by technology transfer and diffusion.

Many in the business community assert that brand equity and human capital are at least as important as R&D.

This study has identified several areas for further refinement of intangible capital concepts and more precise measurement. The best evidence that there is a need to significantly broaden the concept of capital as a source of growth is made by many who are associated with the business community asserting that brand equity and human capital are at least as important as R&D to most businesses. From the narrow standpoint of economic self-interest, policy-makers in high-income countries should encourage investment in intangibles to protect their country's advantage in the globalized world.¹⁷ On the other hand, policy-makers in emerging economies may see the promotion of this form of investment as a way of laying the foundations of higher long-term growth and faster convergence to the technological frontier.

¹⁷ This objective is all the more important in this period of economic downturn, since intangible investments may have been hit harder than other components of GDP, and R&D and other non-production workers have experienced steeper employment losses. See for example, Michael Mandel in Business Week of November 9, 2009.

Annex 1. Sources and methods to measure intangibles in Austria, the Czech Republic, Denmark, Greece and Slovakia

This annex gives an overview of the sources and methods to obtain estimates of intangible capital for the five new European countries that have been added in this study.¹⁸ They largely follow the methodology laid out by Corrado, Hulten and Sichel (CHS 2005 and CHS 2009), which also represents the sources for the US figures used in this study. For the UK we rely on Marrano, Haskel and Wallis (MHW 2007; 2009) while for France, Germany, Italy and Spain, results are based on Hao *et al.* (2009).

1. Computerized information

The major component of computerized information is software. The data source for Austria, Czech Republic and Denmark from 1995 to 2005 is EU KLEMS which is an internationally comparative database on growth and productivity accounts currently housed at the University of Groningen (www.euklems.net). The capital account of EU KLEMS provides estimates of the investment and stocks of eight assets – (1) software, (2) computing equipment, (3) communications equipment, (4) transport equipment, (5) other machinery and equipment, (6) total non-resident investment, (7) residential structures, and (8) other assets. Since EU KLEMS does not provide software investment in 2006, we use national accounts to extend our estimates from 2005 to 2006. We use the estimates of software investment by industry in 2006 for Czech Republic, and use the growth rates from 2005 to 2006 of “intangible investment” provided by national accounts for Austria and Denmark. “Intangible assets” in national accounts include only a small fraction of intangible assets as defined in our research. For example, 90 percent of “Intangible assets” in Danish national accounts are software investment and 10 percent are exploratory drilling and copyrights¹⁹.

For Slovakia, no data source provides software investment, so we have to roughly estimate software investment. Our data source is IT Association Slovakia and EU KLEMS. IT Association Slovakia provides the domestic sales of software in Slovakia in 2000 and 2003. We average the ratio of domestic sales to the output of the software industry, assuming that domestic sales equal software investment, and use that ratio to estimate the software investment for the other years.

For Greece, the data source for the period from 1980 to 2004 is Timmer *et al.* (2003, updated to 2005). They calculate an average ratio of software to office and computer equipment for France, Italy and the UK, and multiply that ratio with investment in office and computer equipment in Greece. We estimate year 2005 using the growth rate of the gross output of industry “computer and related activities” (NACE 72, version 1), which is taken from EU KLEMS. We estimate year 2006 using the growth rate of the turnover of NACE 72 (National Statistical Service of Greece).

The other component of computerized information is databases. Database activities include the following four activities (The Encyclopedia for Classification Codes, 2007): (1) on-line database publishing, (2) on-line directory and mailing list publishing, (3) other on-line publishing, and (4) web search portals. We argue that companies increase their productivity by accessing data online, so we treat the revenues of Database Activities as companies’ investment in databases.

¹⁸ Further details are available from the authors upon request.

¹⁹ National Accounts, sources and methods, 2003. Available at <http://www.dst.dk/HomeUK/Guide/documentation/NatAcc/methods2003.aspx>

We approximate database investment with the output of the database industry (NACE 74 “other business activities”, according to NACE codes list). The data source is EU KLEMS for the years 1995 to 2004, and we update the data to 2005 and 2006 using national accounts. For Austria, the Structural Business Survey of Eurostat provides the output of NACE 724 (“database activities”) in 2006. We average the output of 2004 and 2006 to estimate the output in 2005. For the Czech Republic, we use a time trend to estimate database investment in 2005 and 2006. For Denmark, we assume that the output of NACE 724 grew at the same rate as the output of NACE 72 in 2005 and 2006. The national accounts of Denmark provide the output of NACE 72 from 2004 to 2006. For Greece, we estimate year 2005 using the growth rate of the gross output of NACE 72 (EU KLEMS). We estimate year 2006 using the growth rate of the turnover of NACE 72 (National Statistical Service of Greece). For Slovakia, we estimate database investment using the growth rate of intangible investment in 2005 and 2006 provided by the national accounts.

2. Innovative property

Innovative property includes both scientific and non-scientific innovation. The components of innovative property are (1) R&D in natural science and social science, (2) mineral explorations, (3) copyright and license costs, (4) development costs of new products in the financial industry, and (5) new architectural and engineering designs.

R&D. The data source is Eurostat. Eurostat provides R&D expenditure from 1981 to 2004, including both natural science and social sciences. The R&D data are, *inter alia* broken down by institutional sector: business enterprise sector, government sector, higher education sector, and private non-profit sector. To measure how much market sectors spend on R&D, we exclude expenditure by government and higher education sector.

Mineral explorations. We have no data for mineral exploration, but that is unlikely to impact our estimates. Existing literature shows that mineral exploration is less than 0.04 percent of GDP for countries with intangible estimates other than the US.

Copyright and license costs. We approximate copyright and license costs at three times the production cost of movies. The data source for year 2000 to 2005 is Screen Digest (2007).²⁰ Screen Digest provides production costs of movies for 59 countries from 2000 to 2005. For the year 2006, the turnover of motion picture, music and publishing from the Short-term Business Statistics provided by Eurostat is used to estimate production costs for Austria, Denmark and Slovakia while a time trend is used for the Czech Republic and Greece. A drawback of this estimation method is that some countries have a small movie industry, and we would underestimate copyright and license costs for those countries.

Development costs of new products in the financial industry. The data are intermediate costs in the financial industry provided by EU KLEMS from 1995 to 2005. We update the data to 2006. For Austria, Denmark and Slovakia, the information is taken directly from the national accounts. Since this is not possible for the other two countries, we assume the (unreported) growth rate of intermediate costs to equal the 2006 growth rate of output (Czech Republic) or that of value added (Greece) of the financial sector.

We assume that the financial industry invested 20 percent of the intermediate costs in developing new products.

²⁰ Available at www.screendigest.com

New architectural and engineering designs. For the years 1995-2004, the data source is the output of NACE 742 ('architectural, engineering and other technical activities') and is taken from EU KLEMS. We update output measures to 2006 using national accounts and Eurostat. For Austria, the data source is Structural Business Statistics 2006 provided by the national accounts (www.statistik.at). We use the average of 2004 and 2006 as an estimate of year 2005. For the Czech Republic, Denmark and Slovakia, we use the turnover index of architectural and engineering of 2005 and 2006 from the Short-term Business Survey provided by Eurostat. For Greece, we estimate year 2005 using the growth rate of the gross output of NACE 74 provided by EU KLEMS. We estimate year 2006 using the growth rate of the turnover of NACE 74 provided by the National Statistical Service of Greece.

We estimate investment as half of the gross output coming from NACE 742.

3. Economic competencies

Economic competencies include brand equity, firm-specific human capital and organizational capital.

Brand equity. Firms can increase their brand equity by advertising their brands or by researching the market. The data sources for advertisement are EU KLEMS, World Magazine Trends and national accounts. EU KLEMS provides the gross output of the advertising industry (NACE 744, "advertising") from 1970 to 2004. We update the output to year 2005 and 2006 using national accounts. For Austria, the data source is Structural Business Statistics 2006 provided by Eurostat.²¹ We use the average of 2004 and 2006 to estimate year 2005. For the Czech Republic, Denmark and Slovakia, we use the advertisement index in 2005 and 2006 from the Short-term Business Survey of Eurostat. For Greece, we estimate year 2005 using the growth rate of the gross output of NACE 74 provided by EU KLEMS. We estimate year 2006 using the growth rate of the turnover of NACE 74 provided by the National Statistical Service of Greece.

We assume that 60 percent of spending on advertisement is investment. Some of the advertising expenditure increases current sales but not sales after one year, so part of the advertising costs is current expenditure rather than investment. Classified advertisement is unlikely to form brands. We exclude half of newspaper advertisement. World Magazine Trends provide the percentages of advertisement on newspapers.²²

The data source of market research is the Structural Business Statistics of Eurostat. It provides the turnover of Market Research and Public Opinion Polling (NACE 7413).

Firm-specific human capital. We measure how much firms spend on firm-specific human capital, using spending on initial vocational training and continuing vocational training. Initial vocational training relates to apprentice training (AT), whereas continuing vocational training (CVT) includes training courses, training at work places, training through job rotation, self-learning and learning at conferences, lectures and workshops. Initial vocational training includes apprentice training and full-time schooling. Since firms do not pay for full-time schooling, we exclude it.

Our major data sources of AT and CVT are the Labour Cost Survey (LCS) 2004 provided by Eurostat, Continuing Vocational Training Survey (CVTS) 2005 provided by Eurostat, labour compensations provided by EU KLEMS before 2006 and national accounts in 2006.

²¹ Available at <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>

²² Available at <http://www.warc.com/LandingPages/Data/MagazineTrends/>

Organizational structure. There are two major ways to improve organizational structure. Managers spend time on making firms more efficient (own-account organizational capital), or firms purchase management consultancy services to solve problems of organizational structure.

The data sources of own-account organizational capital are EU KLEMS, national accounts, and the Structure of Earnings Survey (SES) 2002 from Eurostat. We assume that managers spend 20 percent of their time on improving organizational structures. Following CHS (2005), we assume that 4 percentage points of those efforts improve current organizational structure and 16 percentage points improve future organizational structure, so investment in own-account organizational capital is assumed to equal 16 percent of manager compensation.

The data source of management consultancy is the Annual Survey of the European Management Consultancy Market, provided by the European Federation of Management Consultancies Associations (FEACO). The survey covers five classes of management consultancy – operations management, information technology, corporate strategy services, human resources management and outsourcing services – for eleven private sectors and three public sectors. FEACO provides the market size of management consultancy from 1998 to 2006 for Austria, Czech Republic and Denmark, and from 1998 to 2004 for Greece and Slovakia. We update the data to 2005 and 2006. For Greece, we estimate year 2005 using the growth rate of the gross output of NACE 74 (EU KLEMS) and year 2006 using the growth rate of the turnover of NACE 74 (National Statistical Service of Greece). For Slovakia, we estimate year 2005 and 2006 using the turnover index of management consulting from the Short-term Business Survey provided by Eurostat.

Annex 2. Sources and methods to develop growth accounts including intangibles for Austria, the Czech Republic, Denmark, Greece and Slovakia

Value-added and labour input. EU KLEMS provides the real value-added (double-deflated, *i.e.* gross output deflated with output deflators and intermediate inputs deflated with input deflators) and labour input by industry from 2000 to 2005. National accounts provide value-added and labour input for 2006. EU KLEMS provide eight variables of labour input: (1) total hours worked, (2) hours worked of high-skilled labour, (3) hours worked of medium-skilled labour, (4) hours worked of low-skilled labour, (5) total labour compensation, (6) compensation of high-skilled labour, (7) compensation of medium-skilled labour, and (8) compensation of low-skilled labour.

Investment and stock of tangible assets. For Austria, the Czech Republic and Denmark, the data sources are EU KLEMS from 1995 to 2005 and national accounts in 2006. For Greece, the data sources are Timmer *et al.* (2003, updated to 2005) for 1995 to 2004 and national accounts for 2005 and 2006. For Slovakia, the source is national accounts from 2000 to 2006.

We measure two groups of tangible assets for Austria, the Czech Republic, Denmark and Greece. ICT tangible assets include computing equipment and communication equipment. Non-ICT tangible assets include non-residential buildings and other tangible assets. We exclude residential structures because they are not used in production. For Slovakia, we do not separate ICT assets from non-ICT assets because the national accounts of Slovakia provide no data on the division between them.

Investment and stock of intangible assets. EU KLEMS provides data on the investment and stock of software for Austria, the Czech Republic and Denmark. The investment in other intangibles is our own estimate. Furthermore, we estimate the stock of each intangible asset using the perpetual inventory method (PIM), a method to calculate capital stock from investment flows. The capital stock of the current period is the capital stock of the previous period minus depreciation and plus new investment.

Deflators and capital gains. EU KLEMS provides the deflator of tangible assets. We use the deflator of aggregate market-sector value-added as the deflator of intangible assets, following CHS (2005). Also following the method of CHS (2006), we use a three-year average of deflators to calculate the capital gains of each asset.

Depreciation rates. EU KLEMS provides the depreciation rates of tangible assets, software and databases. CHS (2005) provide the depreciation rates for other types of intangible assets. Table A1 below lists the values of depreciation rates.

Table A1. Depreciation rates for intangible capital estimates

Assets	Depreciation rates
<i>Intangible assets</i>	
Software	0.315
Databases	0.315
R&D	0.2
Mineral exploration and evaluation	0.2
Copyright and license costs	0.2
Development costs in the financial industry	0.2
New architectural and engineering designs	0.2
Advertising expenditure	0.6
Market research	0.6
Firm-specific human capital	0.4
Organizational structure	0.4
<i>Tangible assets</i>	
Computing equipment (IT)	0.315
Communications equipment (CT)	0.115
Transport equipment	0.182
Other machinery and equipment	0.119
Non-resident structures	0.032
Other assets	0.119

Source: EU KLEMS and CHS (2005)

References

- Barnes, P. and McClure, A. (2009). "Investments in Intangible Assets and Australia's Productivity Growth". Productivity Commission Staff Working Paper, Productivity Commission, Canberra, Australia.
- Bloom, N. and Van Reenen, J. (2007). "Measuring and Explaining Management Practices Across Firms and Nations". *Quarterly Journal of Economics*, (122:4), pp. 1351-1408.
- Bloom, N., Sadun, R., and Van Reenen, J. (2009). "The organization of firms across countries". NBER Working Paper No. 15129, National Bureau of Economic Research.
- Brooksbank, R., Kirby, D., Tompson, G. and Taylor, D. (2003). "Marketing as a determinant of long-run competitive success in medium-sized U.K. manufacturing firms". *Small Business Economics*, (20), pp. 259-272.
- Brown, S.P. (2008). "Business Processes and Business Functions: a new way of looking at employment". *Monthly Labor Review*, (131:12), pp. 51-70.
- Campbell-Kelly, M. (1995). "Development and Structure of the International Software Industry, 1950-1990". *Business and Economic History*, (24:2), pp. 73-109.
- Clayton, T., Franklin, M., Stam, P. and Haskel, J. (2009). "Interviews with Firms on Innovation Investment". Paper prepared for the conference, Advancing the Study of Innovation and Globalization, Nürnberg, Germany, May 29-30, 2009.
- Corrado, C. and Hulten, C. (2009). "How do you Measure "Technological Revolutions"?. Paper to be presented at the 2010 AEA meetings, Atlanta, Georgia, USA.
- Corrado, C., Hulten, C. and Sichel, D. (2005). "Measuring Capital and Technology: An Expanded Framework", in Corrado, *et al.* (eds.), *Measuring Capital in the New Economy*, National Bureau of Economic Research Studies in Income and Wealth volume 65, pp. 11-45. The University of Chicago Press, Chicago and London.
- Corrado, C., Hulten, C. and Sichel, D. (2009). "Intangible Capital and US Economic Growth". *The Review of Income and Wealth*, (55:3), pp. 661-685.
- Corrado, C. and Lane, J. (2009). "Using Cyber-enabled Transaction Data to Study Productivity and Innovation in Organizations". Paper for the conference, "Advancing the Study of Innovation and Globalization," Nürnberg, Germany, May 29-30, 2009.
- Diewert, W.E. (2008). "The Measurement of Nonmarket Sector Outputs and Inputs Using Cost Weights". Discussion Paper 08-03, Department of Economics, University of British Columbia, Vancouver, B.C., Canada.
- Edquist, H. (2009). "How Much does Sweden Invest in Intangible Assets?". IFN Working Paper No. 785.
- EU KLEMS (2008). *EU KLEMS Growth and Productivity Accounts*, March 2008 Release. Available at www.euklems.net.
- Fukao, K., Hamagata, S., Miyagawa, T. and Tonogi, K. (2007). "Intangible Investment in Japan: Measurement and Contribution to Economic Growth". Research Institute of Economy, Trade and Industry (RIETI) Discussion paper No. 07034.
- Fukao, K., Hamagata, S., Miyagawa, T. and Tonogi, K. (2009). "Intangible Investment in Japan: Measurement and Contribution to Economic Growth". *The Review of Income and Wealth*, (55:3), pp. 717-736.
- Hall, B.H. (1999). "Innovation and Market Value". NBER Working paper No. 6984. National Bureau of Economic Research.

- Hao, J.X., Manole, V. and van Ark, B. (2009). "Intangible Capital and Economic Growth – an International Comparison, August.
- Howitt, P. (1996). "On Some Problems in Measuring Knowledge-Based Growth", in Howitt, P. (ed.), *The Implications of Knowledge-Based Growth for Micro-Economic Policies*, University of Calgary Press, Canada.
- Howitt, P. and Mayer-Foulkes, D. (2005). "R&D, Implementation, and Stagnation: A Schumpeterian Theory of Convergence Clubs". *Journal of Money, Credit and Banking*, (37:1), pp. 147-177.
- Hulten, C. (2006). "The "Architecture" of Capital Accounting: Basic Design Principles", in Jorgenson, D.W., Landefeld, J.S. and Nordhaus, W.D. (eds.), *A New Architecture for the U.S. National Accounts*, The University of Chicago Press, Chicago and London, pp. 193-214.
- Hulten, C. (2009a). "Growth Accounting". NBER Working Paper No. 15341.
- Hulten, C. (2009b). "Decoding Microsoft: Intangible Capital as a Source of Company Growth". Paper presented at the National Bureau of Economic Research Summer Institute, July 15, (forthcoming as TCB working paper).
- Hulten, C. and Hao, J. (2008). "Intangible Capital and the 'Market to Book Value' Puzzle". NBER Working Paper No. 14548.
- Jalava, J., Aulin-Ahmavaara, P. and Alanen, A. (2007). "Intangible Capital in the Finnish Business Sector, 1975-2005". *ETLA discussion papers No. 1103*.
- Jona-Lasinio, C., Iommi, M. and Roth, F. (2009). "Intangible Capital and Innovations: Drivers of Growth and Location in the EU". INNODRIVE, Deliverable No. 15, WP9.
- Katzenstein, P. (1989). "Stability and Change in the Emerging Third Republic, in Katzenstein, P. (ed.), *Industry and Politics in West Germany*. Cornell University Press Ithaca, NY, USA.
- Lev, B. (2001). *Intangibles: Management, Measurement, and Reporting*, Brookings Institution Press, Washington D.C., USA.
- McDuffie, J.P. and Krafcik, J. (1992). "Integrating Technology and Human Employer-Centered Training / 477 Resources for High Performance Manufacturing: Evidence from the International Auto Industry", in Kochan, T.A. and Useem, M. (eds.), *Transforming Organizations*, Oxford University Press, New York, USA.
- Marrano, M.G. and Haskel, J. (2006). *How Much Does the UK invest in Intangible Assets?* Available at <http://www.econ.qmul.ac.uk/papers/doc/wp578.pdf>
- Marrano, M.G., Haskel, J. and Wallis, G.. (2007). "What Happened to the Knowledge Economy? ICT, Intangible Investment and Britain's Productivity Record Revisited." Working paper No. 603. Queen Mary University of London.
- Marrano, M.G., Haskel, J. and Wallis, G. (2009). "What happened to the knowledge economy? ICT, intangible investment and Britain's productivity record revisited". *The Review of Income and Wealth*, (553), pp. 686-716.
- Nakamura, L. (2001). "What is the US Gross Investment in Intangibles? (At least) One Trillion Dollars a Year!". Federal Reserve Bank of Philadelphia Working Paper No. 01-15.
- OECD (2008). *OECD Science, Technology and Industry Scoreboard*, Paris.
- Pakes, A. and Schankerman, M. (1984). "The Rate of Obsolescence of Patents, Research Gestation lags, and the Private Rate of Return to Research Resources" in Griliches, Z. (ed.), *R&D, Patents, and Productivity*. The University of Chicago Press, Chicago, USA, pp. 73-88.

- Schumpeter, J.A. (1934). *The Theory of Economic Development*, Harvard University Press, Cambridge. (New York: Oxford University Press, 1961.) First published in German, 1912.
- Streeck, W. (1992). "On the Institutional Preconditions of Diversified Quality Production", in Streeck, W. (ed.), *Social Institutions and Economic Performance*, Sage, London, UK.
- Solow, R.M. (1987). "We'd Better Watch Out", *New York Times Book Review*, July 12.
- Sturgeon, T. and Gereffi, G. (2009). "Measuring success in the global economy: international trade, industrial upgrading, and business function outsourcing in global value chains". *Transnational Corporations*, (18:2), pp. 1-36.
- Timmer, M.P., Ypma, G. and van Ark, B. (2003). "IT in the European Union: Driving Productivity Divergence?". Groningen Growth and Development Centre Research Memorandum GD-67, Groningen: University of Groningen, Appendix Tables, updated June 2005.
- van Ark, B. (2002). "Understanding Productivity and Income Differentials Among OECD Countries: A Survey", in Sharpe, A. et al.(eds.), *The Review of Economic Performance and Social Progress. Towards a Social Understanding of Productivity*, CSLS/IRPP, pp. 69-92.
- van Ark, B. and Hulten, C. (2007). "Innovation, Intangibles and Economic Growth: Towards a Comprehensive Accounting of the Knowledge Economy". *Yearbook on Productivity 2007*, Statistics Sweden, pp. 127-146.
- van Bakkum, S. (2009). "Do intangible investments create value? Comparing capitalization rates of listed firms". The Conference Board Economic Working Paper EPWP08-05. Available at <http://www.conference-board.org/economics/workingpapers.cfm>
- van Rooijen-Horsten, M., van den Bergen, D. and Tanriseven, M. (2008). *Intangible Capital in the Netherlands: A Benchmark*. Available at <http://www.cbs.nl/NR/rdonlyres/DE0167DE-BFB8-4EA1-A55C-FF0A5AFCBA32/0/200801x10pub.pdf>
- Wolter, S.C., Mühlemann, S. and Schweri, J. (2006). "Why Some Firms Train Apprentices and Many Others Do Not". *German Economic Review*, (7), pp. 249-264.

ABSTRACT

This paper reviews the empirical literature on rates of return on R&D and interprets the economic significance of these estimates using a semi-endogenous growth model with a calibrated knowledge production sector.

We analyse how R&D subsidies, a reduction of entry barriers for start-ups and increasing high-skilled labour would contribute towards raising productivity and knowledge investment in the EU. The simulation results show that substantial efforts will have to be made if Europe wants to come close to achieving the Lisbon productivity and knowledge-investment targets. Achieving US standards in all three areas would reduce the productivity gap by about 50 percent. Improving the quality of tertiary education and increasing competition in non-manufacturing sectors would also help the EU to get to the productivity frontier.

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R&D capital and economic growth: The empirical evidence

1. Introduction

It is now widely recognized in the economic literature that R&D and innovation are major drivers of economic growth. An economy's ability to develop novel technologies and to adapt to a rapidly changing technological environment is seen as essential to its prospects for improving standards of living and prosperity. This paper looks at the empirical evidence on the productivity and growth effects of R&D at the macro, industry and firm levels and discusses the policy implications of the main findings. There are of course numerous approaches for carrying out such an analysis such as calibrated Dynamic Stochastic General Equilibrium (DSGE) models, growth accounting and growth regressions. These latter approaches have generally been complementary, with improved input and output measurement narrowing down growth in total factor productivity (TFP), the unexplained part of GDP growth, and macro, industry and firm-level regressions explaining what drives TFP.

The paper is essentially split into three sections, with Section 2 giving a survey of the literature of regression-type macro, industry and firm level analyses of the link between R&D¹ and productivity growth, with a short summary on the evidence from growth-accounting studies². Section 3 discusses R&D-related policy insights based on simulations with the QUEST III DSGE model and the final section draws some conclusions and policy implications from the analyses presented.

2. R&D and productivity growth: A review of the literature³

The present section focuses on a review of the empirical literature. Most of the evidence presented assesses the strength of the relationship between private R&D and productivity growth, with Box 1 focusing on the efficiency and effectiveness of public sector spending on R&D. Whilst it is clear that direct and indirect public sector spending on R&D has a positive effect on private R&D spending and on the efficiency of private sector research personnel, there is nevertheless considerable evidence to support the view that it is mainly private-sector R&D which drives the positive association between R&D intensity and output growth in economies (see for example Guellec and van Pottelsberghe (2001) and Sveikauskas (2007⁴). This section is divided into four sub-sections. Sub-section 2.1 gives an overview of the different methods employed to assess the impact of R&D as well as looking at important measurement issues which render definitive statements regarding the strength of the relationship between R&D and growth difficult. Sub-section 2.2 reviews econometric estimates of the direct and indirect (*i.e.* spillover) impact of R&D. After a brief summary of growth accounting estimates of the contribution of R&D in Sub-section 2.3, the section closes with an overall assessment of the impact of R&D on growth.



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- 1 R&D is an admittedly narrow definition of intangible capital but, currently, little internationally comparable data is available with respect to other forms of knowledge capital.
- 2 For a growth-accounting perspective on productivity, with and without intangible capital, see Hao and van Ark (2009) in this issue.
- 3 This section of the paper draws in particular on a number of OECD Science, Technology and Industry Outlooks (OECD 2004, 2006, 2008); Australian Industry Commission (1995); Congressional Budget Office (2005); Fraumeni and Okubo (2005) and Sveikauskas (2007).
- 4 Sveikauskas (2007) states: "The overall rate of return to R&D is very large [...]. However, these returns apply only to privately financed R&D in industry. Returns to many forms of publicly financed R&D are near zero."

Box 1. Efficiency and effectiveness of public spending on R&D

Improving the efficiency and effectiveness of public spending represents an important tool for maintaining the fiscal discipline requested by the Stability and Growth Pact and promoting the structural reform agenda of Lisbon. Although the measurement of efficiency and effectiveness of public spending on R&D raises several methodological difficulties, progress has been made in developing the necessary measurement techniques applied to individual spending areas – *i.e.* public activities in R&D, education, health care, infrastructure – on a cross-country basis.

Empirical research in this area indicates that there is a significant potential for increased efficiency in public spending across EU member states (Afonso *et al.* 2005; Mandl *et al.* 2008). There is evidence of the effect from several economic and social indicators, such as the level of education, the strength of Intellectual Property Rights (IPR) systems, trade openness, and transparency in public policy, on the efficiency of public spending across countries (Afonso and St. Aubyn 2006; Jaumotte and Pain 2005a and b). Moreover, several studies underline the existing complementarity between public and private R&D funding (David *et al.* 2000).

A recent study by Cincera *et al.* (2009) uses Stochastic Frontier Analysis and Data Envelopment Analysis to assess the efficiency of public R&D expenditure in stimulating private R&D. Both methods compute an efficiency score of the relationship between inputs (such as public R&D subsidies to the business sector, expenditure on R&D by higher education institutions and R&D conducted in public research organisations) and outputs (as measured by either private R&D spending or R&D personnel in the business sector). The empirical analysis is based on macro-economic data for a panel of OECD countries. The choice of the estimation method seems to affect to some extent the outcome of the analysis. The paper provides some methodological guidance in assessing the choice of the best methodology in relation to the sample of available data.

The main results of the study can be summarised as follows.

1. Innovative inputs, namely public R&D subsidies and expenditures on R&D by higher education institutions, have a positive impact on outputs, *i.e.* on private R&D spending and on R&D personnel in the business sector.
2. The relationship between inputs and outputs provides a measure of the efficiency of public spending on R&D. On the one hand, efficiency is found to be positively affected by stability-oriented economic policies; by a legal structure which ensures security of property rights (including intellectual property rights); by an industrial structure oriented towards high-tech manufacturing sectors; by a more favourable tax regime for international trade; and by more deregulation in labour and product markets. On the other hand, efficiency is negatively influenced by high inflation rates and by the percentage of government expenditures compared with total consumption.
3. Japan, Switzerland and the US are ranked as the most efficient amongst 21 OECD countries. If the analysis is restricted to a shorter time period, these countries are joined on the efficiency frontier by some new member states (Cyprus, Estonia, Lithuania and Malta). This outcome is confirmed by the non-linear relationship between GDP *per capita* and efficiency scores. Indeed, countries having intermediate levels of GDP *per capita* are found to have lower efficiency scores. In turn, this outcome highlights the existence of a large amount of private R&D spending which is inelastic with respect to changes in the quantity of public R&D subsidies, especially in countries with low levels of public R&D.

2.1 Methods and measurement issues

There are a large variety of methods for estimating the contribution of R&D to productivity growth, with researchers using calibrated models, econometric analyses, growth accounting studies, and case studies or cost-benefit analyses.⁵ Since Section 3 will discuss calibrated DSGE model results and since case studies/cost-benefit analyses are generally biased towards an analysis of successful, rather than all, R&D projects, the present section focuses on the results from econometric analyses and growth accounting studies.

Econometric analyses can be used to estimate the direct and indirect (*i.e.* spillover) effects of R&D on productivity growth. Most of these analyses either estimate the effect of R&D spending on production costs (cost function studies) or on output/productivity (production function studies), with the latter in turn broken down into cross-sectional and time series studies. Whilst theoretically speaking, cost functions are broadly equivalent to production functions, they are much more complicated to estimate in practice and consequently production function studies are substantially more prevalent in the literature.

Growth-accounting studies (like calibrated models) use theory or empirical estimates from other studies to set the parameters of the production function, including an elasticity for R&D. Under the assumptions of competitive factor markets, full input utilisation and constant returns to scale, output growth is equal to the (income-share) weighted growth of inputs and TFP. In this way one can establish the proportion of output or productivity growth that is accounted for by the growth in labour, tangible capital, intangible capital (such as R&D) and TFP. However, calculating the share of total capital income which is attributable to intangible R&D investments is extremely difficult since R&D is generally not capitalised in the national accounts and consequently most researchers include R&D capital in the growth accounting framework by simply assuming a rate of return to R&D which has been taken from the empirical literature.

Given the intangible nature of knowledge investments such as R&D, all empirical studies of the impact of R&D on productivity are plagued by a number of fundamental measurement issues which need to be borne in mind when interpreting the empirical estimates.

Measuring the returns to R&D is the first issue. It is hampered by the fact that a great deal of R&D is devoted to quality improvements. National statistical agencies try to capture these improvements in quality by using hedonic price indices. Aside from the inherent difficulties in constructing such indices, additional problems can emerge when quality adjustments are applied to some but not all industries, with a significant risk in these circumstances of R&D gains being wrongly attributed to certain industries. Denis *et al.* (2005) highlight this issue by questioning the results from a series of studies which concluded that the TFP growth in a number of “intensive ICT-using” industries in the US, such as wholesale and

Econometric methods use either cost functions or production functions to assess the productivity effect of R&D investment.

⁵ Given the macro-modelling focus of the analysis in Section 3, we limit our review to those methods which could provide results pertinent to a model such as Quest III. Consequently, the list of the methods given in the text is clearly not exhaustive, with a number of other approaches providing useful insights into the links between technology and productivity. Notable omissions in the text include innovation surveys and research based on firm-level longitudinal databases. Innovation surveys have been extremely useful in demonstrating that R&D expenditures are only one element of a firm's overall expenditure on innovation, showing for example that non-R&D expenditure is the dominant form of innovation spending in many market-services industries. In addition, microeconomic studies using longitudinal databases have highlighted the enormous differences in the productivity performances of firms. These studies have also added to our knowledge of the drivers of productivity within firms (*e.g.* technical change, accumulation of human capital, and “softer” non-technical innovations complementary investments linked with the introduction of organisational / managerial best practices) and of the drivers of productivity growth amongst firms (*e.g.* competition and “neo-Schumpeterian” creative-destruction mechanisms).

retail trade, rather than the TFP gains in the ICT producing sector had been the key factor driving EU-US TFP growth differentials in the post-1995 period. The Denis *et al.* research suggests that due to the above-mentioned problems with industry level output deflators, a higher proportion of the post-1995 acceleration in US TFP should be attributed to the production of ICT rather than to the use of ICT.

***It is difficult to measure
R&D capital stocks,
returns to R&D and
spillovers.***

The second issue concerns the measurement of R&D inputs. A measure of the R&D capital stock is needed to compute the rate of return on R&D investment. Such investment may have similarities with physical-capital investment in that both are undertaken to secure (uncertain) future returns but R&D nevertheless differs from other investment in a number of important respects. Firstly, R&D investment creates intangible not tangible assets. Secondly, there is a greater degree of uncertainty regarding their rates of return. Thirdly, many of the activities which are classified as R&D have no market price. Finally, the economic depreciation/obsolescence rates to be applied to knowledge investment are inherently more complicated to calculate than for physical investment. All of the above factors underline the difficulties of providing an economy-wide measure of R&D capital. Furthermore, R&D capital forms only a subset of the overall knowledge capital stock in an economy, with the focus on R&D reflecting the fact that expenditure data are available for this part of the intangible capital stock. Despite the efforts of Corrado, Hulten and Sichel (2006), Haskel and Giorgio Marrano (2007), van Ark and Hulten (2007) and others, there is currently little “hard” data available with respect to other forms of knowledge capital.⁶ This will hopefully change in the near future due to the progress being made by many national statistical agencies with respect to innovation satellite accounts⁷ and also because many of the “spin-off” research projects linked to the EU KLEMS research programme are expected to produce more comprehensive, internationally comparable, knowledge capital datasets for researchers to exploit.

Measuring the indirect contribution of R&D to growth represents a third issue. Since technical knowledge (*i.e.* R&D capital) is non-rival in consumption and since it is partially non-excludable, R&D investment is likely to be subject to spillover effects, *i.e.* “unintended knowledge transfers” which are of benefit to more than the entity carrying out the R&D itself. R&D spillovers may therefore be one possible engine of endogenous growth, with R&D-based growth models stressing the existence of increasing returns to scale arising from the special property of knowledge to generate externalities.⁸ Whilst it is therefore broadly accepted that national and international R&D/knowledge spillovers could be one of the main driving forces of technical change, innovation and growth in an economy, estimating the effects of external knowledge on the productivity of firms is extremely difficult since, unlike many other types of externalities, knowledge spillovers are not directly observable. According to Mairesse and Mulkey (2008), “Economists can only strive to measure the effects of knowledge flow and stock variables on outcome variables like numbers of innovations or patents, and labour or total factor productivity. A related and difficult issue is to assess the spatial extent of knowledge spillovers. Other major problems are encountered in trying to understand and analyze the underlying channels of spillovers, the “mechanisms” by which they operate, and the conditions allowing firms to benefit from them.

6 See Hao and van Ark (2009, in this issue) for a more detailed account of the measurement of intangible capital more broadly defined.

7 According to Sveikauskas (2007), “Recent years have seen substantial progress towards including research and development (R&D) as a capital investment within the national income accounts (Canberra Group II – 2003). Economists at the US BEA have prepared initial versions of an R&D satellite account. Economists in Australia and in the Netherlands have also reported initial R&D stocks for their countries. One main motive for adding R&D is to broaden the accounts to include a further important source of economic growth”.

8 These R&D-based endogenous growth models assume that the accumulation of R&D (*i.e.* knowledge capital) does not face diminishing returns.

2.2 Econometric estimates of the direct and indirect (i.e. spillover) impact of private sector R&D

The direct impact of private-sector R&D (I): Elasticities

Most empirical studies of R&D's contribution to productivity growth use either time series or cross-sectional data to assess the impact of R&D at the firm, industry or economy-wide levels. Table 1 gives an overview of the type of results obtained for the elasticity of output with respect to R&D at the different levels of aggregation.

With respect to firm and industry level analyses, Table 1 shows that very different results are obtained depending on whether one uses cross-sectional or time-series data. On the basis of cross-sectional data, the elasticity of R&D tends to lie between 0.10 and 0.20, whereas time series data produce much smaller coefficients, roughly half those from cross sectional studies. In principle the results using time series or cross-sectional data should yield broadly comparable coefficients. However, these differences, in a statistical sense, reflect the fact that R&D capital stock data have much less variation in the time series dimension than in the cross-sectional dimension (i.e. the variation across units at a single point in time), with the relatively smooth year-to-year changes in R&D in the time series studies consequently not capable of explaining much of the variation in productivity growth over time. The true value of the coefficient probably lies somewhere in the middle, with cross-sectional studies over-estimating and time series studies under-estimating the effects.

Cross-sectional studies find a 10-percent increase in private R&D to boost output by 1 to 2 percent, time-series studies find only half that effect.

Table 1. Selected estimates of the elasticity of output with respect to private R&D

Study	R&D elasticity	Sample
Cross-sectional data: Selected estimates of the elasticity from studies using firm and industry data		
1. Schankerman (1981)	0.10-0.16	110 US firms (chemical and oil industries) – 1963 cross-section
2. Sveikauskas (1981)	0.22-0.25	144 US manufacturing industries (1959-1969)
3. Cunéo and Mairesse (1984)	0.20	182 French manufacturing firms (1972-1977)
<i>(Sub-sample 1)</i>	<i>(0.21)</i>	<i>(98 firms in scientific sectors)</i>
<i>(Sub-sample 2)</i>	<i>(0.11)</i>	<i>(84 firms in non-scientific sectors)</i>
4. Hall and Mairesse (1995)	0.05-0.25	197 French firms (1980-1987)
5. Wang and Tsai (2003)	0.19	136 Taiwanese manufacturing firms (1994-2000)
Time-series data: Selected estimates of the elasticity from studies using firm and industry data		
1. Griliches (1980a and b)	0.08	883 US firms (1957-1965)
2. Cunéo and Mairesse (1984)	0.05	182 French manufacturing firms (1972-1977)
<i>(Sub-sample 1)</i>	<i>(0.14)</i>	<i>(98 firms in scientific sectors)</i>
<i>(Sub-sample 2)</i>	<i>(0.03)</i>	<i>(84 firms in non-scientific sectors)</i>
3. Griliches and Mairesse (1984)	0.09	133 US firms (1966-1977)
4. Hall and Mairesse (1995)	0-0.07	197 French firms (1980-1987)
5. Verspagen (1995)	(-0.02)-0.17	14 industries in 11 OECD countries (1973-1988)
Time-series data: Selected estimates of the elasticity from studies using economy-wide data		
1. Nadiri (1980)	0.06-0.10	US (labour productivity) (1949-1978)
2. Patel and Soete (1988)	0.61	US (TFP) (1967-1985)
3. Lichtenberg (1992)	0.07	98 Countries (per capita output) (1960-1985)
4. Coe and Moghadam (1993)	0.17	France (output) (1971-1991)
5. Coe and Helpman (1995)	0.23	G7 countries (TFP) (1971-1990)
6. Coe and Helpman (1995)	0.08	Non-G7 OECD countries (TFP) (1971-1990)

Source: Australian Industry Commission (1995), Congressional Budget Office (2005) and Sveikauskas (2007)

Note: The results quoted in Bottazzi and Peri (2007) are qualitatively consistent with those of Coe and Helpman.

The direct impact of private-sector R&D (II): Rates of Return

Estimated private rates of return to R&D fall in a wide range, with a central tendency between 20 and 30 percent.

Rates of return to R&D are shown in Table 2. Although related to R&D output elasticities, they are not directly comparable. R&D rates of return provide a measure of the profitability of R&D investment and are calculated from standard TFP equations whereas R&D elasticities of output provide an estimate of the percentage increase in output resulting from a 1-percent increase in R&D inputs. As with the estimates of the R&D elasticity, Table 2 shows that the estimates for the rates of return to R&D investments vary widely. The table shows gross rates of return (*i.e.*, including depreciation which generally is higher for knowledge capital such as R&D compared with physical capital) of as low as 6 percent and as high as 56 percent, with the central tendency being between 20 and 30 percent.

Table 2. Private R&D's contribution to productivity growth: Selected econometric estimates of the rate of return to R&D

Study	Rate of Return to R&D (percent)	Sample
Mansfield (1980)	27	16 US firms (Chemical & Petroleum industries) (1960-1976)
Griliches and Mairesse(1983)	28	528 US & French firms (1973-1978)
Clark and Griliches (1984)	20	924 US manufacturing plants (1970-1980)
Odagiri and Iwata (1986)	20	135 Japanese firms (1966-1973)
Mansfield (1988)	42	17 Japanese industries (1960-1979)
Goto and Suzuki (1989)	22 - 56	40 Japanese manufacturing firms (1976-1984)
Griliches (1994)	12 - 46	142 US manufacturing industries (1958-1989)
Hall and Mairesse (1995)	6 - 34	197 French firms (1980-1987)
Jones and Williams (1998)	35	12 US manufacturing industries (1961-1989)

Source: Australian Industry Commission (1995), Congressional Budget Office (2005) and Sveikauskas (2007)

Some studies estimate rates of return from a cost function (as opposed to a production function). Concerning these studies, the Australian Industry Commission report on "Research and Development" (1995) suggests that rates of return to R&D are broadly comparable to the rates estimated using TFP equations. Examples of studies using the cost function approach include Bernstein (1989) and Bernstein and Nadiri (1988, 1991). Bernstein (1989) estimates that the mean rates of return to R&D at the industry level are much higher than those on physical capital, with R&D rates of return ranging from 24% to 47% compared with 9% to 12% for physical capital. This conclusion is also supported by the very similar results reported in Bernstein and Nadiri (1988, 1991). These cost function results suggest that not only are returns to R&D higher compared with those of physical capital but the R&D returns are subject to much greater variability. In addition, it is not clear from this segment of the literature whether R&D earns higher rates of return compared with physical capital investments after adjusting for the additional risks involved and once one allows for the negative relationship between the gross rate of return & the length of asset lives. Finally, a notable feature of the results from cost function studies is that R&D capital and physical capital tend to be complements rather than substitutes.

A striking – but common – result from the cost- and production-function studies alike is the large industry variation in rates of return to R&D. This is also a unifying theme in the more recent literature on the determinants of TFP across industries. For example, Griffith *et al.* (2004) study TFP determinants across industries in a panel of OECD countries and show that R&D has both a direct impact on TFP

growth and a role in facilitating the cross-country convergence of TFP levels. The result is interpreted as providing support for the two “faces” of R&D in promoting productivity growth: on the one hand, R&D enhances a firm’s innovative potential (thus increasing directly the rate of TFP growth) and on the other hand, it improves the absorptive capacity of firms and industries, thus facilitating the adoption of existing technologies and spurring TFP convergence.

One drawback with the Griffith *et al.* study is that the industry level analysis is limited to manufacturing industries and many studies show that TFP growth rates in Europe and the US have been diverging, in recent times, especially in private services. Hence, a better understanding of the TFP growth determinants in service industries is crucial in assessing the factors which are driving, amongst other things, the EU’s widening productivity gap with the US. With a view to addressing such questions, Inklaar *et al.* (2007) analyse the determinants of TFP growth in private services using the EU KLEMS database. Their analysis looks in particular at R&D intensive technologies such as ICT and shows that although ICT investments were a main driver of labour productivity growth in the service industries of both the EU and the US, the adoption of ICT-intensive technologies does not appear to be associated with higher growth rates of TFP.

Unlike Inklaar *et al.* (2007), Mc Morrow *et al.* (2009) do not limit the analysis to private services but look at both manufacturing and services. Additionally, they attempt to identify the determinants of TFP growth in those specific industry groupings that contributed most to the EU-US TFP growth gap, namely ICT-producing manufacturing (*i.e.* electrical and optical equipment), retail trade and business services, and for those industries where EU countries exhibited a stronger performance, *i.e.* public utilities. With respect to the role of R&D, this study finds that industries with higher R&D expenditures and higher adoption rates for ICT-intensive technologies appear to exhibit higher TFP growth rates, whilst human capital has mostly a significant effect across countries. Regarding industry-specific determinants, ICT producing industries appear to benefit from R&D in terms of stronger spillovers from TFP gains at the frontier; network utilities are strongly affected by improvements associated with reduced product market regulations; whilst the retail trade industry is significantly influenced by consumption dynamics which permit a better exploitation of scale economies.

Industries with higher R&D expenditure and faster adoption of ICT-intensive technologies exhibit stronger TFP growth.

The indirect impact of private-sector R&D: Social versus private returns

Estimating the magnitude of the spillovers associated with R&D spending is a complex task, with most researchers confident of their existence but less sure as to their significance at the macroeconomic level. In trying to find answers to the key question of the size of R&D spillovers, empirical studies have tended to use one of three basic approaches, two of which use the standard production-function approach and one which uses cost functions:

- “Rates-of-return” approach. If the estimated R&D capital return is higher than the physical capital return or if the R&D returns rise when the production function is estimated using higher levels of data aggregation (*e.g.* using industry level *versus* firm level datasets), then both of these cases provide *prima-facie* evidence of the existence of R&D spillover effects.
- Direct approach using specific “spillover variables”. A number of studies measure R&D spillovers by including variables which attempt to directly measure the spillover effects. This could be done, for example, in research using firm level datasets, by including proxy variables for the industry-/economy-wide stock of knowledge capital, by weighing the R&D stocks according to their technological proximity to the “lead” firm or industry, or by using patent citations to see how much knowledge is taken up by competitors and where this spillover takes place.
- Cost-function approach. This approach to the estimation of spillovers focuses on estimating the effects of the R&D stock from the “lead” firms or industries on the costs or production structures of the receiving firms or industries.

With respect to the empirical results from the above three approaches, the rates of return evidence presented earlier from both the production and cost function approaches appear to strongly support the presence of spillovers. This conclusion is supported by studies using the direct approach.

A useful summary of the overall work in this area is Fraumeni and Okubo (2005) whose broad results are given in Table 3. This table indicates, in keeping with Table 2 above, that gross private rates of return appear to average between 20 and 30 percent.⁹ Of more interest in the present discussion on spillovers are the social rates of return, which are an estimate of the private returns plus the spillover benefits. Table 3 shows that these social returns are substantially higher than the private returns, “ranging from an average lower bound of about 30 percent to an average upper bound of 80 percent”.

Social returns to R&D are substantially higher than private returns due to spillover benefits.

Sveikauskas (2007) summarises the evidence shown in Table 3 as follows: “On balance, private returns of 25 percent and social returns of about 65 percent, which more than double the private returns, seem reasonable. However, these extremely high returns are relevant only for privately financed research.” Taking into account other reviews of the literature, including Griliches (2000), Sveikauskas concludes that “spillovers contribute approximately three-fifths of the total return to R&D”.

Table 3. Estimated rates of return to private R&D

Author (Year)	Private return	Social return (private return + knowledge spillovers)
Sveikauskas (1981)	7-25	50
Bernstein-Nadiri (1988)	10-27	11-111
Bernstein-Nadiri (1991)	15-28	20-110
Nadiri (1993)	20-30	50
Mansfield <i>et al.</i> (1977)	25	56
Goto-Suzuki (1989)	26	80
Terleckyj (1974)	29	48-78
Scherer (1982; 1984)	29-43	64-147

Source: Fraumeni and Okubo (2005)

Note: Rates in Mansfield *et al.* (1977) are median rates.

In addition to the above literature which focuses primarily on domestic spillover effects, there is a considerable body of evidence to support the existence of international R&D spillovers. Empirical studies attempting to assess the importance of knowledge spillovers have identified the international transfer of technology as an important driver of growth (*e.g.* Griliches 1992; Geroski 1996; Mohnen 2001), with foreign innovative activity having a major impact on domestic productivity, especially for smaller, open countries (Eaton and Kortum 1997). A key issue in this literature is the identification of the channels through which knowledge is transferred internationally. Most extensively studied has been the role of international trade, in particular imports. For example, Coe and Helpman (1995) find that the level of a country’s TFP depends not only on its own R&D capital stock but also on the R&D of

⁹ Fraumeni and Okubo (2005) stress that “the private rates of return to R&D based on these studies are considerably higher than the average returns to other types of investments. It can be argued that R&D investments would require a higher rate of return than other investments because of the risk and uncertainty attached to R&D. There are more failures than successes associated with R&D investments – the rule of thumb often used is that for every successful project, ten projects fail. In addition, businesses investing in R&D must take into account the likelihood of imitation by competitors, and also the uncertainty in the timing of commercialization of the R&D project, especially for basic and applied research”.

its trading partners (with the effect being greater for smaller countries) and that foreign R&D has a stronger effect on domestic productivity, the more open an economy is to international trade. Recently, studies have begun to examine the role of foreign direct investment by multinational firms (Lichtenberg and van Pottelsberghe 2001; Branstetter 2000).

However, a considerable degree of caution is needed in drawing excessively optimistic conclusions about the extent of domestic and international spillover effects, given the wide range of measurement and statistical issues. Firstly, as highlighted earlier, there are important unresolved issues with respect to the measurement of quality improvements in R&D intensive industries using hedonic deflators. Are the well documented increases in TFP in a number of the intensive ICT-using industries in the US (e.g. wholesale and retail trade) true spillover effects or do they simply reflect problems in accurately assessing the magnitude of the TFP gains which have occurred in the ICT-producing sector (which is exceptionally R&D intensive)? Secondly, R&D spillovers are not entirely without costs for the receiving firms or for the economy as a whole. In order to take advantage of the knowledge transfer, firms often must make complementary investments in terms of personnel (i.e. additional scientists and engineers), laboratory facilities or organisational changes whereas countries must upgrade their education systems. Many existing studies exaggerate the cost-reducing benefits of spillovers since they do not take account of these additional firm and economy-wide implementation costs. Finally, any assessment of the benefit from R&D spillovers must take due account of lags, with the already long and variable delays for firms reaping private R&D returns (i.e. gains from their “own” R&D activities), suggesting that the time taken for social returns to manifest themselves in the form of transfers of new knowledge to other firms, industries or countries is likely to be even longer.

However, excessively optimistic conclusions from high social-return estimates would be misplaced.

Overall, there is considerable empirical evidence to support the view that domestic and international R&D spillovers exist and that they are of significance at the macro level. However, due to the measurement and statistical *caveats* highlighted earlier, it is not surprising to find that the size and significance of the estimates in the literature vary considerably. This high degree of variation justifies Griliches’ (1995) cautious conclusion: “R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates. [Nevertheless,] “in spite of a number of serious and promising attempts to do so, it has proven very difficult to estimate the indirect contribution of R&D via spillovers to other firms, industries and countries.”

2.3 Growth accounting estimates

As discussed earlier, growth accounting studies estimate the contribution of R&D to productivity growth by assuming a rate of return to R&D which is representative of the estimates provided in the empirical literature. Consequently, the results from such studies depend heavily on the assumption of the lead researcher as to whether the R&D spillover effects are large or not. Results depend not only on assumed rates of return to R&D but also on whether a narrow (i.e. private R&D) or broad (i.e. private and public R&D) measure of the R&D capital stock is employed. Generally the results from growth accounting studies suggest that the impact of R&D on productivity remains modest. However, using more optimistic assumptions for R&D rates of return, the contribution of R&D becomes, not surprisingly, larger. For example, the work of Griliches (1992) implies that R&D spending may have accounted for nearly three-quarter of all of the TFP growth in the US during the post-war period but Griliches admits that “most of the explanatory effect is coming from the spillover component, which is large, in part, because it is the source of increasing returns”.

2.4 Assessing the impact of R&D on economic growth

The effects of R&D on productivity have been analysed in many empirical studies. Comparing these studies is difficult because of the different levels of aggregation (country, industry or firm level),

variations in the definitions of productivity or R&D used (*i.e.*, TFP versus labour productivity; R&D expenditures versus patents etc.) and the various methodological approaches (econometric analysis of production functions versus cost functions; growth accounting studies). Furthermore these studies are plagued by many problems, such as the construction of the R&D capital stock, the use of price deflators for measuring output and quality improvements, and finally the difficulties in measuring R&D spillover effects.

Despite the various approaches and problems, the evidence clearly points to R&D being a major driver of productivity/TFP growth. Following the pioneering work of Griliches (1988), a large number of empirical studies at the country, firm and industry level have confirmed this positive impact of R&D activity on productivity growth. A good synopsis of the main strands of the literature is contained in the 2005 US Congressional Budget Office (CBO) report on “R&D and Productivity Growth” which stated that “a consensus has formed around the view that R&D spending has a significantly positive effect on productivity growth, with a rate of return that is about the same size (or perhaps slightly larger than) the rate of return on conventional investments”. The CBO report goes on to conclude that “if it was necessary to pick a single number to use in macroeconomic models, a reasonable strategy would be to choose a value that lay within the central tendency of the estimates from the empirical literature. Choosing a value in the middle of the range is consistent with the presumption that the rate of return to R&D is slightly higher than that on other types of corporate spending. [...] It also rules out estimates at the upper end of the range, which are unrealistic because they would be unlikely to persist for long periods of time. Thus an estimate of the rate of return between 0.20 and 0.30 would be reasonable, which would imply an output elasticity of R&D that would lie between roughly 0.02 and 0.05”.

3. R&D expenditure and GDP growth: Insights from macro-simulations

As markets may under-invest in R&D, public policy aims at stimulating R&D directly or indirectly.

The previous section has shown that R&D spending is widely regarded as a main driver of technical progress and yields returns which are above average when compared to tangible investments. Since the returns associated with knowledge investments tend to be higher and because such investments are often associated with both regional and intertemporal externalities, there exists the danger that market economies under-invest in R&D. This section addresses some policy issues related to fostering R&D.

The R&D policy debate focuses very often on direct measures to support R&D such as subsidies or tax credits for R&D spending. However, one can also think about wider measures to support the R&D activities of firms, such as increasing the pool of qualified R&D personnel, via increased human-capital formation or high-skilled immigration. One can also think of other measures such as lowering entry barriers for start-ups. These policies could aim at lowering administrative entry costs or alternatively removing the imperfections with respect to the venture capital financing of start-ups. In this section we provide a quantitative evaluation of alternative policy measures. For this analysis we make use of an endogenous growth extension of the Commission’s QUEST III model (see Ratto *et al.* 2009), which is a standard Dynamic DSGE model. The framework that we adopt is the Jones (1995, 2002) extension of the Romer (1990) endogenous growth model, which uses a variety approach for modelling knowledge investment.

The model has been calibrated for the EU (plus individual Member States) and the US, using information from various empirical studies in order to characterise both the production of goods and services as well as the production of knowledge. Concerning the parameters governing the macroeconomic aggregates and the labour market we use information provided by the QUEST III model. Table 4 provides

a summary of the crucial parameters for both the EU and the US. As shown in the Annex, and in keeping with the conclusions of the literature survey in Section 2, the knowledge production parameters imply a rate of return for R&D investment in the range of 30 percent.

Table 4. EU - US parameter comparison

	EU	US	Source
1. R&D sector			
R&D employment share (percent of total employment)	0.6	1.1	EUROSTAT / OECD
R&D intensity (percent of GDP)	1.840	2.670	EUROSTAT / OECD
Output elasticity of R&D workers (λ)	0.393	0.441	Calibration (constrained by equations)
International R&D spillovers (φ)	0.704	0.668	Bottazzi-Peri (2007) / Coe-Helpman (1995)
Domestic R&D spillovers (ω)	0.279	0.312	Bottazzi-Peri (2007) / Coe-Helpman (1995)
R&D efficiency (δ)	0.078	0.090	Calibration (constrained by equations)
2. Intermediate sector			
Mark-up (mup^x)	0.11	0.12	Own estimates
Fixed entry costs (f) (percent of GDP <i>per capita</i>)	38	2	Djankov <i>et al.</i> (2002)
3. Final goods sector			
Mark-up (mup^y)	0.242	0.205	Own estimates
4. Skill distribution			
Low-skilled share (s_L)	0.310	0.121	EUROSTAT / OECD
Medium-skilled share (s_M)	0.628	0.803	EUROSTAT / OECD
High-skilled share (s_H)	0.063	0.076	EUROSTAT / OECD
Elasticity of Substitution between skill groups σ	1.4	1.4	Katz and Murphy (1992)
5. Financial market			
Risk premium (venture capital market) (percentage points)	2.6	1.6	Calibration (constrained by equations)
6. Taxes and subsidies R&D			
B-Index	0.98	0.93	OECD / Warda (2006)

Taking the US as a benchmark, Table 4 highlights some of the deficiencies in the EU's innovation environment. As can be seen from the OECD's B-index (defined as one minus the average subsidy rate on R&D), the EU is providing lower tax incentives for private R&D than the US (see last line of Table 4). However, tax credits for R&D investment have become more popular as several EU member states, notably Belgium, Denmark, Germany and the Netherlands have switched from direct R&D funding towards tax incentives (see European Commission 2007). There are also larger structural impediments for higher innovation spending in the EU, such as larger administrative entry barriers for new firms and higher financing costs for start-ups (see items 2 and 5 in the table). Given the information provided in Table 4, the US outperforms the EU in terms of the costs for starting a new business as measured by Djankov *et al.* (2002) but also in terms of financing costs for start-ups as measured by risk premia in the venture capital market. Finally, when looking at the skill distribution, one can observe that the US has a higher share of high-skilled workers (scientists and engineers). Recently some efforts have been made in the EU to increase the share of high-skilled workers *via* the European Commission's 'blue card' proposal which aims at boosting high-skilled immigration into the EU.

Tax incentives to private R&D are lower in the EU than in the US but have recently been stepped up in some countries.

After a short presentation of the model, Sub-section 3.2 will evaluate the potential for increasing GDP by pursuing policies aimed firstly at increasing tax incentives for R&D, secondly lowering the entry barriers for start-ups, and finally by improving human capital. Since there could be short-run reform costs, we do not only show long run effects but provide the full dynamic solution for the relevant variables.

3.1 A growth model with knowledge production

The model we use in this paper is an extension of the QUEST III model with endogenous growth. The QUEST III model is a global DSGE model employed in the European Commission for quantitative policy analysis. This model belongs to the class of micro-founded DSGE models that are now widely used in economic policy institutions.¹⁰ The equations in these models are explicitly derived using intertemporal optimisation under technological, institutional and budgetary constraints and the model incorporates nominal, real and financial frictions in order to fit the data (Ratto *et al.*, 2009). The model employs the product variety framework proposed by Dixit and Stiglitz (1977) and applies the Jones (1995) semi-endogenous growth framework to explicitly model the underlying development of R&D. A more detailed description of this model can be found in Roeger *et al.* (2008). The semi-endogenous growth model differs from the endogenous growth model in the specification of the research technology. Endogenous growth models assume non decreasing returns of R&D inputs, while semi-endogenous growth models allow for decreasing returns of R&D inputs. Jones (1995) shows empirically that the semi-endogenous research technology hypothesis is more plausible. A formal exposition of the main features of the model is given in Box 2.

High-skilled labour and existing knowledge generate new knowledge ('patents') that producers buy to launch a new good.

To model knowledge investment as a decision of the private sector, the characteristics of the innovation process must be captured. What distinguishes an innovation – which can be traded in the form of a patent – from a standard good is essentially its sunk-cost nature, *i.e.*, a firm which buys a patent and starts production of a new good must recoup the initial expenditure *via* innovation rents over the product life-cycle. This defines an arbitrage condition between the present discounted value of profits of the patent holder and the initial R&D expenditure, which effectively determines the flow of new firms entering the market. In addition, the resource cost associated with the creation of new knowledge undertaken by the research sector is modelled *via* a knowledge production function where research output (in the form of new patents) in a competitive research sector is generated by current research inputs in the form of high-skilled labour, plus the knowledge capital accumulated in the past. As highlighted in the endogenous growth literature, there are two distortions in the innovation process, namely monopoly rents required to cover the cost of patents and the knowledge spillovers embedded in the knowledge capital stock, which will generally lead to a market outcome with too little R&D spending. Thus policy measures can be devised to improve upon the non-interventionist market solution.

The economy is populated by households, final-goods and intermediate-goods producing firms, a research industry as well as a monetary and a fiscal authority. In the final-goods sector, firms produce differentiated goods which are imperfect substitutes for goods produced abroad. Final-goods producers use a composite of intermediate goods and three types of labour (low-, medium- and high-skilled). Intermediate goods must be thought of as investment goods. Households buy the patents of the designs produced by the R&D sector and license them to the intermediate-goods producing firms. The intermediate sector is composed of monopolistically competitive firms which produce intermediate products from rented capital inputs using the designs licensed from the household sector. The production of new designs takes place in research labs, employing high-skilled labour and making use of the existing stock of ideas. Technological change is modelled as increasing product variety in the tradition of Dixit-Stiglitz (1977)

¹⁰ See, for example, the International Monetary Fund's Global Economy Model (Bayoumi *et al.* 2004) and the European Central Bank's New Area-Wide Model (Coenen *et al.* 2008).

Box 2. Overview of the model

Investors / households

There are three types of assets traded in this economy, namely riskless bonds (B_t), physical capital (K_t) and intangible assets (A_t) in the form of patents. Financial assets yield a real rate of return (r_t). The rental rate of return for physical and intangible capital is given by, (r_t^K) and (r_t^A), respectively. Optimal household portfolio diversification implies the following two arbitrage conditions:

$$(B.1) \quad r_t^K = (r_t + \delta^K - (\pi_{t+1}^I - \pi_{t+1}^Y)) + rp_t^K$$

$$(B.2) \quad r_t^A = (1 - \tau^A)(r_t - (\pi_{t+1}^A - \pi_{t+1}^Y)) + rp_t^A$$

The return on physical capital exceeds the rate of return on financial assets because of depreciation (δ^K) and a risk premium associated with the possible default of the borrowing firm (rp_t^K). The return on physical capital can be lower to the extent that investors expect a capital gain, *i.e.* an expected rate of inflation for investment goods exceeding the rate of inflation of final goods ($\pi_{t+1}^I - \pi_{t+1}^Y > 0$). Similarly, the return on intangible capital is equal to the rate of return on financial assets, adjusted for the rate of R&D tax credits (τ^A) and a risk premium rp_t^A associated with technological or economic obsolescence. Holding a patent until the next period could yield a capital gain for the investor if the expected price increase of the patent exceeds final-goods inflation: $\pi_{t+1}^A - \pi_{t+1}^Y > 0$.

Final-output producers

There are n ($j=1, \dots, n$) monopolistically competitive final goods producers. They produce products (Y_t^j) which are imperfect substitutes and charge a mark-up which is inversely related to the elasticity of substitution ($mup^Y=1/\sigma^Y$). In symmetric equilibrium, final output is produced using A varieties of intermediate inputs (x) and labour L_t :

$$(B.3) \quad Y_t = A_t^\gamma K_t^{1-\alpha} L_{Y,t}^\alpha, \text{ where } K_t = A_t x_t$$

where K_t , the physical capital stock, is made up of A varieties of intermediate inputs. This production function is a generalisation of the conventional production function where K_t is implicitly defined as the sum of all different types of capital ($K_t = \sum_{i=1}^A x_{it} = A_t x_t$), or in other words, where all capital goods are perfect substitutes. The expanding product variety model as adopted here assumes that the introduction of new goods ($\Delta A_t > 0$) increases the efficiency of production. The degree to which efficiency rises is inversely related to the elasticity of substitution between capital goods. The inverse of the elasticity of substitution is denoted by γ . Thus the less substitutable the variants of intermediate inputs (the larger γ), the greater difference an additional input variant makes for output. For example, consider computer and communication networks: combining the two imperfectly substitutable or even complementary inputs in production has the potential of yielding extra benefits. An example of close substitutes in production would be trucks and trains. Combining the two in production is likely to yield lower efficiency gains. Notice, A is external to final-goods producers, who only demand labour and intermediate inputs according to the following standard marginal revenue conditions:

$$(B.4) \quad W_t^Y = (1 - mup_t^Y) \alpha \frac{Y_t}{L_{Y,t}}$$

$$(B.5) \quad P_t^x = p_{i,t}^x = (1 - mup_t^Y)(1 - \alpha) \frac{Y_t}{K_t}, i = 1, \dots, A$$

Because of symmetry in factor demand across varieties and identical technology across intermediate producers all intermediate goods prices are identical and are proportional to the aggregate output-to-capital ratio.

Intermediate-goods producers

The intermediate sector consists of monopolistically competitive firms which have entered the market by licensing a design from households and by making an initial payment F to overcome administrative entry barriers. Physical capital inputs are rented at rate r_t^K . Firms which have acquired a design can transform each unit of capital into a single unit of an intermediate input. The demand for intermediate inputs of final goods producers is given by Equation (B.5) above. Each intermediate firm solves the following profit-maximisation problem:

$$(B.6) \quad \Omega_{i,t}^x = \max_{x_{i,t}} \{ p_{i,t}^x x_{i,t} - r_t^K k_{i,t} - r_t^A P_t^A - F \}$$

Intermediate-goods producers set prices as a mark-up over marginal cost. The mark-up is inversely related to the elasticity of substitution of intermediate goods in the production of final goods ($mup^x = 1/\sigma^x$). Therefore prices for the domestic market are given by:

$$(B.7) \quad P_t^x = p_{i,t}^x = (1 + mup^x) r_t^K$$

Free entry requires that entry into the intermediate-goods producing sector takes place until the interest payments from taking up a loan to finance the patent and the administrative entry fee is equal to profits from current production and the expected capital gain from holding the patent:

$$(B.8a) \quad ((1 - \tau_t^A) P_t^A + F) (r_t + r P_t^A) = \Omega_t^x + \Delta P_{t+1}^A$$

or equivalently, the present discounted value of profits is equated to the fixed entry costs plus the net value of patents:

$$(B.8b) \quad P_t^A (1 - \tau^A) + F = \sum_{\tau=0}^{\infty} \prod_{j=0}^{\tau} \left(\frac{1}{1 + r_{t+j} + r P_{t+j}^A} \right) \Omega_{t+\tau}^x$$

The solution for profits is given by:

$$(B.9) \quad \Omega_t^x = mup^x (1 - mup^y) (1 - \alpha) \frac{Y_t}{A_t}$$

Profits in the intermediate-goods sector are a positive function of the mark-up prevailing in that sector (mup^x). Because of a declining marginal product of intermediates in final goods production, the marginal value product declines with new intermediate goods producers (A). Also, market imperfections in the production of final goods lower demand for intermediates and therefore reduce profits.

R&D sector

Innovation corresponds to the discovery of a new variety of intermediate input (ΔA_t) which enhances the efficiency of producing final goods. The R&D sector hires high-skilled labour ($L_{A,t}$) and generates new designs according to the following knowledge production function:

$$(B.10) \quad \Delta A_t = v A_{t-1}^\varphi L_{A,t}^\lambda$$

The Parameter γ measures the spillover effects from the existing stock of knowledge (A_{t-1}). Parameter v can be interpreted as the total factor efficiency of R&D production, while λ measures the elasticity of R&D production with respect to the number of researchers (L_A). We assume that the R&D sector is perfectly competitive and sets prices for new designs that are proportional to unit labour costs and inversely related to λ :

$$(B.11) \quad P_t^A = \frac{1}{\lambda} \frac{W_t^H L_{A,t}}{\Delta A_t}$$

The term W_t^H refers to the wages of high-skilled workers. It is assumed that only high-skilled workers can be employed in both the production and the research sector.

3.2 R&D policy scenarios

In this section we apply the model for an analysis of various policy measures which have the potential to increase R&D spending and which play a prominent role in the policy debate. The measures we analyse are tax credits for R&D investment, a reduction of entry barriers for high tech start-ups and an increase in the supply of high-skilled workers.

Measure I: Raising R&D through tax credits

The fiscal measure which we analyse first is a permanent increase in the EU's rate of tax credit (τ^A) by 5 percentage points, which would approximately increase the rate of R&D tax subsidies to US levels (see Table 4). Subsidies are financed through lump-sum taxes. Table 5 presents the effects on production, R&D intensity, TFP, R&D, employment, total employment and other variables.¹¹

Raising R&D tax incentives to US levels would increase R&D spending by about 0.1 percent of GDP.

Table 5. Effects on the EU economy of a 5 percentage point R&D tax-credit
Percentage difference from baseline

	Years									
	1	2	3	4	5	10	20	50	100	
GDP	-0.01	-0.04	-0.05	-0.06	-0.05	0.00	0.08	0.23	0.31	
TFP	0.00	-0.02	-0.02	-0.01	0.00	0.05	0.13	0.24	0.27	
"Ideas/Patents"	0.06	0.22	0.44	0.67	0.90	1.97	3.50	5.46	6.04	
Capital	0.00	0.00	-0.01	-0.01	-0.02	-0.04	-0.03	0.09	0.21	
Capital intensity	0.01	0.02	0.05	0.07	0.10	0.22	0.38	0.59	0.66	
Employment	0.03	0.04	0.03	0.03	0.03	0.02	0.01	0.00	0.00	
-(Low-skilled workers)	(0.02)	(0.04)	(0.05)	(0.06)	(0.07)	(0.08)	(0.07)	(0.05)	(0.04)	
-(Medium-skilled workers)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(-0.01)	(-0.01)	(-0.02)	
-(High-skilled workers)	(-0.37)	(-0.89)	(-1.21)	(-1.37)	(-1.43)	(-1.38)	(-1.20)	(-0.98)	(-0.92)	
-(R&D workers)	(2.59)	(4.85)	(5.78)	(6.14)	(6.26)	(5.95)	(5.17)	(4.20)	(3.91)	
Investment	-0.01	-0.03	-0.04	-0.05	-0.05	-0.05	-0.01	0.12	0.21	
Wages	0.04	0.09	0.10	0.11	0.11	0.14	0.21	0.33	0.40	
-(Low-skilled workers)	(-0.02)	(-0.03)	(-0.04)	(-0.05)	(-0.05)	(-0.01)	(0.07)	(0.22)	(0.29)	
-(Medium-skilled workers)	(-0.01)	(-0.01)	(-0.01)	(-0.01)	(0.00)	(0.04)	(0.12)	(0.26)	(0.33)	
-(High-skilled workers)	(0.37)	(0.81)	(1.00)	(1.07)	(1.08)	(1.04)	(0.98)	(0.96)	(0.98)	
R&D intensity (% of GDP)	0.10	0.12	0.13	0.14	0.14	0.13	0.11	0.09	0.08	

The simulations show a characteristic feature of semi-endogenous growth models: subsidies for R&D yield a permanent increase in GDP levels but not in the growth rate of GDP. Higher tax credits lower the rental rate for intangibles, thus reducing the fixed costs of firms producing intermediates. This raises entry and increases the demand for blueprints. The output of the research sector increases, and reallocates high-skilled workers from production into research. The size of the effect is however rather limited. The results show a 0.08-percent increase in GDP relative to the baseline 20 years after the initial shock and a 0.3-percent increase in the long run. The number of employees in the R&D sector increases by around 4 percent and R&D intensity rises by 0.08 percentage points in the long-run.

¹¹ Note that in the tables TFP refers to a constructed measure of technological progress defined as $Y/(L^\alpha K^{1-\alpha})$.

It takes time for the output effects to emerge because in the short run there are output losses due to the reallocation of high-skilled workers from production to research. Because of supply constraints for high-skilled workers, part of the fiscal stimulus is crowded out by wage increases for high-skilled workers (see Goolsbee 1998 for empirical evidence). These results suggest that differences in fiscal incentives explain less than 5 percent of the productivity differential and less than 10 percent of the knowledge investment gap (as measured by the R&D share) between the EU and the US.

How can these results be reconciled with estimated return measures for R&D? As shown in the Annex, our knowledge production coefficients suggest a rate of return of 0.3. The R&D subsidy suggests a permanent increase in the R&D share of around 0.1 percent of GDP. According to the rate-of-return estimate, this should lead to an increase in the annual growth rate of TFP of 0.03 percent on average. After 100 years this should lead to an increase in TFP of about 3 percent. However, the long run (100 year) TFP gain is only about 0.3 percent. Two factors explain this discrepancy. First, there is a crowding-out effect in the form of higher wages in the R&D sector which absorbs about 25 percent of the additional R&D spending; and second, there is the declining marginal efficiency of R&D workers in the knowledge production function.

Measure II: Reducing entry barriers for start-ups

Lower barriers to market entry and higher supply of risk capital would foster R&D, innovation and long-term growth.

Transforming new ideas into marketable products and services is probably one of the most central mechanisms generating growth in modern industrial economies. Consequently, administrative entry barriers and financial frictions can be important obstacles to growth and innovation. When it comes to innovation, there are numerous examples which indicate that a larger share of innovations is undertaken by young firms in the US compared to the EU. Venture capital has become a popular form of financing young firms in high-tech sectors. With underdeveloped venture capital markets, investors lack opportunities to diversify risk and therefore they require a larger risk premium¹². Philippon and Véron (2008) suggest a number of measures to increase the supply of venture capital financing. Amongst others, they argue for more competition in the banking sector, changes in insolvency legislation and the removal of prudential regulations, which hamper equity investment by institutional investors such as pension funds and insurance companies.

Also, administrative costs for starting a new company are much larger in the EU compared to the US (see Table 4). However, one has to be careful when making direct comparisons. One important argument for a downward bias in the US level of entry regulation is the high standard of consumer protection legislation in the US. In the case of non-compliance, firms operating in the US face costly litigation procedures and high fines. Entry regulation in Europe can be seen as forcing firms to comply with certain health and safety standards. But given the wide variation in start-up costs in the EU, it seems feasible to lower administrative entry costs towards levels prevailing in best-practice countries.

As both financial and administrative entry barriers are sunk costs for start-up companies in our model and have similar transmission mechanisms, we look at both barriers together. We conduct the following experiment: we simultaneously reduce financial and administrative entry barriers, closing about half the gap relative to the US by a reduction of risk premia for start-ups of 50 basis points and a reduction in administrative costs for new entrants of 18 percent of GDP *per capita*. Table 6 summarises the short- and long-run effects of the experiment.

¹² Alternatively, the risk premium can be interpreted as the shadow price of the collateral constraint for the firm investing in intangible capital.

Table 6. Effects on the EU economy of halving the EU-US gap in entry barriers

Percentage difference from baseline

	Years									
	1	2	3	4	5	10	20	50	100	
GDP	-0.01	-0.10	-0.16	-0.16	-0.11	-0.01	0.18	0.54	0.71	
TFP	0.00	-0.02	-0.02	-0.01	0.00	0.10	0.33	0.59	0.62	
“Ideas/Patents”	0.11	0.53	1.04	1.57	2.10	4.63	8.25	12.94	14.44	
Capital	0.00	0.00	-0.01	-0.01	-0.02	-0.08	-0.08	0.20	0.46	
Capital intensity	0.01	0.08	0.10	0.18	0.25	0.52	0.89	1.41	1.58	
Employment	0.08	0.08	0.08	0.08	0.08	0.02	0.00	-0.01	-0.01	
-(Low-skilled workers)	(0.01)	(0.02)	(0.03)	(0.03)	(0.04)	(0.03)	(-0.04)	(-0.06)	(-0.06)	
-(Medium-skilled workers)	(0.01)	(0.01)	(0.02)	(0.07)	(0.07)	(0.01)	(0.00)	(-0.01)	(-0.01)	
-(High-skilled workers)	(-0.88)	(-2.09)	(-2.82)	(-3.23)	(-3.34)	(-3.24)	(-2.82)	(-2.36)	(-2.20)	
-(R&D workers)	(6.05)	(11.37)	(13.55)	(14.38)	(14.70)	(14.01)	(12.28)	(10.08)	(9.40)	
Investment	-0.01	-0.02	-0.09	-0.09	-0.10	-0.10	-0.01	0.26	0.52	
Wages	0.09	0.19	0.25	0.26	0.27	0.35	0.52	0.80	0.96	
-(Low-skilled workers)	-0.01	-0.02	-0.03	-0.03	-0.02	0.08	0.30	0.60	0.78	
-(Medium-skilled workers)	-0.01	-0.01	-0.02	-0.01	-0.01	0.09	0.26	0.61	0.79	
-(High-skilled workers)	0.87	1.86	2.31	2.47	2.48	2.40	2.30	2.29	2.36	
R&D intensity (% of GDP)	0.24	0.27	0.33	0.34	0.34	0.28	0.26	0.20	0.19	

Reducing entry barriers stimulates the entry of new firms and increases the demand for patents. This raises the price of patents and reallocates high-skilled workers from production to research. Initially this reallocation reduces final-goods production and physical-capital formation. However, over time the positive output effects dominate by increasing the level of TFP. This also increases the marginal product of physical capital and stimulates investment in the long run. Reducing start-up costs relative to the US by about 50 percent could reduce the productivity gap by roughly 10 percent in the long run. It would also stimulate the economy’s R&D intensity by more than the direct R&D subsidy discussed under Measure I.

Measure III: Improving human capital

The share of high-skilled labour in the EU is 1.4 percentage points lower compared to the US (6.2 percent versus 7.6 percent). Table 7 shows the effects of gradually increasing the EU’s high-skilled labour share by 1 percentage point over 40 years. The simulation assumes that this increase comes about *via* high-skilled immigration. The large fraction of the additional high-skilled labour will be employed in the production of final goods (replacing the less efficient medium-skilled workers). However, after five years there is an increase in employment in the R&D sector because of a decline in the wages of high-skilled workers. This reduces the price of patents and stimulates entry in the intermediate goods sector. In the first five years, the anticipated decline in the price of patents exceeds the reduction in high-skilled wages and hence, R&D production and R&D employment slightly decline. Output is gradually built up, with a positive impact of 0.26 percent after 20 years and around 1.40 percent in the long run. Notice that the employment share of R&D workers increases over time but the nominal R&D share does not because the increasing supply of R&D personnel and other high-skilled workers results in a slight reduction in their wages.

Investment in human capital and high-skilled immigration would also raise innovation and growth in the long run.

Table 7. Effects on the EU economy of a 1 percentage point increase in the share of high-skilled workers

Percentage difference from baseline

	Years after the shock									
	1	2	3	4	5	10	20	50	100	
GDP	0.01	0.03	0.04	0.05	0.06	0.11	0.26	0.93	1.40	
TFP	0.01	0.02	0.03	0.04	0.05	0.11	0.27	0.85	1.08	
“Ideas/Patents”	-0.01	-0.04	-0.07	-0.08	-0.09	0.14	1.57	10.10	14.76	
Capital	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.01	0.31	0.89	
Capital intensity	0.00	0.00	-0.01	-0.01	-0.01	0.02	0.17	1.08	1.55	
Employment	0.00	0.00	0.00	0.01	0.01	0.03	0.07	0.12	0.10	
-(Low-skilled workers)	(0.00)	(0.00)	(0.00)	(-0.01)	(-0.01)	(-0.01)	(-0.02)	(-0.07)	(-0.08)	
-(Medium-skilled workers)	(-0.02)	(-0.06)	(-0.10)	(-0.14)	(-0.18)	(-0.37)	(-0.75)	(-1.54)	(-1.55)	
-(High-skilled workers)	(0.34)	(0.86)	(1.34)	(1.76)	(2.16)	(4.07)	(7.95)	(16.10)	(16.61)	
-(R&D workers)	(-0.51)	(-0.78)	(-0.64)	(-0.34)	(0.03)	(2.05)	(5.74)	(12.08)	(9.81)	
Investment	-0.01	-0.01	-0.02	-0.02	-0.02	-0.03	0.00	0.41	0.93	
Real wages	-0.01	-0.01	-0.01	-0.01	0.00	0.04	0.15	0.72	1.12	
-(Low-skilled workers)	(0.00)	(0.01)	(0.02)	(0.02)	(0.03)	(0.06)	(0.17)	(0.77)	(1.21)	
-(Medium-skilled workers)	(0.02)	(0.06)	(0.09)	(0.12)	(0.15)	(0.32)	(0.70)	(1.84)	(2.29)	
-(High-skilled workers)	(-0.26)	(-0.66)	(-0.98)	(-1.26)	(-1.52)	(-2.77)	(-5.18)	(-9.46)	(-9.37)	
R&D intensity (% of GDP)	-0.03	-0.03	-0.03	-0.03	-0.03	-0.02	0.00	0.01	-0.03	

4. Conclusions and policy implications

In this paper we have reviewed the empirical literature on the effects of R&D on technical progress. We have then used a semi-endogenous growth model, with a calibrated knowledge production sector, to analyse the macroeconomic impact of various measures to increase private R&D activity. The model allows one to look at concrete policy measures and trace their impact on the main macroeconomic aggregates over time.

The simulations show that the policy measures under debate would reduce the EU-US gap in innovation and productivity.

The starting point of our analysis has been the stylized fact of a significant under-investment in knowledge capital in the EU. The current policy debate focuses on various measures to increase knowledge investment and innovation in the EU. They range from direct measures such as tax incentives for R&D spending, to indirect measures such as lower administrative entry barriers and better access to credit for start-up companies, as well as policies to increase the supply of R&D personnel. As shown in Section 3, these recommendations are consistent with the predictions made by standard semi-endogenous growth models. Our simulations also show the dynamic response of the economy to research policy measures, *i.e.*, possible short-run crowding out effects and long-run effects from a declining marginal efficiency of knowledge investment.

The simulation results show that substantial efforts will have to be made if Europe wants to come close to achieving the Lisbon productivity and knowledge investment targets. Catching up with the US would require an increase in productivity by about 10 percent and an increase in the R&D share in GDP from 2 to 3 percent.

An important insight from our analysis is that focusing exclusively on the – reportedly high – rate of return on R&D would overstate the productivity and growth effects of direct policy measures such as an R&D subsidy. According to our simulations, which take into account crowding-out effects and decreasing returns to knowledge production, the contribution of R&D subsidies both towards reaching the 3-percent Lisbon target and closing the productivity gap are modest. Hence, the long run gains from direct policy measures, such as R&D subsidies, are likely to be overstated if one only focuses on standard rate-of-return measures, abstracting from crowding out and decreasing returns.

Reducing entry barriers and financial constraints for start-ups is another avenue one could take. As indicated by our simulations, the measures would have to be substantial. Even a reduction of entry barriers to US levels would only close the overall gap by about 20 percent. Finally, increasing the stock of human capital, for example *via* high-skilled immigration, is another option. Raising the share of natural scientists and engineers to US levels could increase the productivity level by another 2 percent in the long run.

Why would all these policies not be enough to reach the Lisbon targets and enable a catching up with the US? The answer is that whilst all these policies would undoubtedly help, there are at least two additional obstacles which prevent the EU from reaching parity with the US. Firstly, the average skill level of high-skilled workers in the US exceeds the level in the EU. Consequently, additional efforts to increase the quality of tertiary education in the EU are required. Secondly, apart from differences in barriers to entry, there is less competition in the EU's non-manufacturing sectors such as services and agriculture, which prevents full convergence to the productivity frontier in these sectors.

Europe also needs to tackle deficiencies in higher-education quality and service-sector competition to enable full catching-up with the US.

Annex: The rate of return of R&D in semi-endogenous growth models

The social rate of return (r) is generally determined by regressing TFP growth on the R&D spending share in GDP (s):

$$g_{TFP,t} = c + r \cdot s_t$$

What is the (social) rate of return in the QUEST III model? The rate of return can be determined by looking at the production of (final) goods and the production of knowledge. The two production functions are given by Equations (A.1) and (A.2):

Goods production:

$$(A.1) \quad Y = A^\varphi K^{1-\alpha} L^\alpha$$

In this formulation aggregate TFP is a function of patents: $TFP = A^\varphi$.

Knowledge production (we neglect international spillovers in this formulation):

$$(A.2) \quad \dot{A} = \nu A^\varphi L_A^\lambda \text{ with } \varphi < 1 \text{ and } \lambda > 0$$

New knowledge is produced with labour diverted to R&D (L_A) and accumulated past knowledge.

We can rewrite (A.2):

$$(A.2') \quad \frac{\dot{A}}{A} = g_A = \nu A^{\varphi-1} s^\lambda \left(\frac{Y}{W^H} \right)^\lambda \text{ where } s = \frac{W^H L_A}{Y}$$

Approximating (A.2') around a trend growth path, denoting the trend variables by \bar{s} , \bar{Y}_t , \bar{A}_t and using the link between A and TFP, we arrive at the following expression for the rate of return on knowledge investment (see Jones *et al.* 1997):

$$(A.2'') \quad g_{TFP,t} = c + \left(\frac{\lambda \bar{g}_{TFP}}{\bar{s}} \right) s_t + \lambda \bar{g}_{TFP} \left(\ln \left(\frac{Y_t}{\bar{Y}_t} \right) - \ln \left(\frac{W_t^H}{\bar{W}_t^H} \right) \right) + (\varphi - 1) g_A \ln \left(\frac{A_t}{\bar{A}_t} \right)$$

We use information on the output elasticity of labour in knowledge production from Bottazzi *et al.* (2007) which suggests a value for λ of 0.73. Given a (neutral) TFP trend in the range between 0.7 and 1 percent *per annum* over the last 10 years and an R&D share of about 2 percent, the implied rate of return on R&D is in the neighbourhood of 0.3. However, one has to be very careful in interpreting this rate-of-return measure. In the empirical R&D literature there is a tendency to concentrate on the estimated elasticity only. This would imply that a 1-percentage-point increase in the R&D share in GDP would lead to a permanent increase in the growth rate of TFP by r percent. In a semi-endogenous growth environment this is not the case as shown by the last term in Equation (2''), which shows the falling marginal productivity schedule of the knowledge production function. That is, every marginal increase in the stock of knowledge reduces the efficiency of R&D workers. Another important feature is that increases in the R&D share in GDP need to be corrected for the part which simply results from increases in the wages of R&D workers.

References

- Afonso, A., Schuknecht, L. and Tanzi, V. (2005). "Public sector efficiency: An international comparison". *Public Choice*, (123:3), pp. 321-347.
- Afonso, A. and St. Aubyn, M. (2006). "Cross-country efficiency of secondary education provision: A semi-parametric analysis with non-discretionary inputs". *Economic Modelling*, (23:3), pp. 476-491.
- Australian Industry Commission (1995). "Research and Development". Report No. 44, Government Publishing Service.
- Bayoumi, T., Laxton, D. and Pesenti, P. (2004). "Benefits and spillovers of greater competition in Europe: A macroeconomic assessment". European Central Bank Working Paper No. 341.
- Bernstein, J.I. (1989). "The structure of the Canadian inter-industry R&D spillovers, and rates of return to R&D". *Journal of Industrial Economics*, (37:3), pp. 315-328.
- Bernstein, J.I. and Nadiri, M.I. (1988). "Interindustry R&D spillovers, rates of return, and production in high-tech industries". *American Economic Review*, (78:2), pp. 429-434.
- Bernstein, J.I., and Nadiri, M.I. (1991). "Product demand, cost of production, spillovers, and the social rate of return to R&D". National Bureau of Economic Research Working Paper No. 3625.
- Bottazzi, L. and Peri, G. (2007). "The international dynamics of R&D and innovation in the long run and in the short run." *The Economics Journal*, (117), pp. 486-511.
- Branstetter, L. (2000). "Is Foreign Direct Investment a Channel of Knowledge Spillovers: Evidence from Japan's FDI in the United States". National Bureau of Economic Research Working Paper No. 8015, Cambridge, MA.
- Cincera, M., Czarnitzki, D. and Thorwarth, S. (2009). "Efficiency of public spending in support of R&D activities: An international comparison". European Economy Economic Paper No. 376.
- Clark, K.B., and Griliches, Z. (1984). "Productivity growth and R&D at the business level: Results from the PIMS Database", in Griliches, Z. (ed.), *R&D, Patents, and Productivity*, Chapter 19, University of Chicago Press, Chicago, USA.
- Coenen, G., Mohr, M. and Straub, R. (2008). "Fiscal consolidation in the euro area: Long-run benefits and short-run costs", European Central Bank Working Paper No. 902.
- Coe, D. and Moghadam, R. (1993). "Capital and trade as engines of growth in France". *IMF Staff Papers*, (40:3), pp. 542-566.
- Coe, D. and Helpman, E. (1995). "International R&D spillovers". *European Economic Review*, (39:5), pp. 859-887.
- Congressional Budget Office (2005). "R&D and productivity growth: A background paper", Washington, D.C.
- Corrado, C., Hulten, C. and Sichel, D. (2006). "Intangible capital and economic growth". *National Bureau of Economic Research Working Paper No. 11948*.
- Cunéo, P. and Mairesse, J. (1984). "Productivity and R&D at the Firm Level in French Manufacturing". In Zvi Griliches, (eds.), *R&D, Patents, and Productivity*. University of Chicago Press. 36, Chicago, USA.
- David, P.A., Hall, B.H. and Toole, A.A. (2000). "Is public R&D a complement or substitute for private R&D? A review of the econometric evidence". *Research Policy*, (29: 4-5), pp. 497-529.
- Denis, C., Mc Morrow, K., Röger, W. and Veugelers, R. (2005). "The Lisbon Strategy and the EU's structural productivity problem". European Economy Economic Paper No. 221.

- Dixit, A.K. and Stiglitz, J.E. (1977) "Monopolistic competition and Optimal Product Diversity". *American Economic Review* (67:3), pp. 297-308.
- Djankov, S., La Porta, R. Lopez-De-Silanes, F. and Shleifer, A. (2002). "The regulation of entry". *The Quarterly Journal of Economics*, (117:1), pp. 1-37.
- Eaton, J. and Kortum, S. (1997). "Trade in ideas: Patenting and productivity in OECD". *Journal of International Economics*, (40), pp. 251-278.
- European Commission (2007), "The EU Economy: 2007 Review".
- Fraumeni, B.M. and Okubo, S. (2005). "R&D in the National Income and Product Accounts: A first look at its effect on GDP", in Corrado, C., Haltiwanger, J. and Sichel, D. (eds.), *Measuring Capital in the New Economy*, pp. 275-316, National Bureau of Economic Research, University of Chicago Press, Chicago, USA.
- Geroski, P. (1996). "Innovation and the sectoral sources of UK productivity growth". *Economic Journal*, (101), pp. 1438-1451.
- Goolsbee, A. (1998). "Does government R&D policy mainly benefit scientists and engineers?", NBER Working Paper No.W6532.
- Goto, A. and Suzuki, K. (1989). "R&D capital, rate of return on R&D investment and spillover of R&D in Japanese manufacturing industries". *Review of Economics and Statistics*, (71:4), pp. 555-564.
- Griffith, R., Redding, S. and Van Reenen, J. (2004). "Mapping the two faces of R&D: Productivity growth in a panel of OECD countries". *Review of Economics and Statistics*, (86:4), pp. 883-895.
- Griliches, Z. (1980a). "R&D and the productivity slowdown". *American Economic Review*, (70), pp. 343-348.
- Griliches, Z. (1980b). "Returns to research and development expenditures in the private sector", in Kendrick, J. and Vaccara, B. (eds.), *New developments in productivity measurement and analysis*, University of Chicago Press, Chicago, USA.
- Griliches, Z. (1988). "Productivity puzzles and R&D: Another nonexplanation". *Journal of Economic Perspectives*, (2:4), pp. 9-21.
- Griliches, Z. (1992). "The search for R&D spillovers". *Scandinavian Journal of Economics*, (94, Supplement), pp. S29-S47.
- Griliches, Z. (1994). "Productivity, R&D, and the data constraint". *American Economic Review*, (84:1), pp. 1-23.
- Griliches, Z. (1995). "R&D and productivity: Econometric results and measurement issues", in Stoneman, P. (ed.), *Handbook of the Economics of Innovation and Technological Change*, Blackwell Publishers, Cambridge, MA, USA.
- Griliches, Z. (1998). *R&D and productivity: The econometric evidence*, University of Chicago Press, Chicago, USA.
- Griliches, Z. (2000). *R&D, education and productivity: a retrospective*. Harvard University Press, Cambridge, MA, USA
- Griliches, Z. and Mairesse, J. (1983). "Comparing productivity growth: An exploration of French and U.S. industrial and firm data". *European Economic Review*, (21:1), pp. 89-119.
- Griliches, Z. and Mairesse, J. (1984). "Productivity and R&D at the firm level", in Griliches, Z. (ed.), *R&D, patents, and productivity*, University of Chicago Press, Chicago, USA.
- Guellec, D. and van Pottelsberghe, B. (2001). "The impact of public R&D expenditure on business R&D". OECD Science, Technology and Industry Working Paper No. 2001/4.

- Hall, B.H. and Mairesse, J. (1995). "Exploring the relationship between R&D and productivity in French manufacturing firms". *Journal of Econometrics*, (65:1), pp. 263-293.
- Hao, J. and van Ark, B. (2009). "Measuring intangible capital and its impact on economic growth in Europe". *EIB Papers*, (14:1), in this issue.
- Haskel, J. and Giorgio Marrano, M. (2007). "How much does the UK invest in intangible assets?". Centre for Economic Policy Research Discussion Paper No. 6287, London.
- Inklaar, R., Timmer, M. and van Ark, B. (2007). "Market services productivity across Europe and the US". *Economic Policy*, (23:53), pp. 139-194.
- Jaumotte, F. and Pain, N. (2005a). "From ideas to development: The determinants of R&D and patenting". OECD Economics Department Working Paper No. 457.
- Jaumotte, F. and Pain, N. (2005b). "An overview of public policies to support innovation", OECD Economics Department Working Paper No. 456.
- Jones, C.I. (1995). "Time series tests of endogenous growth models". *Quarterly Journal of Economics*, (110), p. 495-525.
- Jones, C.I. (2002). "Sources of U.S. economic growth in a world of ideas". *American Economic Review*, (92:1), pp. 220-239.
- Jones, C.I. and Williams, J. (1998). "Measuring the social return to R&D". *Quarterly Journal of Economics*, (113:4), pp. 1119-1135.
- Katz, L. and Murphy, K. (1992). "Changes in relative wages, 1963-1987: Supply and demand factors". *Quarterly Journal of Economics*, (107:1), pp. 35-78.
- Lichtenberg, F. (1992). "R&D investment and international productivity differences". National Bureau of Economic Research Working Paper No. 4161.
- Lichtenberg, F. and van Pottelsberghe, B. (2001). "Does foreign direct investment transfer technology across borders?". *Review of Economics and Statistics*, (83:3), pp. 490-497.
- Mairesse, J. and Mulkay, B. (2008). "An exploration of local R&D spillovers in France". National Bureau of Economic Research Working Paper No. 14552.
- Mandl, U., Dierx, A. and Ilzkovitz, F. (2008). "The effectiveness and efficiency of public spending". European Economy Economic Paper No. 301
- Mansfield, E., Rapoport, J., Romeo, A., Wagner, S. and Beardsley, G. (1977). "Social and private rates of return from industrial innovations". *Quarterly Journal of Economics*, (91:2), pp. 221-40.
- Mansfield, E. (1980). "Basic research and productivity increase in manufacturing". *American Economic Review*, (70:5), pp. 863-873.
- Mansfield, E. (1988). "Industrial R&D in Japan and the United States: A comparative study". *American Economic Review*, (78:2), pp. 223-228.
- Mc Morrow, K., Röger, W. and Turrini, A. (2009). "The EU-US total factor productivity gap: An industry level perspective". Centre for Economic Policy Research Discussion Paper No. 7237.
- Mohnen, P. (2001). "International R&D spillovers and economic growth", in Pohjola, M. (ed.), *Information technology, productivity and economic growth*, Oxford University Press, Oxford, UK.
- Nadiri, M.I. (1980). "Sectoral productivity slowdown". *American Economic Review*, (70:2), pp. 349-352.
- Nadiri, M.I. (1993). "Innovations and technological spillovers". National Bureau of Economic Research Working Paper No. 4423.

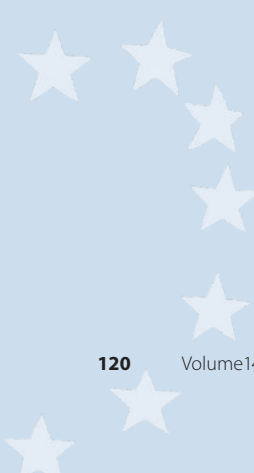
- Odagiri, H. and Iwata, H. (1986). "The impact of R&D on productivity increase in Japanese manufacturing companies". *Research Policy*, (15:1), pp. 13-19.
- OECD (2004). *OECD Science, Technology and Industry Outlook*, Organisation for Economic Co-operation and Development, Paris.
- OECD (2006). *OECD Science, Technology and Industry Outlook*, Organisation for Economic Co-operation and Development, Paris.
- OECD (2008). *OECD Science, Technology and Industry Outlook*, Organisation for Economic Co-operation and Development, Paris.
- Patel, P., and Soete, L. (1988). "Measuring the economic effects of technology". *STI Review*, (4), Organisation for Economic Cooperation and Development, pp. 121-166.
- Philippon, T. and Véron, N. (2008). "Financing Europe's fast movers". *Bruegel Policy Brief*. January.
- Ratto M., Roeger, W. and In 't Veld, J. (2009). "QUEST III: An estimated open-economy DSGE Model of the euro area with fiscal and monetary policy". *Economic Modelling*, 26, pp. 222-233.
<http://dx.doi.org/10.1016/j.econmod.2008.06.014>
- Roeger W., Varga, J. and In 't Veld, J. (2009). "Modelling the Lisbon Strategy: Analysing policies to promote knowledge investment with an endogenous growth model". *Comparative Economic Studies*.
www.palgrave-journals.com/ces/journal/vaop/ncurrent/abs/ces200913a.html
- Roeger W., Varga, J. and In 't Veld, J. (2008). "Structural reforms in the EU: A simulation-based analysis using the QUEST model with endogenous growth". *European Economy Economic Paper No. 351*.
- Romer, P. (1990). "Endogenous technological change". *Journal of Political Economy*, (98:5, part 2), pp. S71-S102.
- Schankerman, M (1981). "The effects of double-counting and expensing on the measured returns to R&D". *Review of Economics and Statistics*, (63:3), pp. 454-458.
- Scherer, F.M. (1982). "Inter-industry technology flows and productivity growth". *Review of Economics and Statistics*, (64:4), pp. 627-634.
- Scherer, F.M. (1984). "Using linked patent and R&D data to measure inter-industry technology flows", in Griliches, Z. (ed.), *R&D, patents, and productivity*, Chapter 20, University of Chicago Press, Chicago, USA.
- Sveikauskas, L. (1981). "Technology inputs and multifactor productivity growth". *Review of Economics and Statistics*, (63:2), pp. 275-282.
- Sveikauskas, L. (2007). "R&D and productivity growth: A review of the literature". *Bureau of Labour Statistics Working Paper No. 408*.
- Terleckyj, N. (1974). "Effects of R&D on the productivity growth of industries: An exploratory study". *National Planning Association, Washington, D.C.*
- van Ark, B. and Hulten, C. (2007). "Innovation, intangibles and economic growth: Towards a comprehensive accounting of the knowledge economy". *The Conference Board EPWP No. 07-02*.
- Verspagen, B. (1995). "R&D and productivity: A broad cross-section cross-country look". *Journal of Productivity Analysis*, (6), pp. 117-135.
- Wang, J.C., and Tsai, K.H. (2003). "Productivity growth and R&D expenditure in Taiwan's manufacturing firms". *National Bureau of Economic Research Working Paper No. 9724*.
- Warda, J. (2006). "Tax Treatment of business investments in intellectual assets: An international comparison". *OECD Science, Technology and Industry Working Paper No. 2006/4*.

ABSTRACT

This article analyzes the potential benefits of industry-science collaborations for samples of Flemish and German firms. A firm collaborating with science may benefit from knowledge spillovers and public subsidies as industry-science collaborations are often granted preferred treatment. I shed light on the potential spillover and subsidy effects by estimating treatment effect models using nearest neighbour matching techniques. For both countries, I find positive effects on business R&D. Firms that engage in industry-science collaborations invest more in R&D compared to the counterfactual situation where they would not collaborate with science. Furthermore, within the sample of firms collaborating with science, a subsidy for that collaboration leads, on average, to higher R&D in the involved firms. Thus there is no full crowding-out of subsidies targeted to science-industry collaborations.

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The virtue of industry-science collaborations

1. Introduction

The successful creation of new knowledge often depends on the ability of firms to establish collaborative R&D agreements in order to combine their resources, exploit complementary know-how, and internalize R&D externalities (Katz 1986; d'Aspremont and Jacquemin 1988; Kamien *et al.* 1992).

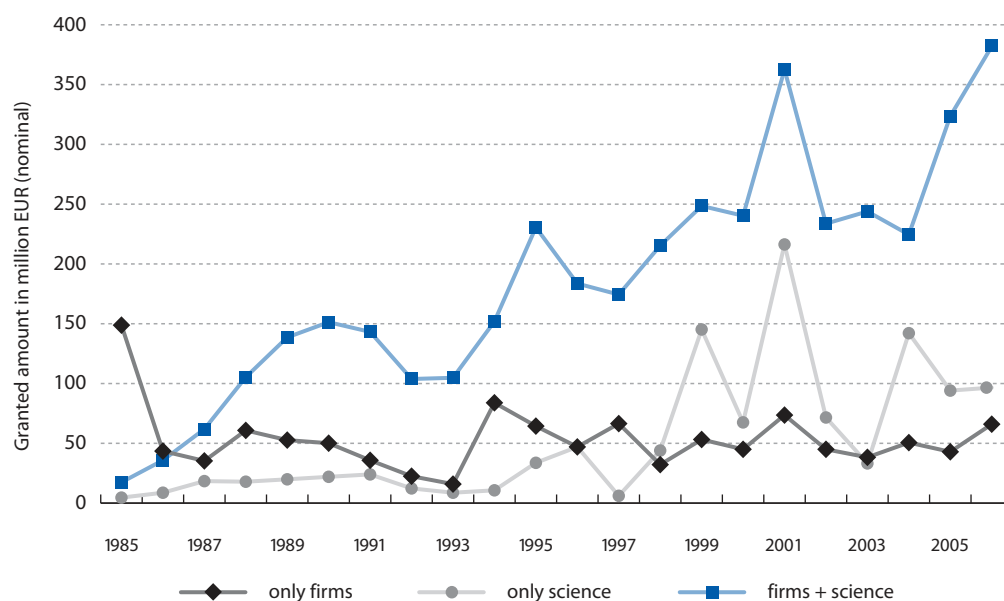
Governments have long understood the virtues of R&D collaboration and have exempted R&D partnerships from anti-trust legislation. In the European Union, for instance, the Treaty of Rome already contained a notice in article 85(3) that collaborating in R&D is permitted as long as post-innovation rivalry is not blocked. In 1984, the European Commission approved a block exemption for R&D collaborations that also allows joint exploitation of results (see Martin 1997 for an overview on policy practices in the US, Japan and Europe).

In addition, governments often subsidize R&D collaborations. Governments of EU member states often maintain subsidy schemes whereby grant applications from consortia are preferred over single-firm applications. In the recent past, technology transfer from science to industry has attracted the attention of policy makers and, as a result, industry-science collaborations are often granted a preferential treatment in public grant systems. It is believed that an enhanced knowledge and technology transfer from science to industry also contributes to the long-run innovativeness and thus competitiveness of the business sector. Figure 1 shows the development of grants from the German federal government to research consortia. It becomes apparent that, over time, industry-science partnerships were increasingly preferred in grant schemes when compared to pure company consortia or pure public science consortia.



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Figure 1: Division of collaborative research grants by type of research consortia in Germany



Source: PROFI database from Germany's Federal Ministry of Education and Research; own calculations

R&D collaborations can help to internalize spillovers and to exploit synergies and scale economies.

The potential benefits of R&D collaborations can be summarized as follows. First, technological spillovers are internalized, thus eliminating the free-rider problem within the group of collaborating firms. Second, since R&D often exhibits economies of scale it might well be that only a consortium of firms has the necessary resources both financially and physically to undertake the ever larger, more complex, and more expensive research projects that are common today. Third, economies of scope also often characterize the R&D process. Hence, synergetic effects and risk pooling can broaden the research horizon of collaborating firms. It can thus be expected that sustaining R&D collaborations leads to an increase in private R&D activity. From the growing literature on R&D collaboration, it can be concluded that collaborative R&D levels exceed non-collaborative levels when technological spillovers are large, while the opposite holds for small technological spillovers (see Veugelers 1998 for a survey of the theoretical and empirical literature).

This study discusses the potential impacts of R&D subsidies to consortia of firms and public research institutions. It can be assumed that such collaborations are undertaken for projects where the research conducted concerns more basic and generic knowledge that may be difficult to be discovered by a single firm and may also lead to results that are more difficult to appropriate than those of more regular R&D conducted in the firm. First, I discuss the potential market failures in R&D and the economics of R&D collaborations, reviewing both the theoretical and the empirical literature. Second, I give a brief overview of the recent literature on effects of R&D policies at the firm level. The third goal of the study is the combination of both strands of literature which leads to an empirical study on how R&D subsidies to industry-science partnerships influence private R&D at the firm level.

2. Theory

2.1 The market failure for R&D investment

The standard argument for governmental intervention in the market for R&D is based on two market failure arguments. First, R&D creates positive external effects, that is, R&D creates knowledge and as Arrow (1962) hypothesized, something intangible such as knowledge cannot be kept fully secret by the original R&D investor. This implies that a private company investing in R&D will not be able to appropriate all returns on its initial investment as knowledge will spill over to rivals and other third parties that subsequently free-ride, *i.e.* build on the knowledge, without having participated in the investment. This may happen through the mobility of personnel, but also through many other channels such as joint customers or suppliers (see *e.g.* Mansfield 1985). Thus the social benefit of R&D investment is typically larger than the private return. As, however, firms only embark on investment with a positive expected private return, many R&D projects that are socially desirable may not be undertaken. This leads to a gap between social and private equilibrium and, consequently, a justification for government intervention.

The second market failure argument is typically established with respect to financing constraints for R&D. If a firm seeks external financial resources for an investment, R&D features several characteristics that make it more difficult or expensive to finance externally than, for instance, investment in tangible assets. For instance, the lion's share of an R&D investment project is sunk cost, as R&D mainly consists of wages for researchers. In contrast to physical capital investment, R&D itself cannot be used as collateral in credit negotiations with banks. Furthermore, the outcome of an R&D project is typically much more uncertain than the return on investment in physical capital, which also makes financiers less likely to invest (see *e.g.* Hall 2002 or Hall and Lerner 2009 for surveys of this strand of the literature).

Although these are good economic reasons for governments to support R&D by financing R&D in universities and also in the form of grants or tax credits to private companies, it is not straightforward to establish a clear-cut theoretical market failure argument for a preferential treatment of industry-science collaborations within certain schemes. Exempting R&D collaboration from anti-trust legislation can already be seen as a policy itself, as the possibility of collaborating in R&D (i) allows firms to internalize the potential external effects at least within the consortium of project partners, (ii) spreads the risk of outcome uncertainty and (iii) divides the cost of R&D among involved agents.

However, in combination with some empirical evidence from the literature on knowledge and technology transfer between science and industry, arguments for such extra incentives may be made.

It seems to be a generally accepted opinion that the involvement of universities or other public research institutions concerns more basic research projects and the transfer of more generic knowledge than the “usual” business R&D projects. The idea is that companies seek university collaboration for more fundamental, long-term and possibly strategic R&D projects. Empirical evidence supports this view (e.g. Hall *et al.* 2003; Belderbos *et al.* 2006). Thus, it could be argued that R&D conducted within industry-science collaborations involves projects that are socially more desirable than others, as more basic knowledge is created which expectedly would lead to higher knowledge spillovers, *i.e.* the social return on these investments is high. From the company perspective, however, basic research suffers from worse appropriability conditions than other projects. For instance, without any specific industrial application in mind, the original investor may not be able to take out a patent to protect the results of the initial investment.

Companies seek university collaboration for longer-term, more fundamental research whose results are more difficult to appropriate.

In addition, the uncertainty about expected pay-offs of such investments is typically even higher than for other R&D investment, as projects of more basic research are further away from the market and its potential applicability to new products and processes may be largely unknown at the time of investment. Thus, financial constraints may be more binding for basic research than for experimental development, for instance (see Czarnitzki and Hottenrott 2009; Czarnitzki *et al.* 2009).

This reasoning leads to the conclusion that the market failures due to external effects and financial constraints apply even more for research conducted within industry-science consortia than for other projects, justifying a higher degree of government intervention than for other R&D.

2.2 Theory of R&D collaboration

In the literature on policy evaluation, the standard question to be answered is “How much would a subsidized firm have invested in R&D if it had not been subsidized?” Econometric models are typically designed to estimate the potential “additionality effect” of a subsidy with respect to its pure monetary value. As I will outline in the following, however, the evaluation of industry-science collaborations should include and separate two effects: first, the effect of the subsidy in terms of its additional capital that becomes available for investment of the recipient firm, and a possible effect on investment because of knowledge spillover effects between the collaborating parties. As the core of the industrial organization literature focuses on horizontal collaboration, that is, collaboration between competitors, I briefly outline the main aspects of this literature, and then turn to the differences in vertical and diagonal collaborations, *i.e.* collaborations with customers, suppliers and finally universities.

Horizontal collaboration

The question of how and why firms engage in R&D collaborations and how that affects welfare emerged during the 1980s in the economic literature (see Veugelers 1998 for a survey). The industrial organization literature emphasizes the importance of knowledge spillovers in the context of collaborative research (e.g. Katz 1986; d'Aspremont and Jacquemin 1988; Beath *et al.* 1988; De Bondt and Veugelers 1991; Kamien *et al.* 1992; Motta 1992; Suzumura 1992; Vonortas 1994; Leahy and Neary 1997). Such studies relate decisions to collaborate in R&D to the presence of spillovers and the effects on market performance with respect to profits. Models rely on the fact that returns from R&D are not fully appropriable by the firm, but knowledge leaks out to competitors such that social returns are higher than private returns. This leads to underinvestment in innovative activities from a social point of view. R&D collaborations are one possibility to internalize such knowledge spillovers and thus increase the appropriability of returns within research consortia. Three main issues with respect to collaborative R&D are considered in the following: coordination, free-riding and information sharing.

Investment in collaborative R&D increases with the level of knowledge spillovers.

Coordination in such models is typically described through joint profit maximization. One finding is that investment in R&D among collaborators increases with the level of spillovers. A second result states that if spillovers are high enough, that is, above some critical level, collaborating in R&D will result in higher investment compared to the status of no collaboration (see De Bondt and Veugelers 1991). As this will also lead to higher profits, firms have an increased incentive to engage in R&D collaborations in the presence of spillover effects. It should be noted, however, that the cost of coordinating R&D is often ignored in these models.

Collaborations bear the inherent risk of free-riding that may jeopardize the stability of the collaboration. Partners may free-ride as they could try to absorb knowledge from their partners but conceal their own (see e.g. Shapiro and Willig 1990; Baumol 1993; Kesteloot and Veugelers 1995). Models find that collaborative agreements for being profitable and stable require that involuntarily outgoing spillovers be not too high. This is in contrast with the results on coordination, where profits are higher with larger spillovers, regardless of their direction. Here the profitability of collaboration increases with the firms' ability to manage the outgoing spillovers in order to protect against the possible free-riding of partners.

Some models explicitly account for information sharing among partners, that is, for managing spillovers (e.g. Kamien *et al.* 1992, Katsoulacos and Ulph 1998). Katsoulacos and Ulph find that research joint ventures will always share at least as much information as non-collaborating firms because research joint ventures maximize joint profits. Another issue for managing spillovers is absorptive capacity. Cohen and Levinthal (1989) point out that incoming spillovers can be used more efficiently (in reducing own cost) when the firm is engaged in own R&D. Engaging in own R&D builds absorptive capacity, that is, the ability of a firm to benefit from the knowledge others have created through R&D activity. Kamien and Zang (2000) take that into account, and find ambiguous results of collaboration with respect to the level of firms' R&D investment. Yet, collaboration is still the more profitable option.

To conclude, theory states that non-collaborative R&D levels decrease with the magnitude of spillovers, while collaborative investment tends to increase with spillovers. Thus, imperfect appropriability of knowledge generating processes increases the benefits from collaborative agreements. The presence of spillovers increases the incentive for R&D collaboration as a means of internalizing this externality.

Theoretical results have initiated a debate on the implications of R&D collaborations for antitrust and the treatment of research joint ventures, leaving a favourable policy stance towards this type of collaboration (Ordovery and Willig 1985; Jacquemin 1988; Shapiro and Willig 1990). Although it seems to be an important policy conclusion leading to more lenient policies towards R&D collaborations, it should be stressed that this only holds for co-operation restricted to R&D. If R&D collaboration facilitated product market collusion, the welfare enhancing results would not necessarily hold any longer.

Furthermore, it should be stressed that the vast majority of theoretical models deals only with horizontal R&D collaboration, that is, collaboration with competitors. While this set-up is predominant in theory, it stands in stark contrast to survey evidence: in practice, the most important partners are customers, suppliers and universities or other research institutions. By contrast, collaboration with competitors is not found to be frequent in R&D collaborations. This is a gap between theory and empirical “stylized facts”. Thus all interpretations with respect to linkages between economic theory and empirical results should be interpreted with care.

Vertical and diagonal R&D collaboration

As outlined above, the theoretical literature on vertical collaboration including industry-science collaboration is scarce. The economics of vertical R&D collaboration is different because vertical collaboration partners do not impose a negative externality on each other, as they do not compete in the same product market. Thus, the theoretical concerns about trade-offs in cost and benefits of R&D collaborations apply to a lesser extent to vertical collaboration. Firms may engage in vertical R&D collaboration to reduce the cost of R&D, e.g. a firm decides to collaborate with a university as the public research institution may possess superior knowledge for certain projects than the firm has internally available. Rather than generating this knowledge in-house, it may be preferable to seek it externally. Furthermore, seeking complementary knowledge may lead to economies of scale and scope which in turn result in increased in-house R&D (see Cassiman and Veugelers 2006).

Vertical R&D collaboration does not impose a negative externality on partners because they do not compete in the same product markets.

Similarly to horizontal collaboration, risk sharing arguments concerning the outcome uncertainty of R&D investment are a further motive for engaging in vertical collaboration. Firms would choose to engage in vertical collaboration if the expected benefits outweigh the transaction cost involved. Steurs (1995) is the first paper that extends models of R&D collaboration to inter-industry spillovers in a two-industry, two-firm-per-industry setting. It is assumed that intra-industry and inter-industry spillovers exist. As firms engaging in inter-industry collaboration do not impose a negative externality on each other, it is found that inter-industry collaboration is socially more beneficial than collaborations whose members come from a single industry. In the Steurs (1995) model, the industries are not related except for the presence of spillovers. This framework is extended by Inkmann (2000) who explicitly models strategic R&D investment in the presence of R&D spillovers between vertically related industries. The R&D investment of the upstream firm affects the production process or quality in the downstream firm which in turn leads to higher demand in the final product market and thus also for the intermediate good. In equilibrium, vertical collaboration maximizes the profits of the participating firms, and leads to increased R&D in the economy. A similar model is presented in Atallah (2002) where vertical R&D collaboration unambiguously leads to higher R&D and welfare in the economy. These papers are able to explain the empirical finding that vertical collaborations are more frequent than horizontal collaborations in reality. In addition, the paper by Steurs (1995) shows that “diagonal” collaboration is more beneficial than intra-industry collaboration. Industry-science collaborations could be seen as inter-industry collaborations as universities are not active in any market and thus neither horizontally nor vertically related to the firm in question.

3. Empirical evidence

This section first reviews a selection of empirical studies on the determinants of collaboration with special attention to industry-science partnerships and also reports some empirical evidence on the effects of these collaborations at the firm-level. Thereafter, results of empirical studies on the evaluation of R&D policies are briefly introduced. These two components then lead to studies that analyze both the effects of R&D policies and collaboration on firms' innovation activity.

3.1 Empirical studies on collaboration

Recent empirical studies have established that contractual forms of R&D, such as joint R&D, have become a very important mode of inter-firm and science-firm collaboration as the number of partnerships has largely increased (Sakakibara 1997; Hagedoorn and Narula 1996). Several empirical papers on R&D collaborations are reviewed in Veugelers (1998). As one recent example, Cassiman and Veugelers (2002) explore the effects of knowledge flows on R&D co-operation. Their results suggest that firms with higher incoming spillovers and better appropriability conditions have a higher probability of co-operating in R&D which confirms the arguments on spillovers made by theoretical contributions.

The role of universities may be a translation of basic science into an applicable technology.

Not many studies analyze industry-science collaborations explicitly. Hall *et al.* (2003) conduct a survey-based study of research projects having universities as research partners within the US ATP program. They argue that universities are involved in such projects that apply "new science", *i.e.*, firms seek for expertise to absorb results of basic research. The role of the university may be a translation of basic science towards an applicable technology for selected problems. This interpretation is supported by the fact that universities are engaged in industry collaboration in fields where business R&D is closer to science, particularly in areas where technology tends to be more complex. University involvement also occurs more frequently in projects that are broader in scope. Projects where results are expected in a timely manner for a specific technological problem are typically not conducted in collaboration with universities.

Veugelers and Cassiman (2005) explore the determinants of industry-science collaboration using Belgian Community Innovation Survey (CIS) data. They emphasize that there are large cross-industry differences in the probability of a firm collaborating with science. Firms in the chemical and pharmaceutical industry are most likely to collaborate with universities. Furthermore, firms that are impeded by high cost of innovation are often attracted by government subsidized cost-sharing in public-private partnerships. In addition, larger firms are more likely to collaborate with universities than smaller firms indicating that some minimum absorptive capacity is needed for fruitful collaboration. Moreover, it is often hypothesized that research projects involving a high uncertainty of outcome are preferably conducted within research consortia, as this allows to spread the risk. However, Veugelers and Cassiman find no evidence for the risk-sharing argument in industry-science collaborations with their data. The authors argue that the risk-sharing effect is possibly confounded with higher transaction cost when communicating with science. As long as these effects cannot be separately measured, results may remain ambiguous.

Belderbos *et al.* (2004a) also analyze the determinants of university collaboration. They account for collaborations with different types of partners by including a measure of incoming spillovers from these potential collaboration partners. Among others, one interesting finding is that spillovers received from universities not only stimulate industry-science partnerships but also R&D collaboration with other partners.

Belderbos *et al.* (2004b) investigate the impact of R&D collaboration on firm performance using panel data of Dutch manufacturing firms. The noteworthy feature of this study is the distinction of two dependent variables, growth of labour productivity and growth of firms' innovative sales, where the latter is measured as the growth rate in sales of products that were market novelties. Although these variables are treated as separate dependent variables not connected in a simultaneous-equation system, the results are interesting. It turns out that R&D collaborations with competitors and suppliers positively affect productivity growth. Belderbos *et al.* refer to this as a result of incremental innovation leading to higher sales of established products. In boosting innovative sales, however, university collaborations play an important role along with the collaboration with rivals. They also find that customers and universities are important sources of sales growth in market novelties even in the absence of formal collaborative agreements.

3.2 Empirical studies on R&D subsidies¹

The impact of R&D policies on firms' innovation behaviour has been of interest in the economic literature for decades. The predominant question investigated is whether public subsidies crowd-out private investment. David *et al.* (2000) survey microeconomic and macroeconomic studies on that topic. One result of their survey is that most of the estimations reviewed are subject to a potential selection bias as recipients of subsidies might be chosen by the government because they are the most promising candidates for successful research projects. In this case, public funding becomes endogenous to innovative activity, leading to bias in simple regressions of, for example R&D investment on government subsidies (selection bias).

More recent studies addressing the selection bias include Busom (2000), Wallsten (2000), Lach (2002), Czarnitzki and Fier (2002), Almus and Czarnitzki (2003), Duguet (2004), González *et al.* (2005) and Hussinger (2008). Results are ambiguous. Busom finds positive effects of public funding on R&D in Spanish manufacturing, but cannot rule out partial crowding-out for a sub-sample of firms. Wallsten finds full crowding-out effects in the US SBIR program, an initiative to foster innovation in small and medium-sized US companies. Lach reports large positive effects for small firms in Israeli manufacturing, but no effects for large firms. The analysis of Czarnitzki and Fier rejects full crowding-out effects in German service industries. Almus and Czarnitzki analyze East German manufacturing where the government has offered high amounts of subsidies in order to enhance the transformation process from central planning to a market economy since the German re-unification in 1990. They conclude that about 50 percent of R&D performed in East Germany would not have been carried out in the absence of public innovation programs. Duguet (2004) rejects crowding-out in R&D using a sample of French firms, as does Hussinger (2008) based on a sample of German firms using semi-parametric selection models. González *et al.* (2005) employ a large panel of Spanish manufacturing firms and find no evidence for crowding-out either.²

R&D subsidies tend to increase total R&D expenditure but often by less than the amount of the subsidy.

3.3 Studies combining collaboration and R&D subsidies

Just a few empirical analyses, however, deal with R&D co-operations as a part of firms' innovative behaviour *and* as a policy instrument. Among those, Sakakibara (2001) analyzes Japanese government-sponsored R&D consortia over 13 years and finds evidence that the diversity of a consortium is associated with greater R&D expenditure by participating firms. The results support the hypothesis of large spillover effects. The effect of participating in an R&D consortium on a firm's R&D expenditures is found

1 For an evaluation of another policy tool, the R&D tax credit, see Ientile and Mairesse (2009) in this issue.

2 Fewer studies deal with public policies and innovation outcomes such as growth of employment or sales. See the survey by Klette *et al.* (2000) for examples of such studies.

to be 9 percent on average. Branstetter and Sakakibara (2002) examine the impact of government-sponsored research consortia in Japan. They find evidence that participants of research consortia tend to increase their patenting after entering a consortium, which is interpreted as evidence for spillovers effects. The marginal increase of participants' patenting in targeted technologies, relative to the control firms, is large and statistically significant.

Czarnitzki and Fier (2003) employ econometric matching analysis to investigate the relationship between R&D collaboration and patent outcome as a measure of intermediate innovative output. Controlling for R&D input, firm size, industry heterogeneity and other common covariates, they find that firms that collaborate achieve higher patent outcomes than under no collaborative agreements. Using German data they also demonstrate that German R&D policy in the 1990s increasingly subsidized research consortia comprising firm-firm partnerships or industry-science partnerships. Czarnitzki and Fier find that firms in publicly-sponsored research consortia file more patents than other collaborators. However, they cannot disentangle whether this stems from more intensive science-industry interactions or simply from the R&D increase in response to the subsidy receipt.

Firms that both engage in R&D collaboration and receive R&D subsidies spend more on R&D than comparable firms with only one or none of these characteristics.

Czarnitzki *et al.* (2007) employ a heterogeneous treatment effects estimator where R&D collaboration, R&D subsidies and the combination of both are considered as a treatment. Their analysis is conducted for Community Innovation Survey data from Germany and Finland. Although the two countries have similar frameworks for technology policy, it can be observed that the frequency of R&D collaborations is much higher in Finland than in Germany in the early 2000s. Czarnitzki *et al.* (2007) find that both R&D collaboration and public R&D grants result in higher R&D in the treated firms. Firms that receive subsidies and are engaged in R&D collaboration exhibit complementarities in the sense that they invest more in R&D when benchmarked against each of the three following counterfactual situations: "only subsidy receipt", "only collaboration" and "neither subsidy receipt nor collaboration". This also points to the presence of sufficiently large spillovers in collaborative agreements, so that firms increase R&D inputs.

Another interesting result of Czarnitzki *et al.* (2007) is the analysis of "treatment effects on the untreated". As said above, the level of R&D collaboration is high in Finland. The econometric estimations show that firms not engaged in collaboration would not invest more in the counterfactual situation of engaging in R&D collaboration. In Germany, however, where R&D collaboration is less frequent, the authors find that firms would, on average, invest more in R&D if they did engage in collaboration. Thus, the authors conclude that there would be additional room for fostering collaboration in German technology policy while in Finland this seems to be limited. The Finish population of non-collaborating firms is to a larger extent characterized by very small firms, other than in Germany. Such firms may not have the necessary absorptive capacity or capabilities to benefit from R&D collaborations.

4. Econometrics: The evaluation question

To investigate the effect of public subsidies one has to construct the counterfactual situation: What would have been the behaviour of the subsidized firms had they not been subsidized? As the counterfactual cannot be observed it has to be estimated. Our fundamental evaluation question can be illustrated by an equation describing the average treatment effect on the treated firms. That is:

$$(1) \quad E(\alpha_{TT}) = E(Y^T|S=1) - E(Y^C|S=1)$$

where Y^T is the outcome variable. The status S refers to the group: $S=1$ is the treatment group and $S=0$ the non-treated firms. Y^C is the potential outcome which would have been realized if the treatment group ($S=1$) had not been treated. The problem is obvious. While the outcome of the treated individuals

What would have been the outcome of untreated firms if they had been treated?

in case of treatment, $E(Y^T|S=1)$, is directly observable, it is not the case for the counterfactual situation: What would these firms have realized if they had not received the treatment? $E(Y^C|S=1)$ is a counterfactual situation which is not observable and, therefore, has to be estimated.

The literature on the econometrics of evaluation offers different estimation strategies to correct for selection bias (see Heckman *et al.* 1999 or Imbens and Wooldridge 2009 for surveys). For cross-sectional data, popular choices for treatment-effect estimations are instrumental variable regressions, control function approaches (selection models) and matching estimators.

In this study, I employ a nearest-neighbour propensity score matching. The advantage of matching is that no parametric model for the R&D equation has to be specified. The counterfactual outcome of treated firms is constructed from a control group of non-treated firms. The matching relies on the intuitively attractive idea to balance the sample of program participants and comparable non-participants. Remaining differences in the outcome variable, *e.g.* R&D intensity, between both groups are then attributed to the treatment. Initially, the counterfactual situation cannot simply be estimated as the observed average outcome of the non-participants, because due to the possible selection bias, the subsidized firms and non-subsidized firms are expected to differ. Hence, $E(Y^C|S=1) \neq E(Y^C|S=0)$.

Rubin (1977) introduced the conditional independence assumption (CIA) to overcome the selection problem. The CIA states that participation and potential outcome are independent for firms with the same set of exogenous characteristics X . Phrased differently, the selection only occurs on observables:

$$(2) \quad Y^C \perp S \mid X$$

If this assumption is valid, it follows that

$$(3) \quad E(Y^C \mid S = 1, X) = E(Y^C \mid S = 0, X).$$

Equation (3) states that the outcome of the non-participants can be used to estimate the counterfactual outcome of the participants in case of non-participation, provided that there are no systematic differences between both groups. The treatment effect can be written as

$$(4) \quad E(a_{TT}) = E(Y^T|S=1, X=x) - E(Y^C|S=0, X=x)$$

Conditioning on X takes account of the selection bias due to observable differences between participants and non-participants. In nearest-Neighbour matching, one picks the most similar firm from the potential control group of non-subsidized firms. In addition to the CIA, another important precondition for consistency of the matching estimator is common support: it is necessary that the control group contains at least one sufficiently similar observation for each treated firm. In practice, the sample to be evaluated is restricted to common support. However, if the overlap between the samples is too small the matching estimator is not applicable.

As one often wants to consider more than one matching argument, one has to deal with the “curse of dimensionality”. If we employ a lot of variables in the matching function, it will become difficult to find appropriate controls. Rosenbaum and Rubin (1983) suggested to use a propensity score as a single index and thus to reduce the number of variables included in the matching function to just one. Therefore a probit model is estimated on the dummy indicating the receipt of subsidies S . The estimated propensity scores are subsequently used as a matching argument. Lechner (1998) introduces a modification of the propensity score matching (“hybrid matching”) as it is often desirable to include additional variables in the matching function. In this case, instead of a single X (the propensity score), other important characteristics may be employed in the matching function.

5. Empirical study

For the first analysis, I employ data obtained from the Flemish Community Innovation Survey (CIS) 2005 and 2007, *i.e.*, the data refer to the years 2004 and 2006. In these surveys, respondents were requested to indicate whether they received public subsidies from the local, federal or European authorities. In addition, they were asked to specify if the subsidy was granted within a research consortium and whether that consortium included at least one public research institution. The latter will be defined as subsidized industry-science collaboration.

For a second analysis, I use data from the German CIS. Here, data from the surveys of the years 2001 and 2005 can be used, *i.e.*, the data refer to the years 2000 and 2004.³ Firms were also asked whether they received subsidies from the government. However, the information on whether the subsidized projects involved industry-science collaboration, too, needs to be collected separately from the PROFI database of the German Federal Ministry for Education and Research (BMBF) which covers all federally subsidized civilian R&D projects in Germany (BMBF 2009).

5.1 Data description

In total, the usable sample of the Flemish CIS comprises 3,331 firm-year observations of which 1,791 can be classified as innovators. An innovator is a firm that introduced at least one product or one process innovation in the past three years, or had ongoing or abandoned innovation projects. Thus, this constitutes the sub-population of firms that at least attempted to innovate.

Out of those innovating companies, 890 firms engaged in some type of collaborative agreement, of which 532 firms were involved with partners from public science (60 percent). Of the 532 firms with industry-science partnerships, 230 received public subsidies for the industry-science partnership (43 percent).

For Germany, the data are quite similar. 1,074 collaborating companies can be identified within the survey data. Out of those, 804 collaborate with public science (75 percent). Among those 804 observations, 284 received subsidies from the federal government (35 percent).

5.2 Set-up of econometric study and variables

For this study, we use the sub-sample of firms engaging in any type of collaborative agreement as a starting point, and investigate two research questions:

Do firms that collaborate with public science spend more on R&D than in the counterfactual situation where they would not?

Among firms collaborating with public science, do firms that receive subsidies spend more on R&D than in the counterfactual situation of not receiving subsidies?

For both research questions, I employ the nearest-neighbour matching technique described above. First, industry-science collaboration is interpreted as a “treatment” within the sample of collaborating firms. Subsequently, the subsidy receipt within the sample of industry-science partnerships is considered as a treatment.

³ Although the CIS is harmonized across countries, the questionnaires are not identical in each year and for all countries. In Flanders, the question on collaboration behavior is available for 2005 and 2007 while it was asked only in 2001 and 2005 in Germany. For a detailed description of the CIS see *e.g.* Eurostat (2008).

Do firms engaged in industry-science collaboration spend more on R&D than firms collaborating with other firms?

The dependent variable is R&D intensity (*RDINT*), measured as R&D spending divided by sales, times 100.

For the matching procedure, a relatively large set of control variables can be included. Firm size is measured in terms of employment (EMP). As the firm size distribution is skewed, the variable enters in logarithms. I also allow for a potential non-linear relationship by including $[\ln(\text{EMP})]^2$. Furthermore, the log of firms' age is considered, as younger firms might be relatively more innovative ($\ln(\text{AGE})$). Another important control is previous successful R&D activities. On the one hand, this may account for the absorptive capacity in the firm. On the other hand, it may approximate the attractiveness of a firm as a potential collaboration partner. I measure previous successful innovation by a dummy variable indicating whether the firm has filed at least one patent in the past. For the Flemish sample this takes into account patents filed with the European Patent Office (EPO) before the corresponding survey year. For Germany, this variable also accounts for patents filed with the German national patent office. In order to control for the degree of competition a company faces, I include an export dummy (EXPORT) that equals one if the firm is an exporter and zero otherwise, as firms in international markets may be forced to innovate more than others if they want to remain competitive in the global economy.

In addition, I use a dummy indicating whether the company is part of an enterprise group, such as a multinational company or a holding company (GROUP). It may imply more professional innovation management of the firm (especially when compared to small stand-alone companies). A further control variable indicates whether or not the parent company is located abroad (FOREIGN). Such firms may be less likely to receive local public funding. Last but not least, a set of industry dummies controls for unobserved heterogeneity across sectors and a time dummy captures common macroeconomic shocks.

Table 1 shows the means of all variables used for the different Flemish sub-samples. In the upper panel, it can be seen that firms engaged in industry-science partnerships show higher R&D intensity than other collaborators (6.3 percent *versus* 2 percent). However, the two groups also differ significantly with respect to export and patenting activities. Thus, the difference in R&D intensity cannot simply be assigned to the fact that firms engage in industry-science partnerships and receive spillovers that lead to higher investment.

In the lower panel of Table 1, the 532 firms with industry-science partnerships are split into those that received public subsidies for their projects and others. Similarly as above, firms that received subsidies show higher R&D intensity but they also differ in export and patenting activities. It remains to be investigated if the higher R&D input can be assigned to the subsidy.

The matching of treated with untreated firms is based on firms' size, age, R&D track record and competitive pressure.

Firms engaged in industry-science partnerships have higher R&D intensity than firm-firm collaborations but they differ with respect to other variables as well.

Table 1. Flemish data – Means of all variables by sub-sample

Sample 1: Firms that collaborate but not with public science versus firms that collaborate with public science			
	No industry-science partnership (358 obs.)	Industry-science partnerships (532 obs.)	t-test on mean differences
Ln(EMP)	4.20	4.34	
GROUP	0.62	0.67	*
FOREIGN	0.33	0.32	
DEX	0.79	0.86	***
Y2006	0.54	0.58	
Ln(AGE)	3.10	3.18	
PATENT	0.09	0.26	***
RDINT	2.00	6.30	***
Sample 2: Firms that collaborate with public science without subsidy receipt versus subsidy recipients			
	Non-subsidized industry-science partnerships (302 obs.)	Subsidized industry science partnerships (230 obs.)	t-test on mean differences
Ln(EMP)	4.31	4.39	
GROUP	0.70	0.63	*
FOREIGN	0.33	0.30	
DEX	0.90	0.84	*
Y2006	0.56	0.62	
Ln(AGE)	3.22	3.12	
PATENT	0.19	0.35	***
RDINT	3.65	9.76	***

Notes: *** (**, *) indicate a significance level of 1 percent (5 percent, 10 percent). Industry dummies omitted.

For the German sample, we also find differences between firms collaborating with public science and other collaborators. The former are on average larger, more active on export markets, and are more likely to have at least one patent. On average, their R&D intensity amounts to 8.8 percent, compared with 4.2 percent for the group of other collaborators (Table 2).

Within the group of German firms that collaborate with science, there are also significant differences between firms that receive a subsidy for the science collaboration and those that do not. Interestingly, on average, the subsidized firms are smaller and younger than the non-subsidized firms. They are nevertheless more likely to have a patent. With respect to R&D intensity, subsidized firms reach almost 13 percent and the non-subsidized firms roughly 7 percent.

Table 2. German data – Means of all variables by sub-sample

Sample 1: Firms that collaborate but not with public science versus firms that collaborate with public science			
	No industry-science partnership (270 obs.)	Industry-science partnerships (804 obs.)	t-test on mean differences
Ln(EMP)	4.45	4.78	***
GROUP	0.57	0.59	
FOREIGN	0.15	0.13	
DEX	0.65	0.76	***
Y2004	0.53	0.54	
Ln(AGE)	2.93	2.86	
PATENT	0.72	0.85	***
RDINT	4.21	8.78	***
Sample 2: Firms that collaborate with public science without subsidy receipt versus subsidy recipients			
	Non-subsidized industry- science partnerships (520 obs.)	Subsidized industry science partnerships (284 obs.)	t-test on mean differences
Ln(EMP)	4.93	4.52	***
GROUP	0.62	0.55	*
FOREIGN	0.13	0.14	
DEX	0.74	0.79	*
Y2004	0.53	0.55	
Ln(AGE)	2.93	2.73	***
PATENT	0.83	0.89	**
RDINT	6.65	12.69	***

Notes: *** (**, *) indicate a significance level of 1 percent (5 percent, 10 percent). Industry dummies omitted.

5.3 Matching

In this sub-section I report the results of the nearest-neighbour matching. First, it is investigated whether the differences in R&D intensity between firms that collaborate with science and other collaborators can be assigned to the fact of engaging in industry-science collaboration. Thus, for each firm in the sample of firms that collaborate with science, I pick the most similar firm from the control group, *i.e.* collaborating firms that chose not to involve public science in their research consortia. The R&D intensity of the drawn controls is used as an estimate for the counterfactual situation, that is, what the firms that collaborate with science would have invested if they had not collaborated with science.

To implement the nearest-neighbour matching, I require that the picked control operates in the same industry as the firm in question. Among those, the firm with the most similar propensity to collaborate is drawn as control (see Table A1 in the Annex for a detailed matching protocol). The propensity to collaborate with public science is determined by the estimation of probit models on the treatment indicator. Results of the probit models are presented in Tables A2 and A3 in the Annex.

Table 3 below presents the matching results for Flanders. Out of the 532 firms that collaborate with science, the matching algorithm succeeds in finding a twin firm for 500 observations. As one can see in the upper panel, the samples are now balanced in the covariates after the matching routine.

Firms engaged in subsidized industry-science collaborations spend more on R&D than non-subsidized R&D collaborators but other variables are different, too.

The treated group of firms does no longer differ significantly in its characteristics from the selected control group which can now be used as an estimate for the counterfactual situation.

For the first estimation, the treatment effect amounts to 3.1 percentage points of R&D intensity (5.87 – 2.77), and is significant at the 1-percent level. Thus, we conclude that firms engaging in industry-science collaborations increase their R&D spending as a response to this “treatment”, all else constant.

The treatment effects estimation for subsidized industry-science collaborations in Flanders is presented in the lower panel of Table 3. Now the group of firms collaborating with public science is split into those that receive subsidies for the public-private partnership and non-subsidized industry-science consortia. The controls for the subsidized firms are drawn as nearest neighbours from the sample of non-subsidized firms. For 222 out of the 230 initial observations, the matching algorithm could find an appropriate control. For this second estimation, the treatment effect is about 5.1 percentage points (9.4 – 4.3), and is also significant at the 1-percent level. Thus, we find that even within the sub-sample of firms engaging in industry-science partnerships, the public subsidy receipt triggers still higher R&D investment. Consequently, full crowding-out effects of the policy of funding research consortia with involvement of public science can be rejected in this setting, as the estimated treatment effect due to the subsidy (about 5 percentage points in terms of R&D intensity) is significantly larger than zero.

When controlling for differences in other variables, treatment effects are positive both for industry-science collaborations and subsidized industry-science collaborations in Flanders.

Table 3. Flemish data – matching results: Means of all variables by sub-sample for treated firms and selected controls

Sample 1: Firms that collaborate but not with public science versus firms that collaborate with public science			
	No industry-science partnership (500 obs.)	Industry-science partnerships (500 obs.)	t-test on mean differences
Ln(EMP)	4.03	4.27	
GROUP	0.62	0.67	
FOREIGN	0.29	0.32	
DEX	0.84	0.86	
Y2006	0.61	0.58	
Ln(AGE)	3.14	3.16	
PATENT	0.22	0.19	
RDINT	2.77	5.87	***
Sample 2: Firms that collaborate with public science without subsidy receipt versus subsidy recipients			
	Non-subsidized industry- science partnerships (222 obs.)	Subsidized industry science partnerships (222 obs.)	t-test on mean differences
Ln(EMP)	3.90	4.34	
GROUP	0.58	0.63	
FOREIGN	0.31	0.32	
DEX	0.92	0.89	
Y2006	0.66	0.62	
Ln(AGE)	3.14	3.13	
PATENT	0.27	0.34	
RDINT	4.33	9.44	***

Notes: *** (**, *) indicate a significance level of 1 percent (5 percent, 10 percent). Industry dummies omitted. Selected controls are active in the same industries as the treated firms.

For the German data, the results of the matching estimator are quite similar. The procedure is equivalent to that run on the Flemish data with the exception that the survey year needs to be added as a matching argument. Thus, the samples are here exactly balanced with respect to industry and year. Based on these restrictions, the most similar firm in terms of the propensity score is drawn as control group for the respective firm in the treatment group. In the sample of firms collaborating with science, the matching algorithm finds appropriate controls for 775 out of the initial 804 firms in the treatment sample. The estimated treatment effect of industry-science collaboration amounts to about 4 percentage points of R&D intensity (8.91 – 4.87), and is significant at the 1-percent level.

Among the industry-science collaborators, we can match 261 of the 284 firms that received a subsidy with appropriate controls, *i.e.* firms collaborating with science without being subsidized. Here, too, the treatment effect is of similar magnitude as in the Flemish sample. It amounts to about 3.7 percentage points (13.01 – 9.33) and is also significant at the 1-percent level.

Table 4. German data - matching results: Means of all variables by sub-sample for treated firms and selected controls

German firms have positive treatment effects, too.

Sample 1: Firms that collaborate but not with public science versus firms that collaborate with public science			
	No industry-science partnership (775 obs.)	Industry-science partnerships (775 obs.)	t-test on mean differences
Ln(EMP)	4.43	4.62	
GROUP	0.57	0.58	
FOREIGN	0.16	0.14	
DEX	0.77	0.75	
Y2004	0.55	0.55	
Ln(AGE)	2.79	2.85	
PATENT	0.85	0.85	
RDINT	4.87	8.91	***

Sample 2: Firms that collaborate with public science without subsidy receipt versus subsidy recipients			
	Non-subsidized industry- science partnerships (261 obs.)	Subsidized industry science partnerships (261 obs.)	t-test on mean differences
Ln(EMP)	4.65	4.57	
GROUP	0.54	0.56	
FOREIGN	0.17	0.13	
DEX	0.79	0.79	
Y2004	0.55	0.55	
Ln(AGE)	2.86	2.78	
PATENT	0.88	0.89	
RDINT	9.33	13.01	***

Notes: *** (**, *) indicate a significance level of 1 percent (5 percent, 10 percent). Industry dummies omitted. Selected controls are active in the same industries as the treated firms and refer to the same year.

Therefore, we can conclude that subsidizing industry-science partnerships does not appear to be subject to full crowding-out effects in either Germany or Flanders.

Treatment effects would not necessarily remain as strong if the schemes were extended to additional firms.

It should be noted, however, that it is not possible to conclude that an expansion of such policy schemes would lead to higher R&D in the economy. The treatment effects estimation only allows evaluating the program effect for the firms that were actually treated. An expansion of such a policy may lead to entry of firms that show significantly different characteristics from the currently treated firms. Thus, it may happen that treatment effects would get smaller if firms that newly enter the schemes lack the necessary absorptive capacity to benefit from scientific knowledge or are in a different financial situation so that they are not able to raise additional capital for further R&D (even in the presence of a subsidy) and thus cause higher crowding-out effects of the scheme. Consequently, the analysis above is only able to report positive treatment effects for the *status quo* but these findings cannot be used as *ex-ante* evaluations of changes in the schemes.

As a robustness check, I finally control for heterogeneous collaboration patterns of the firms in the sample. Firms may either collaborate horizontally, vertically or in both directions over and above their collaboration with public science. Consequently, I perform analyses equivalent to those above but include dummies for the other collaboration patterns as a matching argument. Thus, the drawn controls are active in the same industry, are most similar in the control variables as used above and also show the same collaboration pattern with respect to vertical and horizontal collaboration as the treated firms. As the results are virtually the same as above I do not present them here.

6. Conclusions

This study has shown an example for the evaluation of industry-science R&D collaborations. Industry-science partnerships may influence the R&D activities of the involved business partners. As outlined, theories of industrial organization suggest that R&D collaborations may lead to higher R&D because firms can internalize potential external effects of R&D, that is, free-riding of other firms due to knowledge spillovers. Furthermore, it has been described that collaborations with universities or other public research institutions may lead to higher R&D than collaborations with horizontally related firms as the former do not exert a negative externality on profitability since universities are not involved in any market rivalry with the firm.

In addition to the potential knowledge spillover effect, business R&D may be influenced by subsidies. Granting subsidies to research consortia rather than individual firms is currently a popular policy, and among the former, industry-science partnerships receive preferential treatment in many EU member states. Thus, firms may benefit in two ways from the collaboration with science. First, they may benefit from knowledge spillovers and second, public subsidies lower the price of R&D conducted in the firm.

As an example for possible evaluations of the benefits of industry-science collaborations I employ nearest-neighbour matching techniques to firm level data from Germany and Flanders. First, treatment effects of R&D collaboration with public science are estimated using comparable firms that collaborate in R&D, but not with public science, as a control group. Second, the firms that collaborate with public science are split into those that engage in subsidized industry-science consortia and those that collaborate with public science without being subsidized. For both scenarios, I find positive treatment effects, and can thus reject full crowding-out effects of policy schemes supporting industry-science collaborations.

It should be noted, however, that the analysis cannot tell whether an expansion of such policies would lead to similar treatment effects. In the extreme case, all companies that could potentially benefit from collaborating with science may actually do so already. New entrants into a policy scheme for (subsidized)

science-industry collaboration may not show an increase in R&D as they, for instance, may lack the necessary absorptive capacity. Thus, the results of the treatment effects analysis can only shed light on actual program participants. The findings cannot be extrapolated to a hypothetical situation with more participating firms.

In addition, industry-science collaborations may not be unambiguously welfare-enhancing. If it is believed that the primary task of university research is basic science and that results of basic science lead to higher welfare in the long run, one may ask whether basic research suffers from industry-science collaboration in the long term. Increased commercialization of university research may distract researchers from their basic research tasks. This assumption is not implausible as a firm typically seeks specific solutions for technological problems emerging in its business. Thus, engaging in industry-science collaborations may force university researchers to shift their attention to more applied research questions that possibly have to be addressed within tight deadlines. Basic research output might suffer under these circumstances. Czarnitzki *et al.* (2009) analyze this question using individual data of German professors. They correlate their publication counts and quality with patenting activity where patents are differentiated into purely academic patents and corporate patents. The latter are patents where the university researcher appears as the inventor and a firm as the patent applicant. This can be interpreted as an indicator for an engagement in industry-science collaboration. Regression analysis shows that such collaboration harms the publication output of the scientist with respect to both quantity and quality whereas commercialization activity measured as academic patenting does not. Lower(-quality) publication output may be an indication of the opportunity cost of science-to-industry technology-transfer policies, especially if additional subsidies to industry-science collaborations are financed by reductions in basic public university budgets – a trend that can be observed for Germany.⁴ The potential benefits in business R&D should therefore be carefully assessed against potentially negative effects occurring in knowledge output of public science.

The benefit of industry-science collaboration for business R&D should be carefully balanced against the opportunity cost in terms of lower academic publication output.

⁴ Between 1981 and 2005, German higher education R&D expenses remained more or less constant at 0.4 percent of GDP. During the same time, however, the share of higher education R&D financed by the business sector grew from 2 percent to 14 percent (OECD 2009).

Annex: Matching protocol and probit estimations

The following matching protocol summarizes the empirical implementation of the nearest neighbour matching procedure used in this study.

Table A1. The matching protocol

Step 1	Specify and estimate a probit model of engaging in industry-science collaboration and receiving a subsidy, respectively, to obtain the propensity scores $\hat{P}(X)$.
Step 2	Restrict the sample to common support: delete all observations on treated firms with probabilities larger than the maximum and smaller than the minimum in the potential control group. In this study, I apply the common support restriction for each industry separately, as it is required that the treated firms and selected controls belong to the same industry (see Step 5).
Step 3	Choose one observation from the sub-sample of treated firms and delete it from that pool.
Step 4	Calculate the distance between this firm and each non-subsidized firm in order to find the most similar control observation. As we match on the propensity score, we use a Euclidian distance. (In case multiple matching arguments are used a standard choice is the computation of a Mahalanobis distance. This has been done for the robustness check where hybrid matching has been used.)
Step 5	Select the observation with the minimum distance from the remaining sample. In this study, I restrict the potential control group to firms that are active in the same industry as the treated firm in question. (Do not remove the selected controls from the pool of potential controls, so that it can be used again.)
Step 6	Repeat Steps 3 to 5 for all observations on subsidized firms.
Step 7	Using the matched comparison group, the average effect on the treated can thus be calculated as the mean difference of the matched samples: $\hat{\alpha}_{\pi} = \frac{1}{n^T} \left(\sum_i Y_i^T - \sum_i Y_i^C \right)$ with Y_i^C being the counterfactual for firm i and n^T the sample size (of treated firms). Note that the same observation for Y_i^C may appear more than once in that group.
Step 8	As we perform sampling with replacement to estimate the counterfactual situation, an ordinary t -statistic on mean differences is biased, because it does not take the appearance of repeated observations into account. Therefore, we have to correct the standard errors for valid statistical inference. We follow Lechner (2001) and calculate his estimator for an asymptotic approximation of the standard errors.

Tables A2 and A3 present the propensity score estimation for the Flemish and German samples. The propensity scores are used to pick the most similar control observation within the matching procedure.

Table A2. Flemish data: Probit regressions on treatment dummies

Variable	SAMPLE 1	SAMPLE 2
LnEMP	-0.689*** (0.128)	-0.507*** (0.134)
(LnEMP) ²	0.076*** (0.014)	0.062*** (0.014)
GROUP	0.296** (0.117)	-0.228 (0.158)
FOREIGN	-0.169 (0.116)	-0.061 (0.146)
Y2006	0.088 (0.092)	0.199* (0.121)
EXPORT	0.221* (0.126)	0.279 (0.184)
LnAGE	0.072 (0.054)	-0.062 (0.077)
PATENT	0.646*** (0.133)	0.451*** (0.141)
Intercept	0.868** (0.348)	0.435 (0.425)
Industry dummies	YES	YES
McFadden R ²	0.09	0.11

Note: Standard errors in parentheses. *** (**, *) indicate a significance level of 1 percent (5 percent, 10 percent).

Table A3. German data: Probit regressions on treatment dummies

Variable	SAMPLE 1	SAMPLE 2
LnEMP	-0.092 (0.118)	-0.117 (0.110)
(LnEMP) ²	0.019* (0.011)	0.007 (0.009)
GROUP	-0.081 (0.105)	-0.141 (0.116)
FOREIGN	-0.177 (0.136)	0.228 (0.150)
Y2004	-0.196* (0.109)	-0.037 (0.109)
EXPORT	0.177* (0.110)	0.347*** (0.125)
LnAGE	-0.127*** (0.054)	-0.049 (0.059)
PATENT	0.530*** (0.135)	0.438*** (0.159)
Intercept	0.615 (0.386)	-0.597 (0.434)
Industry dummies	YES	YES
McFadden R ²	0.07	0.07

Note: Standard errors in parentheses. *** (**, *) indicate a significance level of 1 percent (5 percent, 10 percent).

References

- Almus, M. and Czarnitzki, D. (2003). "The effects of public R&D subsidies on firms' innovation activities: the case of Eastern Germany". *Journal of Business and Economic Statistics*, (21:2), pp. 226-236.
- d'Aspremont, C. and Jacquemin, A. (1988). "Cooperative and Noncooperative R&D in Duopoly with Spillovers". *American Economic Review*, (78:5), pp. 1133-1137.
- Arrow, K.J. (1962). "Economic Welfare and the Allocations of Resources of Invention", in: Nelson, R.R. (ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton University Press, Princeton, NJ, USA.
- Atallah, G. (2002). "Vertical R&D Spillovers, Cooperation, Market Structure, and Innovation". *Economics of Innovation and New Technology*, (11:3), pp. 179-209.
- Baumol, W. (1993). *Entrepreneurship, Management and the Structure of Payoffs*, MIT Press, Cambridge, MA, USA.
- Beath, J., Katsoulacos, Y. and Ulph, D. (1988). "R&D rivalry versus R&D cooperation under uncertainties". *Recherches Economiques de Louvain*, (54), pp. 373-384.
- Belderbos, R., Carree, M., Diederer, B., Lokshin, B. and Veugelers, R. (2004a). "Heterogeneity in R&D cooperation strategies". *International Journal of Industrial Organization*, (22:8-9), pp. 1237-1263.
- Belderbos, R., Carree, M. and Lokshin, B. (2004b). "R&D cooperation and firm performance". *Research Policy*, (33:10), pp. 1477-1492.
- Belderbos, R., Carree, M. and Lokshin, B. (2006). "Complementarity in R&D Cooperation Strategies". *Review of Industrial Organization*, (28:4), pp. 401-426.
- BMBF (German Federal Ministry of Education and Research) (2009). *PROFI Database*. <http://foerderportal.bund.de/foekat/jsp/SucheAction.do?actionMode=searchmask>
- Branstetter, L.G. and Sakakibara, M. (2002). "When Do Research Consortia Work Well and Why? Evidence from Japanese Panel Data". *American Economic Review*, (92:1), pp. 143-159.
- Busom, I. (2000). "An empirical evaluation of the effects of R&D subsidies". *Economics of Innovation and New Technology*, (9:2), pp. 111-148.
- Cassiman, B. and Veugelers, R. (2002). "R&D Co-operation and Spillovers: Some Empirical Evidence from Belgium". *American Economic Review*, (92), pp. 1169-1184.
- Cassiman, B. and Veugelers, R. (2006). "In Search of Complementarity in Innovation Strategy: Internal R&D, Cooperation in R&D and External Technology Acquisition". *Management Science*, (52:1), pp. 68-82.
- Cohen, W. and Levinthal, D. (1989). "Innovation and learning: the two faces of R&D". *The Economic Journal*, (99), pp. 569-596.
- Czarnitzki, D., Ebersberger, B. and Fier, A. (2007). "The Relationship between R&D Collaboration, Subsidies and R&D performance: Empirical Evidence from Finland and Germany". *Journal of Applied Econometrics*, (22:7), pp. 1347-1366.
- Czarnitzki, D. and Fier, A. (2002). "Do innovation subsidies crowd out private investment? Evidence from the German Service Sector". *Applied Economics Quarterly (Konjunkturpolitik)*, (48:1), pp. 1-25.
- Czarnitzki, D. and Fier, A. (2003). "Publicly funded R&D collaborations and Patent Outcome in Germany". ZEW Discussion Paper No. 03-24, Mannheim, Germany.
- Czarnitzki, D., Glänzel, W. and Hussinger, K. (2009). "Heterogeneity of Patenting Activity and Its Implications for Scientific Research". *Research Policy*, (38), pp. 26-34.

- Czarnitzki, D. and Hottenrott, H. (2009). "Financial Constraints: Routine versus Cutting Edge R&D Investment". *Journal of Economics and Management Strategy*, forthcoming.
- Czarnitzki, D., Hottenrott, H. and Thorwarth, S. (2009). "Industrial Research versus Development Investment: The Implications of Financial Constraints". ZEW Discussion Paper No. 09-049, Mannheim, Germany.
- David, P.A., Hall, B.H. and Toole, A.A. (2000). "Is public R&D a complement or substitute for private R&D? A review of the econometric evidence". *Research Policy*, (29), pp. 497-529.
- De Bondt, R. and Veugelers, R. (1991). "Strategic investment with spillovers". *European Journal of Political Economy*, (7), pp. 345-366.
- Duguet, E. (2004). "Are R&D subsidies a substitute or a complement to privately funded R&D? Evidence from France using propensity score methods for non experimental data". *Revue d'Economie Politique*, (114:2), pp. 263-292.
- Eurostat (2008). *Science, Innovation and Technology in Europe*, Luxembourg.
- González, X., Jaumandreu, J. and Pazó, C. (2005). "Barriers to innovation and subsidy effectiveness". *RAND Journal of Economics*, (36:4), pp. 930-949.
- Hagedoorn, J. and Narula, R. (1996). "Choosing organisational modes of strategic technology partnering: international and sectoral differences". *Journal of International Business Studies*, (27), pp. 265-284.
- Hall, B.H. (2002). "The financing of research and development". *Oxford Review of Economic Policy*, (18:1), pp. 35-51.
- Hall, B.H. and Lerner, J. (2009). "The financing of R&D and innovation". NBER Working Paper No. 15325, Cambridge, MA, USA.
- Hall, B.H., Link, A.N. and Scott, T.J. (2003). "Universities as research partner". *Review of Economics and Statistics*, (85:2), pp. 485-491.
- Heckman, J.J., Lalonde, R.J. and Smith, J.A. (1999). "The economics and econometrics of active labor market programs." in Ashenfelter, A. and Card, D. (Hrsg.), *Handbook of labor economics, Volume 3*, pp. 1866-2097, Amsterdam, The Netherlands.
- Hussinger, K. (2008). "R&D and Subsidies at the Firm Level: An Application of Parametric and Semi-Parametric Two-Step Selection Models". *Journal of Applied Econometrics*, (23), pp. 729-747.
- Imbens, G.W. and Wooldridge, J.M. (2009). "Recent Developments in the Econometrics of Program Evaluation". *Journal of Economic Literature*, (47:1), pp. 5-86.
- Inkmann, J. (2000). "Horizontal and Vertical R&D Cooperation". CoFE Discussion Paper No. 00-02, Center of Finance and Econometrics, University of Konstanz, Germany.
- Jacquemin, A. (1988). "Co-operative agreements in R&D and European antitrust policy". *European Economic Review*, (32), pp. 551-560.
- Kamien, M.I., Muller, E. and Zang, I. (1992). "Research Joint Ventures and R&D Cartels". *American Economic Review*, (82:5), pp. 995-1012.
- Kamien, M.I. and Zang, I. (2000). "Meet Me Halfway: Research Joint Ventures and Absorptive Capacity". *International Journal of Industrial Organization*, (18:7), pp. 995-1012.
- Katsoulacos, Y.S. and Ulph, D.T. (1998). "Endogenous Spillovers and the Performance of Research Joint Ventures". *Journal of Industrial Economics*, (46:3), pp. 333-357.
- Katz, M.L. (1986). "An Analysis of Cooperative Research and Development". *RAND Journal of Economics*, (17:4), pp. 527-543.

- Kesteloot, K. and Veugelers, R. (1995). "Stable R&D co-operation with spillovers". *Journal of Economics and Management Strategy*, (4), pp. 651-672.
- Klette, T.J., Møen, J. and Griliches, Z. (2000). "Do subsidies to commercial R&D reduce market failures? Microeconomic evaluation studies". *Research Policy*, (29), pp. 471-495.
- Ientile, D. and Mairesse, J. (2009), "A policy to boost R&D: Does the R&D tax credit work?". *EIB Papers*, 14(1), in this issue.
- Lach, S. (2002). "Do R&D subsidies stimulate or displace private R&D? Evidence from Israel". *Journal of Industrial Economics*, (50:4), pp. 369-390.
- Leahy, D. and Neary, P. (1997). "Public policy towards R&D in oligopolistic industries". *American Economic Review*, (87:4), pp. 642-662.
- Lechner, M. (1998). *Training the East German labour force: microeconomic evaluations of continuous vocational training after unification*, Physica, Heidelberg, Germany.
- Lechner, M. (2001) "Identification and Estimation of Causal Effects of Multiple Treatments under the Conditional Independence Assumption", in Lechner, M. and Pfeiffer, F. (eds.), *Econometric Evaluation of Labour Market Policies*, Physica, Heidelberg, pp. 43-58.
- Mansfield, E. (1985). "How Rapidly does New Industrial Technology Leak Out?" *Journal of Industrial Economics*, (34:2), pp. 217-223.
- Martin, S. (1997). "Public policies towards cooperation in research and development: The European Union, Japan, the United States", in W. Comanor, A. Goto, L. Waverman (Eds), *Competition policy in the global economy*, Routledge, pp. 245-288, London, UK/New York, USA.
- Motta, M. (1992). "Co-operative R&D and vertical product differentiation". *International Journal of Industrial Organisation*, (10), pp. 643-661.
- Ordover, J. and Willig, R. (1985). "Antitrust for high-technology industries: assessing research joint ventures and mergers". *Journal of Law and Economics*, (28), pp. 311-333.
- Rosenbaum, P.R. and Rubin, D.B. (1983). "The central role of the propensity score in observational studies for causal effects". *Biometrika* (70:1), pp. 41-55.
- Rubin, D.B. (1977). "Assignment to treatment group on the basis of covariate". *Journal of Educational Statistics*, (2), pp. 1-26.
- Sakakibara, M. (1997). "Evaluating government-sponsored R&D consortia in Japan: who benefits and how?". *Research Policy*, (26), pp. 447-473.
- Sakakibara, M. (2001). "The Diversity of R&D Consortia and Firm Behaviour: Evidence from Japanese Data". *The Journal of Industrial Economics*, (49:2), pp. 181-196.
- Shapiro, C. and Willig, R. (1990). "On the antitrust treatment of production joint ventures". *Journal of Economic Perspectives*, (4), pp. 113-130.
- Steurs, G. (1995). "Inter-industry R&D spillovers: What difference do they make?" *International Journal of Industrial Organization*, (13), pp. 249-276.
- Suzumura, K. (1992). "Co-operative and noncooperative R&D in oligopoly with spillovers". *American Economic Review*, (82), pp. 1307-1320.
- Veugelers, R. (1998). "Technological collaboration: an assessment of theoretical and empirical findings". *De Economist*, (149), pp. 419-443.

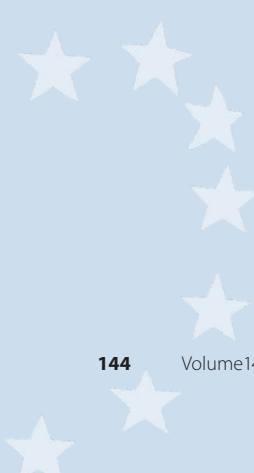
- Veugelers, R. and Cassiman, B. (2005). "R&D cooperation between firms and universities – Some empirical evidence from Belgian manufacturing". *International Journal of Industrial Organization*, (23), pp. 355-379.
- Vonortas, N. (1994). "Inter-firm co-operation in imperfectly appropriable research". *International Journal of Industrial Organisation*, (12), pp. 413-435.
- Wallsten, S.J. (2000). "The effects of government-industry R&D programs on private R&D: the case of the Small Business Innovation Research Programm". *RAND Journal of Economics*, (31:1), pp. 82-100.

ABSTRACT

In this article we address various issues raised by the evaluation of the R&D tax credit policy. We first consider the studies that estimate the direct effects of the tax credit on R&D inputs. We discuss results obtained through different approaches and methods and show that they give a contrasted picture of the policy's effectiveness. Next we argue that a comprehensive evaluation of the R&D tax credit should include other outcomes and present studies focussing on them. We also initiate a very tentative meta-analysis to obtain a more synthetic view on the various evaluation results. We finally conclude that harmonization and increased comparability in evaluation studies would be useful to bridge the gap between evaluation and policy design and implementation.

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A policy to boost R&D: Does the R&D tax credit work?

1. Introduction

Any government has scarce resources to fulfil their various responsibilities and should therefore make use of them as wisely and efficiently as possible. In the last thirty years there has been an increasing demand from citizens and firms for improved accountability of government management and policies. The need for systematic quantitative evaluations of the efficiency of economic instruments and the use of public resources has now become well-established in the public debate in modern democracies.

In parallel, the emergence of the knowledge-driven economy has led to research and innovation being considered as crucial factors of competitive advantage and main sources of future economic growth. Accordingly, public policies to stimulate investment in Research and Development (R&D) by private firms are actively implemented in most industrialized countries. They are rooted in the concern that due to knowledge spillovers private firms invest less in R&D than would be desirable from society's viewpoint.

The R&D tax credit, which was launched in the early 1980s in the US, France and Canada and which has gained importance and spread to other countries since then, is a major such policy instrument. The large amounts of public money it involves, under the form of forgone tax revenue, make it an obvious object of public-policy evaluations. Asking "Does the R&D tax credit work?" is an important and legitimate question, and indeed a significant international literature has developed to address it.

Concurrently to these evolutions, from a technical perspective, the remarkable progress in data collection, processing and possibilities of diffusion and the development of statistical methods made it possible to conduct much more rigorous and convincing econometric analyses and policy evaluations. In particular, the micro-level data available today allow for more relevant, precise and reliable analyses by providing highly variable and richer information. When also accessible in the form of panels (*i.e.*, not only as a cross-section but also in the time dimension), such micro-data allow for more realistic dynamic model specifications and for useful controls of potential estimation bias resulting from unobserved heterogeneity across firms. International comparisons of econometric studies and policy evaluations, in spite of their many additional difficulties, can also offer important insights and help in improving policy design.

There are two very different kinds of policy evaluations. Implementation evaluations focus on delivery times and deadlines, cost optimization and transparency of public policies; they consist mainly in building indicators and scoreboards, doing specific surveys and applying audit methods. Outcome evaluations which measure the effects of policies on their targets usually take the form of statistical analyses and econometric studies. They are most difficult since outcomes can be uncertain and variable, being affected by many uncontrolled variables and differing in the short and long terms. Policies can also have side effects or unintended consequences, good or bad, besides their targeted outcomes.

This article intends to shed light on the effectiveness of R&D tax credit by explaining how it can greatly differ in its design, by discussing the main methods of evaluations which are used, and by briefly surveying the results of several of the more recent studies, already published or not, in the international literature. Hall and Van Reenen (2000) in their excellent survey article consider a wide array of older articles and review the methods of evaluations from a broadly similar perspective as ours.



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In the next section of the article, we present the R&D tax credit in its different forms within the broader scope of public policies towards research and discuss the various outcomes to be considered for its evaluation. In the third section, we explain the evaluation methods focusing on the direct impacts of the tax credit on firms' R&D expenditures and illustrate them by some of the results of recent analyses. In the fourth section, we consider the much less frequent evaluations that have been conducted for other types of outcomes. In the fifth section we evoke the difficulties of comparing appropriately the results of the various evaluation studies, and illustrate some of these difficulties by presenting a tentative and yet incomplete exercise in meta-analysis. The sixth section concludes.

2. What is the R&D tax credit? Designs, objectives and outcomes

Firms cannot fully appropriate the benefits of their R&D investments: Patents are circumvented in different ways, and valuable process and product innovations are emulated more or less quickly. Even when intellectual property rights are enforced effectively, R&D generates positive externalities that spill over to other firms and benefit the economy at large. Firms thus tend to invest less in R&D projects than they should since they know that other firms will capture part of the returns, or they tend to wait for other firms to engage in R&D projects rather than doing so themselves. As a result firms will normally tend to increase their R&D expenditures to the size where their expected private returns and marginal costs will match, but they will not increase them further to the level that would equalize marginal social costs and marginal social returns and maximize economic efficiency and social welfare. This market failure can be corrected by direct public funding of research activities performed by public research organisations and universities and by economic policies supporting private R&D.

2.1 R&D tax credit and direct subsidies

An R&D tax credit allows firms to deduct part of their R&D expenditure from the corporate tax bill.

The basic idea of the tax credit is to provide a built-in incentive for firms to increase their research activities by allowing them to deduct a share of their corresponding expenditures from their corporate taxes, and thus lowering their cost and increasing their expected returns. It is a relatively recent answer to the need for public intervention in private research and is part of a broader public research policy that, besides the funding and monitoring of public research, mainly includes subsidies directly granted to firms.¹ The R&D tax credit is generally opposed to R&D subsidies, since they have different advantages and downsides. The main advantage of the tax credit is that firms are completely free in choosing, financing and conducting their R&D projects. This argument is consistent with the basic view that profit-maximizing agents make more efficient decisions than centralized authorities. However, it remains possible that firms might use the tax credit to support poor-quality or excessively risky projects.

R&D subsidies consist in funds directly provided to firms applying for financial support of a given research project to specialized public agencies. The main advantage of subsidies is that before being granted, the research projects submitted by the firms are examined and selected by these agencies, which can control their quality and orientation and are ideally able to decide on projects with high social returns. Research subsidies can thus be targeted to specific goals and their implementation can be quite flexible. To a lesser extent, the tax credit can also be modulated with respect to firms' characteristics, in particular their size and overall R&D expenditure. In a number of countries, such as

¹ It also includes the immediate direct deductibility of the major part of R&D investment (wages of R&D personnel and intermediate consumption expenditures of R&D activities) from the base of corporate taxes. This is in contrast to the other types of investments, such as buildings and equipments, which in general have to be amortized over given fiscal service lives.

the Netherlands and Norway, the rate of the tax credit is higher for smaller firms; in France it can decrease for the fraction of eligible R&D expenditure exceeding certain ceilings. Finally, a drawback of subsidies relative to the tax credit is that they involve higher costs both for the firms applying and competing for them and for the public agencies monitoring them.

Hægeland and Møen (2007a) have studied the relationship and relative efficiency of R&D subsidies and the tax credit on the same representative panel of Norwegian firms. They conclude that both instruments are complements at the level of the firm, while they seem to be substitutes at the level of the economy as a whole. They also provide evidence that the tax credit generates more additional private R&D than direct subsidies.

2.2 Main designs

Two main designs of the R&D tax credit can be distinguished, the “volume tax credit” and the “incremental tax credit”. The two have different implications in terms of allocation of the credit and in terms of incentives and efficiency. Deciding which of these two designs is better is still an open question raising many issues, in theory as well as in practice. Before going further, it is useful to shortly recall their main features.

The volume tax credit is based on current R&D expenditures in the fiscal year, either all of them or a part of them depending on their exact definition. For example if the eligible base is the total current R&D expenditures and the rate is equal to 20 percent, then firms can deduct an amount equal to 20 percent of these expenditures from their corporate taxes, implying that at the margin (as well as on average in this simple case) the R&D cost for the firm is 20 percent lower than its market price. Firms that invest in R&D can always benefit from the volume tax credit, irrespective of whether they are increasing or decreasing their R&D expenditures.

The ‘volume tax credit’ applies to total R&D expenditure, the ‘incremental tax credit’ only to spending increases.

By contrast, under the incremental tax credit only firms that tend to increase their R&D expenditures may benefit, since the tax credit is based on the difference between a reference level and the current level of expenditures. This reference level is usually defined as an average of past expenditures. In France at the beginning of the R&D tax credit, from 1983 to 1990, the reference level was simply expenditures in the previous year, and later until 2004 it was the average of expenditures in the two previous years. Thus, the tax credit is positive when R&D expenditures are increasing and negative if they are decreasing. In the latter case, the (negative) tax credit will be deductible from future positive tax credits, if a mechanism of negative tax credit is implemented like it was in France; it will be zero if such mechanism is not implemented. The incremental tax credit is difficult to analyze because its effects are reduced by the fact that current expenditures increase the reference level of the following years. Mixed tax credit policies that are a combination of the two types of tax credit can also be implemented. That was the case of France from 2004 to 2008, when a particularly generous pure volume tax credit was adopted.

Simple microeconomic theory will tend to give preference to the incremental tax credit, since it seems rational for the government to support private R&D only when private marginal productivity is lower than marginal cost while (expected) social marginal productivity is higher. The first-best policy would thus be to subsidize only the R&D activities that firms would not have done in the absence of the tax credit (and only up to the point where their social marginal productivity and cost are equalized). However, the government do not know how much firms would have invested in R&D in the absence of the tax credit, which is difficult to assess. In this setting of asymmetric information, the conservative assumption usually made is that the firm’s R&D expenditures would have been stable (in constant prices) in the absence of the tax credit. The incremental tax credit thus appears as a second-best policy

The incremental tax credit tends to avoid subsidizing R&D that is done anyway but it is more complex and might lead to opportunistic behaviour.

which avoids supporting R&D expenditures that firms would do anyway. In contrast, the volume tax credit subsidizes R&D expenditures in their entirety.

However, the comparison between the volume tax credit and the incremental tax credit involves other considerations, too. In particular, the incremental tax credit can incite firms to adopt opportunistic R&D strategies of stop-and-go and of outsourcing. It is also deemed to be complex and costly for them. The negative tax credit mechanism, when it is implemented, is much criticized for its deterring effect. It cancels out or weakens the tax credit incentives to catch up on R&D activities for firms which have been cutting them down because of economic difficulties and are currently recovering.

Besides the major differences between the volume and incremental tax credit, there exist numerous smaller variations, which may nonetheless matter in practice. Only eligible R&D expenditures can be declared by firms, and eligibility can be defined by law in specific ways, favouring for example cooperative research with academic and public laboratories or the hiring of young PhD researchers, as is currently the case in France. The definition of the tax credit also generally includes one or several ceilings as well as carry-forward and carry-back rules (which allow to transfer to following years the part of tax credit which is higher than the current corporate tax). Such smaller design differences tend to vary across countries and possibly sectors, as well as over time in a given country. They contribute to the complexity of evaluations and to making evaluations more difficult to compare among each other. For example, a volume tax credit with a rate of 30 percent and a ceiling on the total of eligible R&D expenditures is not equivalent to a volume tax credit with a rate of 20 percent and no ceiling, and assessing which one is more efficient is not straightforward.

2.3 Direct objectives and main evaluation outcomes

Although the question of the objective(s) of the R&D tax credit is essential, it is scarcely addressed explicitly. The answer has important implications for the evaluation of the policy. Depending on the objective of the policy, its performance should not be measured in the same way. Thus whether “the R&D tax credit works” depends on the objective(s) and, hence, on what “working” means precisely. Does it mean “increasing R&D investment” – full stop? Or does it mean increasing R&D investment with positive follow-on effects on innovation, productivity, competitiveness, and social welfare?

The objective of the tax credit can also change over time. This point may be illustrated by the French example. When introduced in 1983, the French tax credit was mainly aimed at fostering private R&D (expenditure and R&D personnel). This is still its official objective as part of the Lisbon Strategy of the European Union.² However, it is also considered today as a major fiscal incentive to attract foreign R&D investment and deter French firms from relocating to other countries. The transition from an incremental to a volume tax credit, which multiplies the amount of public funding by a factor of about three, is thus a way to protect the domestic industry and to make it more attractive. It may be viewed as a compensation for lower corporate tax rates elsewhere.

A comprehensive analysis of the objectives of the tax credit should distinguish between those which are directly related to R&D and innovation and those which are less directly related and ultimately target other economic variables. As most of the literature, the scope of this article is limited to the former and to the main outcomes naturally following from them that should be taken into account in

² The Lisbon strategy was defined by the European Council in March 2000 to make the European Union “the most dynamic and competitive knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the environment by 2010”. As far as R&D is concerned, the objective was to reach a ratio of R&D expenditures to GDP of 3 percent by 2010 with the following decomposition: two-thirds for the private sector and one-third for the public sector.

the evaluations of the performance of the R&D tax credit. All in all, the various outcomes that can be considered are the following:

- Impact on existing R&D activities (level or rate of growth of R&D expenditures, R&D-to-output ratios, R&D capital, number of researchers, shares of researchers and engineers in R&D personnel *etc.*);
- Impact on starting R&D activities (as above, *plus* the number of firms performing R&D);
- Impact on innovation output (product and process innovations, patents), productivity (labour and total factor productivity) and other performance indicators (share of “innovative sales”, profitability *etc.*);
- Other (possibly unintended) impacts such as impact on researcher wages; and
- Impact on social welfare (comprehensive cost-benefit analysis).

The results of the evaluation analyses can be presented and summarized in very different ways, which make them often difficult to compare precisely. The results concerning the impact on R&D level and intensity are usually cast in terms of elasticities and multipliers. Elasticities of R&D with respect to the tax credit measure the impacts on R&D expenditures of changes in the tax credit rate. Such elasticities have to be assessed in the short and long run and cannot be directly interpreted in terms of policy efficiency; but they can serve to do simulations of policy changes. Multipliers, also labelled “bang for the buck” (BFTB), estimate the amount of additional R&D (say in euros) that is generated by one euro of tax credit. A number of authors tend to consider that a multiplier above one is an indication that the tax policy is efficient. Conversely, a multiplier below one would point to an inefficient policy on the argument that since one euro of forgone tax receipt generates less than one euro of additional R&D, direct public funding of R&D, through public research or subsidies, would be a better instrument. However, this is not obvious – at least as long as the multiplier is not negative – since in principle what matters is the comparison of the corresponding net social returns.

The ‘bang-for-the-buck’ multiplier is the increase in firms’ R&D per euro of R&D tax credit.

3. Evaluation of the effects of the R&D tax credit on R&D investment

Even when focusing on a precisely defined outcome, evaluations vary widely in terms of methods of analysis. We distinguish four broad methods here: survey analyses; quasi-natural experiments relying on time and policy-design changes; dummy-variable regressions and matching techniques; and structural econometric modelling. We mainly concentrate on the last one, which we tend to prefer. Of course these methods are complementary. They are also related in many respects and the distinction between them is not always clear-cut in practice. As shown below, the dummy-variable regressions and matching techniques can be very close either to quasi-natural experiments or to structural econometric models, depending on how these methods are understood and implemented.

Ideally, one might consider that evaluations should be based on randomized experiments. To adopt the language used in such experiments, we would say that the objective of the tax credit evaluation is to assess whether, and to what extent, a “treatment”, *i.e.*, the tax credit has an effect on the R&D behaviour of firms. Treatment evaluations usually rely on the comparison between the average outcome of a treatment group and that of a control group which is not treated. Of course the allocation of firms to one group or the other must be exogenous and random. Otherwise the treated firms may be intrinsically different from the ones that are not treated. If the allocation is randomized, the control group is considered a valid counterfactual and can be used to determine the outcome the treatment group would have had in the absence of the treatment. The evaluation of new drugs is usually conducted on the basis of such randomized experiments. In the field of economics, experiments have been applied to the evaluation of schooling policies (see Krueger and Whitmore 2001 for a famous example).

A crucial issue when trying to evaluate the R&D tax credit along similar lines is the absence of a directly observable counterfactual, since the implementation of an experiment would imply that only some randomly selected firms receive the tax credit (which is forbidden by competition law). In order to circumvent this limitation, researchers rely on the various methods described in the following subsections. Surveys may be viewed as an undemanding way of constructing a counterfactual by asking beneficiary firms directly “What if you did not benefit from a tax-credit?”, and *vice versa*. In turn, quasi-natural experiments and matching methods use exogenous variations in the design of the tax credit and in the firm’s self-selection to benefit from it, together with appropriate statistical techniques, to overcome the lack of randomization. Finally, structural econometric modelling applies similar statistical techniques but relies more strongly on an economic model of the firm’s behaviour, with the ambition of being more informative in the assessment of policy efficiency.

3.1 Survey analyses

As firms themselves know best what their R&D expenditure would have been absent the tax credit, some studies use surveys.

The survey-based approach relies on the straightforward idea that firms themselves know best what their R&D expenditures would have been in the absence of the tax credit. The multiplier (or BFTB) is simply the ratio between the total expenditures that would have been forgone in the absence of the tax credit and the total amount of the tax credit (possibly adding monitoring costs). Such an estimate, however, does not allow to foretell the effect of future policy changes or to distinguish between short- and long-run impacts. Mansfield and Switzer (1985) in a pioneer survey of the Canadian tax credit find a BFTB equal to 0.3-0.4, which is weak. Hægeland and Møen (2007b) in a recent survey of the Norwegian R&D tax credit obtain a BFTB between 2.12 and 2.65, which is quite high. Yet, contrary to Mansfield and Switzer, they rely on qualitative data to which they assign numerical values in a debatable fashion.

The first limitation of the survey approach is the usually small sample size due to high cost of implementation. The second weakness is limited reliability of the answers. Indeed, surveyed executives may ignore the answers or give incorrect ones because of the intrinsic difficulty to assess the relative weight of all other factors that motivate their R&D decisions. They may also bias the answers for marketing and strategic reasons. On the former, executives in firms where innovation is a marketing argument may not readily admit that the tax credit has a strong incentive effect on their R&D. On the latter, they may exaggerate the effect strategically, anticipating that their opinion would be of some influence in future public-policy decisions.

Although they might not be very reliable to evaluate the overall impact of the tax credit on R&D expenditures, surveys may often appear the best way to bring complementary insights on specific features of the policy (such as special rules aimed at encouraging firms to collaborate with public research laboratories and hiring young researchers). They can also inform policy makers by providing a better understanding and detailed feed-back on industry-specific concerns.

3.2 Quasi-natural experiments relying on time and policy-design discontinuities

These methods rely on discontinuities in the implementation and design of the R&D tax credit policy. A natural idea is to compare R&D expenditures or growth rates of similar firms (preferably the same firms) before and after the introduction of the tax credit. If R&D increases substantially, then it can be argued that such a change can only be explained by the implementation of this policy. Yet, this before-after analysis cannot by itself separate the effect of the tax credit from that of macroeconomic shocks and changes in industry and market trends. Indeed, it could be that the government and firms understand the importance of R&D in a knowledge-based economy at about the same time, inducing the former to launch the tax credit and the latter to increase R&D. In the opposite direction, for example, the current economic crisis might deter firms from increasing their R&D and make governments less

generous. In these cases, the before-after analysis would indicate that the tax credit has a significant effect on R&D even if in fact it does not.

One way to address such an identification problem is the so called difference-in-difference analysis, which takes advantage of a second source of discontinuity. In most R&D tax-credit schemes the total R&D amount eligible for the tax credit is subject to a ceiling above which there is either no tax credit or the rate of the tax credit declines. A ceiling generates such a discontinuity that may be considered as producing a quasi-natural experiment in which firms above the ceiling (*i.e.*, those that are not, or are less, affected by the public policy) can be used as a control group for the firms below the ceiling (treatment group). The difference-in-difference analysis combines the comparison between these two groups with the difference over time, that is, before and after the introduction of the tax credit.

Other studies exploit discontinuities in policy design such as the introduction of a tax credit and a ceiling for the eligible amount.

Hægeland and Møen (2007b) have followed this approach for Norway where a 20-percent volume tax credit was introduced in 2002 with a ceiling of NOK 4 million (about EUR 0.45 million at the time). They argue that the firms which would have had R&D expenditures above the ceiling in the absence of the tax credit do not benefit from tax credit for their marginal units of R&D, whereas the firms which would have had R&D expenditures below the ceiling in the absence of the tax credit do. The latter have stronger incentives than the former to increase their R&D investment and, hence the effect of the tax credit should be higher for them. To determine which two groups of firms would have been respectively above and below the ceiling in the absence of the tax credit, the authors simply select them according to whether their R&D expenditures were already above or below the ceiling in 2001, one year before the introduction of the tax credit. The results show that the firms of the 'below-ceiling group' had indeed a higher rate of growth of R&D from 2001 to 2003 than the 'above-ceiling group'. Their study provides evidence that the Norwegian policy is effective in stimulating R&D, as already suggested by the results of the survey analysis, but it does not allow to quantify the impact of the R&D tax credit accurately.

3.3 Dummy-variable regressions and matching techniques

These methods basically rely on the comparison between the firms that receive the tax credit and the firms that do not. The dummy-variable approach is the simpler one, consisting of econometric regressions of a dependent variable such as R&D expenditures, R&D growth rates or intensity ratios on 0/1- variables indicating whether or not firms have benefited from the R&D tax credit and on a set of other relevant explanatory and control variables.

Hægeland and Møen (2007a and 2007b) follow such a regression approach, too, estimating and testing a number of different specifications on their panel of Norwegian firms. In particular they try to separate short-term from long-term effects and they also try to address the endogenous-selection issue.³ Their estimations yield sizeable and statistically significant stimulating effects. They find that the tax credit increases R&D expenditure by 1.35 percent on average. From their favourite specification they derive a multiplier (BFTB) higher than one (but weakly significant) for the firms above the ceiling and higher than 2 for the firms below the ceiling (highly significant). Duguet (2007) estimates a similar dummy-variable regression on a panel of French firms, taking the rate of growth of private R&D net of the tax credit and subsidies received as the dependent variable. He finds that on average the tax credit increases the rate of growth of private R&D by 0.05 to 0.10 percent but he does not compute the corresponding multiplier.

³ They also include dummies indicating firms' position with respect to the ceiling of the tax credit in addition to the dummy indicating whether or not they benefit from the tax credit. They use sales as an explanatory variable and they take advantage of the panel nature of their sample by controlling for firm fixed effects and year dummies interacted with an indicator of whether the firm R&D was below or above the ceiling before the introduction of the tax credit.

**Yet another technique
matches beneficiary
firms with otherwise
comparable non-
beneficiary firms.**

The matching method is a more general and sophisticated approach than the dummy-variable regression. Basically, it compares the respective outcomes (e.g. the R&D expenditures) of pairs of firms that are alike or as comparable as possible, except for the fact that only one of them has received the treatment (i.e. the R&D tax credit). Since this is the only difference between the pairs of firms, the differences in outcomes can only be explained by the treatment. Of course, in practice it is impossible to find firms that are perfectly comparable, so the comparison is made on the basis of a set of control variables under the assumption that only these control variables have a potential effect on the selected outcomes. In a first step, two groups of firms are created, the treatment and the control group. Each firm in the treatment group is associated with the firm in the control group that is most comparable to it. This association or matching process can be achieved using various techniques. In a second step, the difference in outcomes (for instance, R&D expenditures or R&D intensity) is computed pair by pair, and the average difference between pairs is interpreted as an estimation of the effect of the tax credit.

Duguet (2007) applies the matching method to the evaluation of the effect of the R&D tax credit in France over the period 1993-2003 during which the tax credit was fully incremental and its major features did not change much. The precise purpose of the analysis is to evaluate the effect of the tax credit, considered in a binary way (treatment – no treatment), on the annual rate of growth of private R&D expenditures. When two firms have the same estimated probability to obtain the tax credit but only one asks for it and effectively receives it, then one may assume that the tax credit was randomly attributed. This is an artificial way to create an experiment in which the tax credit is proposed only to randomly-selected firms, using the others as the control group.

In fact Duguet considers two sets of estimates for each year: one computed on the full sample of firms (including firms that do not perform R&D or reduce their R&D expenditure, and hence cannot benefit from the incremental tax credit) and one based on the sub-sample of firms that have increased their R&D expenditures. Working with the sub-sample requires that there are enough firms that qualify for the tax credit but do not ask for it. This may be because (i) firms ignore the existence of the policy; (ii) most of their R&D expenditures are not eligible for the tax credit; (iii) they consider that asking for the credit is too complex and costly; or (iv) they fear that asking for the tax credit increases the likelihood of a tax audit.

The two sets of estimates produce quite different results. Results also vary a lot from year to year and many of them are not statistically significant, with effects on yearly growth rates of R&D ranging from 0.01 percent to 0.1 percent. The estimates obtained from the sub-sample of firms with growing R&D are lower than those obtained on the full sample, which is not surprising. Presenting the results as multipliers (BFTB), Duguet finds a BFTB of zero (one euro of tax credit generates zero additional R&D) for the sub-sample and a BFTB of 2.3 for the full sample. It is difficult to say which control group to prefer.⁴

3.4 Structural econometric modelling

This approach of evaluating the R&D tax credit has been developed by the US Government Accounting Office (1989) and by Hall (1993) and has since been followed by a number of studies for different countries. It follows the traditional framework of 'structural' econometric analysis, relying on an

⁴ The sub-sample might be preferred because the control group (only firms with growing R&D) arguably contains better matches for the treated firms. On the other hand, one might prefer the full sample and consider all non-treated firms as the control group because the tax credit is in principle available to all firms (i.e., firms in the control group can receive it as soon as they start increasing their R&D expenditure again).

economic model of the firm's R&D investment behaviour and using those econometric techniques that seem most appropriate given the model and the available data. The model states that the level of R&D investment of the firm is determined by the user cost of R&D capital, that is, the real cost faced by the firm when it makes an R&D investment decision, which is a function of the rate of the tax credit scheme, among other variables. "Other things being equal", the higher the R&D user cost, the lower the R&D investment. One advantage of the approach is that it allows a more informative evaluation of the policy and of policy changes.

The structural econometric approach thus does not directly estimate the effects of the R&D tax credit on R&D but involves two main steps, namely:

- Computing the response of the user cost of R&D to changes in the rate of the tax credit also taking into account other characteristics of tax credit design (incremental *versus* volume tax credit, existence of ceilings etc.); and
- Specifying and estimating an econometric model of the response of the firm's R&D investment or -capital to changes in the user cost of R&D capital.

The user cost of R&D capital, like any rental cost is defined as the cost of using one unit of capital for one year (Hall and Jorgenson 1971). The user cost involves the price to buy this one unit of capital, the interest rate that could have been generated by the money used to buy it, the unit's economic rate of depreciation and an inflation gain or loss⁵. It also depends on the corporate tax rate of the firm, the specific fiscal rules of amortization of R&D and the characteristics of the R&D tax credit.

Usually the econometric model is a regression of R&D capital or investment on the user cost of R&D capital and a set of explanatory firm-specific variables (in particular sales), involving different lags of these variables to take into account the firm dynamic behaviour. It thus allows estimating short-run and long-run own-price elasticities of R&D capital (*i.e.* the time profile of variations of R&D when the user cost changes). When panel data are available, individual firm effects may be included to correct for unobserved heterogeneity (*i.e.* unobserved, albeit relevant, variables that vary across firms but not over time are practically constant over time). Under an incremental or mixed tax credit scheme, the user cost of R&D is endogenous since it depends on the level of R&D expenditures.

To evaluate the R&D tax credit in France, Mairesse and Mulkey (2004) rely on such an econometric model for an unbalanced panel of 2,431 firms (mainly in the manufacturing sector) over the 18-year period 1980-1997. They find a long run elasticity of R&D capital to its user cost of -2.7 , providing evidence of a positive and significant effect of the tax credit on R&D expenditures. The authors also make a policy simulation for 2003. They assume an increase of the statutory rate of the incremental tax credit by 20 percent (from 50 percent to 60 percent) together with an increase of the tax-credit ceiling by 20 percent too. Such a policy change would have generated between EUR 168 million and EUR 320 million of additional private R&D expenditures, substantially more than the additional government expenditures on the tax credit (EUR 88 million or 20 percent). The BFTB multiplier is thus between 2 and 3.6. That is, one euro of tax credit generates between EUR 1 and EUR 2.6 of additional private R&D.⁶

5 That is, if the price of one unit increases during the year, the user cost is reduced because at the end of the year the firm can sell the unit of capital at a price higher than the buying price.

6 In an update Mairesse and Mulkey (2008) use the analysis on a similar sample but over the 24 years 1980-2003 and find an even stronger effect on R&D capital of a decrease in its user cost. Their provisional estimation of the long-term elasticity of R&D capital with respect to its user cost appears to be about twice as high as that before. However the BFTB multiplier corresponding to a similar simulation as the one in their 2004 study remains of about the same order of magnitude.

Several articles have recently been published on the evaluation of the R&D tax credit in Spain. They are all based on panel data samples covering the 1990s, constructed from the same firm survey (*Encuesta Sobre Estrategias Empresariales*). The Spanish tax credit has changed several times since its introduction and has a mixed design, combining a volume base and an incremental base (Romero and Sanz 2007). All these analyses distinguish small firms from large firms, showing that the results are different for the two groups and suggesting that the tax credit can be more cost efficient when taking into account the size of the firms.

Marra (2004) finds a user-cost elasticity of R&D expenditures of -0.6 and -0.8 for small and large firms, respectively, and an elasticity of the user cost to the tax credit rate of about -0.5 for both types of firms, and hence a combined elasticity of R&D to the tax credit rate of about 0.3 for small firms and 0.4 for large firms. Corchuelo (2006) obtains a higher user-cost elasticity of R&D expenditures (-1.2). Romero and Sanz (2007) find a user-cost elasticity of R&D expenditures of about -1.0 and an elasticity of the user cost to the rate of tax credit of about -1.5 , and hence a combined elasticity of R&D to the tax credit rate of 1.5 .⁷ They also compute a BFTB multiplier equal to 0.25 , suggesting that the R&D tax policy is not very efficient.

The R&D tax credit seems to be more efficient in France and in Norway than in Spain and in the Netherlands.

One of the most recent studies following the user-cost structural econometric method is the evaluation of the Dutch R&D tax credit (WBSO) by Lokshin and Mohnen (2009). The WBSO is a volume tax credit which is based on R&D labour costs and has two ceilings defining a first bracket with a higher tax credit and a second one with a lower tax credit.⁸ As in Mairesse and Mulkey (2004) but for a smaller and shorter unbalanced panel (of 400 firms for the period 1996 to 2004), the authors compute a firm-specific user cost of R&D capital which depends on the characteristics of the R&D tax credit and they estimate the user-cost elasticity of R&D capital considering various dynamic regression specifications and taking care of the endogeneity of the user cost in different ways. They find significant short-run user cost elasticities ranging from -0.2 to -0.5 depending on the dynamic specification and long-run elasticities ranging from -0.5 to -0.8 . To compute a BFTB multiplier, Lokshin and Mohnen also simulate a counterfactual scenario in which the tax credit does not exist and estimate how much firms would have invested in R&D in such a scenario. They obtain that on average for all firms the multiplier is about 0.5 , but that it is significantly higher at 1.2 for small and medium-sized firms (SMEs) with less than 250 employees and smaller at 0.4 for large firms.

4. Evaluation of the effects of R&D tax credit on other outcomes

This section aims at providing a more comprehensive view of the tax-credit evaluation by completing the input-oriented approach presented and developed in the previous section. It evaluates the effect of the tax credit on other outcomes, namely the decision to start R&D, R&D output, researcher wages and social welfare.

4.1 Effects on the decision to start R&D

Increasing R&D can be achieved through stimulating the firms that already perform R&D but also through encouraging firms (in particular SMEs) to start R&D. The evaluation of the tax credit's impact on the decision to start R&D raises specific and difficult issues. Engaging in R&D activities even at a

⁷ Romero and Sanz use a somewhat different approach based on a system of demand equations (not only an R&D equation), derived from a cost function as in Fuss (1977), but on a much smaller sample than Marra and Corchuelo.

⁸ In 2004 firms could deduct 42 percent below a first ceiling of EUR 110,000 of their R&D labour cost and 14 percent above this ceiling and up to the second ceiling set at EUR 7.9 million.

small scale involves various fixed and learning costs for the firm, on which there is little or no information. The decision to start investing in R&D may justify special policy provisions.⁹

The lack of appropriate information is a major reason why only very few evaluation studies have considered the issue in spite of its importance. More research on the process of engaging in R&D would help to shed light on the following questions:

- What are the determinants of the decision of firms to perform R&D? For example, exports are highly positively correlated with R&D but it is hard to disentangle which is the cause and which the effect.
- Do fiscal incentives really encourage firms to start R&D activities? One could fear that fiscal incentives might not be sufficient to trigger the decision to invest in R&D. One could also think that fiscal incentives incite firms to reveal R&D activities they already have or to redefine informal innovation activities as R&D. The true impact of the tax credit would thus be difficult to distinguish from a revelation or re-labelling effect.
- Is the true tax credit impact on real beginners a long-lasting one or is the pool of potential R&D-performing firms rapidly exhausted?
- Is it really efficient to push small firms to start R&D activities? If fixed costs and economies of scale are important, it should not be surprising that the majority of small firms cannot afford to invest in R&D and be strong innovators.
- From a technical-evaluation point of view, making progress in explaining the decision to start R&D would also help in controlling for the potential selection bias in assessing the impact of the tax credit on R&D-performing firms.

Corchuelo (2006) in her evaluation of the Spanish tax credit estimates a generalized Tobit model with the user cost of R&D capital in both the selection probit equation and intensity regression. She obtains a significant user-cost elasticity of the probability to do R&D of about -2.7 . Hægeland and Møen (2007b) in their analysis of the Norwegian R&D tax credit find that in 2003 and 2004, just after the introduction of the tax credit, the firms that did not perform R&D two years earlier had a higher probability by about 7 percent to engage in R&D than in 1995-2001, but that this is not true anymore in 2005, suggesting that the pool of firms likely to engage in R&D was largely exhausted by then.

The R&D tax credit also raises the probability that firms start doing R&D.

4.2 Innovation outputs and productivity

Under the assumption that the marginal productivity of R&D is decreasing within firms, additional R&D generated by the tax credit would be less productive and could lead to only limited achievements. It is thus important to be able to evaluate the R&D tax credit not only in terms of R&D inputs but also outputs. Two variables are usually considered to measure R&D outputs: the number of patents granted to or applied for by the firm and the process and product innovation indicators reported in innovation surveys. These are of course imperfect measures because not all patented or reported innovations are productive for the firm or the economy as a whole. A realistic vision of the innovation-production process would also require taking time into account. A patent or a reported innovation may be the result of several years of research on a project, and the average duration of a project depends on the industry and the type of research (fundamental, applied or development).

⁹ Stimulating firms to engage in R&D for the first time has been a constant objective of the French tax credit policy since its beginning in 1983. Also the current system of a pure volume tax credit applies a specific tax credit rate for firms starting R&D activities. For these firms the rate is equal to 50 percent in the first year and 40 percent in the second, with the ordinary rate of 30 percent applied as from the third year.

The effect of the R&D tax credit on patents and product and process innovations should also be translated into firm productivity and sales. The firm model developed by Crépon, Duguet and Mairesse (1998) – known as the CDM model – offers an econometric framework to analyze these issues. It relates R&D, innovation and productivity in a three-step model. The first step accounts for the firm decision to do R&D and for its R&D intensity. The second step explains innovation (either in terms of patents, process and product innovation indicators, or the share of new or improved products in sales) as a function of R&D and other variables. The third step is a regression of productivity on innovation and the traditional factors of production (labour and physical capital intensity).

It would be possible to combine the CDM model with the structural modelling approach described in Sub-section 3.4 by including a user cost of R&D capital in the first-step intensity equation and in the selection equation. The direct effect of the R&D tax credit on firm R&D expenditure and its indirect effects on innovation and productivity could thus be estimated consistently in the CDM framework. As far as we know, this has not been attempted, probably because of data limitations and intrinsic econometric difficulties.

Czarnitzki *et al.* (2005) focus on the effect of the tax credit on innovation, using matching techniques for a large representative cross-sectional sample of Canadian manufacturing firms. They take advantage of the information which is provided by the 1999 Survey of Innovation conducted by Statistics Canada. They rely particularly on four product innovation variables. The first two are binary indicators of whether the firm introduced an innovation that was new to Canada or new to the world, while the third is the number of new or significantly improved products produced by the firm and the fourth is the share of these innovative products in sales.

Czarnitzki and his coauthors are thus able to compare the innovation outputs of the firms that receive the R&D tax credit with those of firms that do not. As Duguet (2007), they consider two control groups: the first based on all firms that do not benefit from the tax credit, the second based only on the firms that perform R&D but do not apply for the tax credit.¹⁰ They show that Canadian firms that receive the tax credit declare a higher number of product innovations, are more likely to generate innovations new to the market and have a higher share of total sales accounted for by innovative products. They thus conclude that the Canadian tax credit encourages firms to do more R&D, which leads to innovations valued by the market.¹¹

Canadian firms benefiting from the R&D tax credit are found to introduce more new products and to have a higher share of sales from innovative products.

4.3 Researchers' wages

Public policies in general may have unintended or side effects, positive and negative, which should be taken into account by policy makers when designing or modifying policies. The possibility of an increase of R&D prices and particularly of researchers' wages is the side-effect of the R&D tax credit that is most often acknowledged, though it is still little studied. An R&D tax credit that strongly stimulates firm R&D expenditure may foster the demand for R&D personnel, resulting in an increase in their wages, at least in the short run, if the supply of such personnel is relatively inelastic. In this situation, the additional R&D expenditures fuel higher R&D prices and do not correspond to effective additional R&D. Still, this does not directly imply that the policy is a failure as the price increase is likely to trigger

¹⁰ Here again, the construction of the second control group implies that a number of firms could apply for the tax credit but do not do so. In matching tax credit recipients with non-recipients, the authors also use various other control variables: the size of the firm, its R&D organization (whether R&D is performed internally or contracted out), its R&D intensity, its price-cost margin, its operations in new markets, and industry dummies as well as geographical dummies accounting for differences in the tax credit scheme across provinces.

¹¹ However, in complementary analyses, the authors find no evidence that the tax credit encourages firms to start R&D or contribute to increasing productivity, profitability or their market shares.

an increase in supply and to lead to an increase in the economy's R&D capital and personnel in the long run. Thus the tax credit may have effects on the price of R&D (i.e. the interest rate on R&D capital and researcher wages) and on the stock of R&D and the number of R&D personnel. Assessing the efficiency of the tax credit includes focusing on those matters, but only a few researchers have done so.

Goolsbee (1998) has initiated such a research with a study on the income of 17,700 researchers and engineers, using information from the US Current Population Survey (for the period 1968-1994) and macroeconomic data. He runs regressions of individual incomes on the shares of R&D spending to GDP and government-funded R&D to GDP, which also includes a set of covariates aimed at capturing the effect of economic trends and individual characteristics. He finds that there is a positive and significant relation between R&D spending and the income of R&D personnel, and argues that this is a causal relation showing that R&D spending has a strong and significant effect on the R&D personnel's wages. The conventional estimates of the effect of R&D policies would be largely overestimated because of this effect. Goolsbee's analysis, however, is not fully convincing since it does not take into account, for example, gains in the productivity of researchers and it does not explicitly address the question of reverse causality (the government supports private R&D because it is more and more costly).¹²

Rising researcher wages weaken the volume effect of the R&D tax credit today but help ensure higher supply of researchers in the long run.

Notwithstanding its weaknesses, Goolsbee's analysis raises a question that should be part of a comprehensive evaluation of R&D policies. Answering the question of R&D-price effects requires a precise identification strategy. Indeed, it is likely that a common underlying movement may account for both the implementation of R&D policies and the increase in R&D personnel productivity. For instance, globalization puts pressure of the innovative capacities of firms and countries in industrialized countries, which may increase wages to attract more productive personnel and urge governments to strengthen R&D policy. Two recent studies on firm data concur in finding that the effect of the R&D tax credit on the wages of R&D personnel is rather weak. Haegeland and Møen (2007b) estimate that the wage effect could amount to a reduction of 0.3 of the high BFTB multipliers they obtain for Norway (one third of a dollar of tax credit goes into higher wages). Lokshin and Mohnen (2008), in a companion paper to their main analysis for the Netherlands, find an estimate in the order of 0.10 for the elasticity of R&D wages with respect to the fraction of the wage bills supported by the Dutch tax credit scheme.

4.4 Social welfare

Social welfare is more complex an outcome to measure than R&D expenditure. The evaluation of a policy in terms of social welfare should be done in the framework of a cost-benefit analysis taking ideally into account all the significant direct and indirect effects of the policy on the economy and society. The R&D tax credit is considered efficient in terms of social welfare if it stimulates innovation and productivity over and above boosting R&D and if it does so without mobilizing resources that could be used more efficiently elsewhere. To our knowledge, the only attempt of an evaluation of the R&D tax credit policy on social welfare is Parsons and Phillips (2007). In their cost-benefit analysis for Canada, the effects of the tax credit on social welfare work through five main channels which are quantified in cent per dollar and which sum up to the global net effect of the policy:

- The tax credit stimulates R&D investment to reach a socially more efficient level, helping to bridge the gap between the level that is optimal to individual firms and the optimal level for society. Its primary effect is thus the social return in the form of R&D externalities ('spillovers');
- The tax credit increases the producer surplus of firms by lowering the cost of each unit of R&D as well as stimulating them to do more R&D at this lower cost;

¹² Reverse causality also partly invalidates Goolsbee's other central result, namely that government-funded R&D crowds out private R&D activity (as evidenced in a negative correlation between the ratios of government-funded R&D and private R&D to GDP).

Evaluations should consider the tax credit's impact on social welfare in a cost-benefit analysis accounting for R&D spillovers and administrative and opportunity costs.

- The tax credit has a direct social cost equal to the amount of tax revenue forgone;
- The tax credit also has compliance and administration costs affecting both firms and the authorities; and
- The tax credit has an opportunity cost since the forgone tax revenue could have been used to fund other public expenditures or other tax cuts.¹³

Parsons and Phillips carefully survey many previous studies to calibrate the benefits and costs for all five channels. All in all, the median increase in social welfare would be around 10 cents per dollar of tax credit, suggesting that the Canadian tax credit policy is indeed socially efficient. However, the authors also analyze the sensitivity of this result to the uncertainty and imprecision of the different estimations underlying their calibration, and they show that even within a range of small variations, the global net effect of the policy on social welfare can be either positive or negative. This illustrates the limitations of such a cost-benefit analysis, which is as difficult as it is ambitious.

5. Comparability of evaluations and a tentative exercise in meta-analysis

As evidenced by the recent studies presented above, evaluations of the tax credit may yield contrasting results, even when focussing on a definite outcome such as the BFTB multiplier. An isolated evaluation study can give very useful indications on the effectiveness of a given policy in a specific context. But comparisons of studies in different countries and for different periods may provide insights on what policy design characteristics may be more appropriate and efficient than others. Such comparisons would thus be more helpful to policy makers faced with the decision whether or not to introduce an R&D tax credit or how to radically reform an existing tax credit policy. However, taking stock of the results of the various studies raises great difficulties, and the best way would be to compare them in the framework of a meta-analysis, trying to take into account the main sources of differences. This section first stresses these sources of differences and then presents an incomplete and tentative attempt of meta-analysis mainly to illustrate.

5.1 Limits to the comparability of evaluation studies

The comparison between different evaluation analyses should in principle help policy makers in assessing the efficiency and improving the design and implementation of public policies. Yet, the various evaluations of the R&D tax credit yield very different and potentially contradictory results. How to interpret such differences in evaluation results? To what extent is it possible and indeed legitimate to compare these evaluation results? The comparison in terms of BFTB multipliers seems attractive for at least three reasons. First, they are easy to understand for non-specialists and give a synthetic idea of the policy's efficiency. Second, they seem to provide a standardized way of presenting the results and making them directly comparable across countries, periods, and tax credit characteristics. Third, all the estimates stemming from the various evaluation methods can, in principle, be converted into corresponding multipliers. All in all, and although limited to the one outcome of additional R&D expenditures, BFTB multipliers seem to be a good yardstick for the comparison of tax credit evaluations. Parsons and Philips (2007) also strongly argue for using them as a first basis of comparison.

¹³ The alternative use considered by Parsons and Phillips is the allocation of lump-sum tax refunds to citizens and firms that are equivalent to the expected tax expenditure for the R&D tax credit. However, allocating the funds to public research and higher education would have been politically more realistic alternatives.

Ideally, differences in estimated multipliers should mainly reflect differences in policy efficiency. However, they are more or less precisely estimated and can be biased to a varying degree. Studies conducted for the same country and same time period may find very different results, as evidenced, for example, by the contrast between Mairesse and Mulkay (2004; 2008) who find that the French tax credit is efficient by following an econometric structural approach, and Duguet (2007) who reach a similar conclusion or a far less optimistic one (depending on the control group chosen) by applying matching techniques.

The differences in the BFTB multiplier between studies in practice may reflect:

- Genuine differences in policy efficiency. These differences are the ones of interest for policy makers.
- Methodological differences. Some methods may be more demanding than others; they may also be more relevant and generate more informative results.
- Country heterogeneity. For various reasons such as industry composition, market structure, features of economic policy in general and corporate tax policy in particular, firms in different countries might react differently to identical tax credit policies.
- Time differences. Studies conducted over different periods may yield diverse results because of changes in the national economic situation and international environment. Depending on the length of the study period, long-term effects may be more or less reliably identified and more or less precisely estimated.
- Publication biases (Ashenfelter *et al.* 1999). Such biases can arise from the fact that authors may have a natural tendency to look for positive results and that it is easier to publish articles showing a significant impact of a policy than those showing no effect.

Estimated multipliers do not only reflect differences in policy efficiency but also differences in evaluation methods and country heterogeneity.

Estimated BFTB multipliers from different evaluation studies should thus be compared with great caution and not be taken for granted “naively”. Gathering them and examining them in the framework of a ‘meta-analysis’ is probably the best way to control for potential sources of differences unrelated to true efficiency and make the results more comparable. Yet, the relatively limited number of evaluations of the R&D tax credit coupled a relatively large variety of methodological approaches, policy designs and economic contexts, makes it a challenge to attempt such a meta-analysis.¹⁴ Also, many studies also do not present results in the form of a BFTB; some of them do not document standard deviations or confidence intervals; some also provide so many different estimates, depending on various assumptions, that it is hard to make a choice of the one(s) to be selected in a meta-analysis. In spite of all these difficulties, there is value in gathering most of the studies that assess the impact of the R&D tax credit in terms of BFTB multipliers (and/or elasticities) and in carefully comparing them, even if not in the framework of a formal meta-analysis.

In the future, policy makers should also support efforts to enhance comparability and harmonization in evaluation practices of R&D tax incentives (European Commission 2006 and 2008). Without preventing researchers from using different methods of investigation and trying to improve them, a harmonized framework of evaluation and a set of recommendations should be defined and agreed upon at the level of the European Union or the OECD countries. This would contribute to widening the scope of evidence-based policy decisions. Instead of simply answering the question “Is this policy design efficient?” it would help answer the question “Which is the most efficient design?”.

¹⁴ A “simple” meta-analysis would consist in running a regression of the BFTB multipliers estimated in a “sufficiently” large sample of studies on a set of dummies indicating at least the country, type of tax credit and main evaluation method.

5.2 An incomplete and tentative meta-analysis

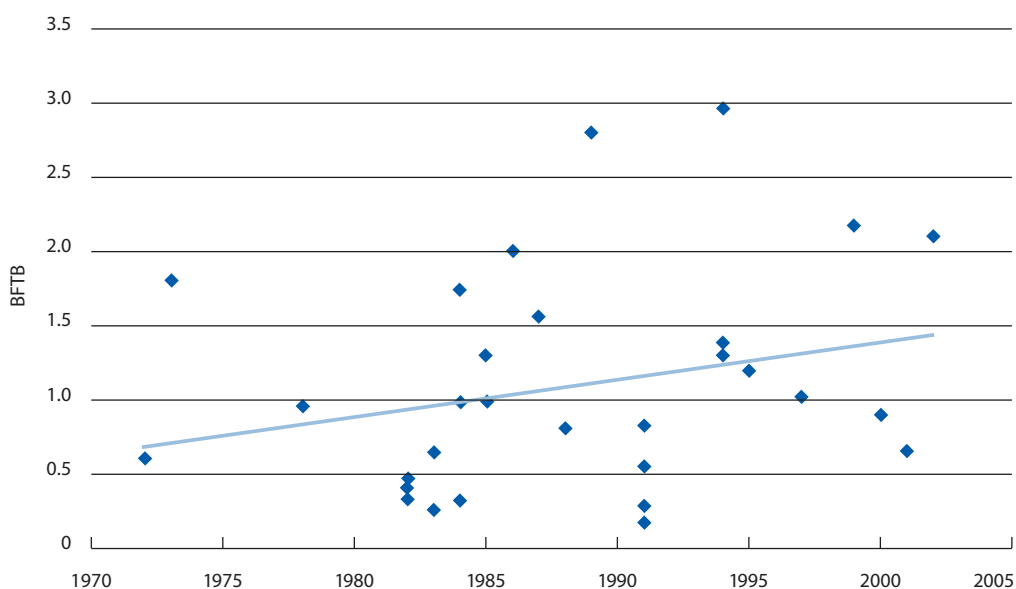
A careful meta-analysis of the R&D tax-credit evaluations including a number of potentially relevant control variables in a regression setting would imply a tremendous effort. Still, it is possible to give a feeling of what kind of insights one could gather from a first step towards such a meta-analysis.

Parsons and Phillips (2007) have already adopted a meta-analytical approach, focused on the country dimension, when they compare the country averages of the estimated R&D tax credit impacts in studies available for Canada and the United States. They find that on average the BFTB multiplier is equal to 0.91 in Canada compared with 1.42 in the United States. This suggests that the American R&D tax credit is more efficient than the Canadian one, with one dollar of tax credit generating 50 cents more of R&D in one country than in the other. From the policy maker's standpoint, this could be interpreted in terms of relative efficiency of policy designs. Since the American tax credit is incremental whereas the Canadian one is a volume tax credit, one could be tempted to conclude that the incremental design is preferable to the volume design. The gap in tax credit efficiency could also be imputed to country heterogeneity but this is not too convincing in the present case since the United States and Canada are commercially integrated and their economies are comparable in terms of general organization and performance.

Relying on 33 BFTB multiplier estimates, mostly gathered from the studies quoted by Parsons and Phillips (2007), we first look whether results differ in the time dimension. An increasing trend might indicate some overall progress in tax policy design and implementation and in learning by firms. Yet a significant trend (positive or negative) could also reflect improvement in evaluation methods. In order to assign a year to each estimate, we take the average year of the study period. For example, we assign the multiplier estimated by Mairesse and Mulkey (2004) to 1989, the mid-point of their sample period (1982-1996). The BFTB estimates and their average years of estimation are reported in the Annex (Table A1). Figure 1 plots the estimated BFTB multipliers on the Y-axis and the corresponding sample mid-point years on the X-axis.

The effectiveness of the R&D tax credit appears to have increased over the past 30 years.

Figure 1. Estimated BFTB multipliers over time



Source: See Annex Table A1

The linear regression adjusted through the data points shows that the BFTB estimates tend to increase over time at a (weakly significant) average annual rate of 2.5 percent¹⁵. This is rather huge, implying an overall average increase of 60 percent in the 30 years from the earliest to the latest estimates. Of course such a result should be taken with a pinch of salt, but at least it does not contradict the idea that the R&D tax credit policies might have been increasingly efficient over the years, possibly because of the sharing of good practices in launching or reforming policy designs and in their implementation.

We also look for some evidence of publication bias, relying on the method developed and used by Ashenfelter *et al.* (1999) who analyze the numerous estimates of returns to education. A basic reason for the existence of a publication bias is that at equal levels of scientific quality, a study showing that an effect is positive as expected and significantly different from zero is more likely to be submitted for publication and published than another study showing that this effect is insignificant or even negative. As a result, the average of the estimates from published studies would tend to be an overestimation of the true average effect.

Since it is much more difficult, if not impossible, to access unpublished publications, finding evidence of a publication bias is of course a challenge. Ashenfelter *et al.* make the point that in the absence of a bias there is no reason why the precision of published estimates (as measured by the standard error) should depend on their magnitude and, hence that we should not observe a significant correlation between these estimates and their standard errors. By contrast, if there is a publication bias, one might expect to find a positive correlation between the published estimates and their standard errors. Indeed, when the level of precision decreases (increasing standard errors), higher estimates are more likely to be reported than lower ones. A significantly positive correlation between reported estimates and standard errors thus gives some presumption of a publication bias, even if it could also be due to other factors¹⁶.

If higher 'bang-for-the-buck' estimates are less precisely estimated, this might point to a publication bias.

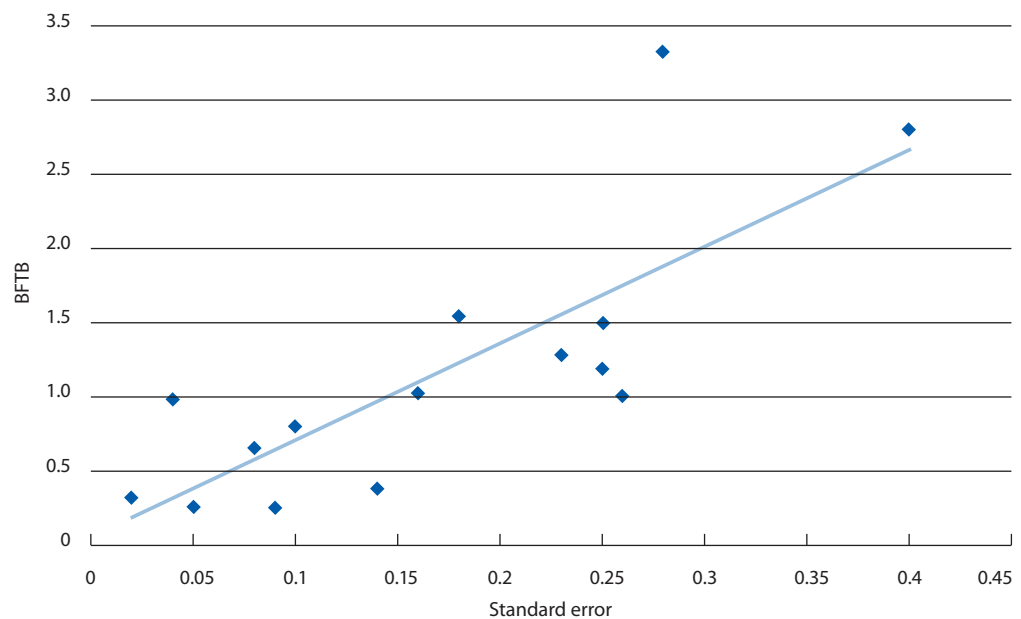
In Annex Table A2 we report those 15 estimated BFTB multipliers (out of the 33 presented above) for which we are able to retrieve standard errors. In fact many studies do not provide standard errors for the BFTB multipliers, so we compute them whenever it seems possible. When a 95-percent confidence interval is provided, we derive the standard error of the estimate using the fact that it is approximately normally distributed and thus that the length of the 95-percent confidence interval is four times the standard error. Otherwise, when a study was reporting various estimates under different hypotheses and methods, we assume boldly that the 95-percent confidence interval is equal to the range between the maximum and minimum reported estimates.

The following Figure 2, which plots the BFTB multipliers on the Y-axis and their corresponding standard errors on the X-axis, shows a strong positive and highly significant correlation between the two (correlation coefficient of 0.79). The correlation remains very high and significant (at about 0.73) when we delete the two highest estimates with also the highest standard errors. This suggests that there might be a publication bias leading to overestimating the efficiency of the R&D tax credit. Although our evidence at this point must be taken with caution, it clearly calls for a thorough meta-analysis that should be based on a larger sample of estimates with standard errors and include a variety of controls.

15 The standard error is of 1.7, corresponding to a Student *t*-value of 1.5 with 31 degrees of freedom and a unilateral *p*-value of 7.5 percent.

16 For example, instrumental-variable estimates of R&D user cost elasticities, which correct for measurement errors in the user cost tend to be higher and to have higher standard errors than estimates which do not correct for such errors.

Figure 2. BFTB multipliers estimates and standard errors



Source: See Annex Table A2

6. Conclusions

We have seen that a comprehensive evaluation of the R&D tax credit involves a number of different questions. In particular, the efficiency of the policy should be assessed through its effect on several outcomes. So far the literature has concentrated on the effect on R&D inputs, in general R&D expenditure, which is a natural first step for all evaluation. The results obtained through various methods and for various countries are very different, which makes it hard to answer the question “Does the R&D tax credit work?” in a clear-cut way.

The effect of the tax credit on R&D inputs varies widely across countries and studies.

The results reported here give indeed a contrasted picture. Hægeland and Møen (2007b) gather strong evidence that the Norwegian tax credit is efficient. It is noteworthy that their estimates appear to be particularly robust because they are constant across various methods. For France, Mairesse and Mulkey (2004; 2008) conclude that the French tax credit efficiently stimulates R&D expenditures on the basis of a structural econometric model. However, studies following the same approach for other countries like the one for the Netherlands by Lokshin and Mohnen (2009) and those for Spain come to less optimistic conclusions.

Overall the evidence obtained in terms of BFTB multipliers appears to be more scattered than the evidence from estimated elasticities with respect to the user cost of R&D capital. While these elasticities cannot be directly translated into measures of efficiency, they are useful to simulate small policy changes. However, they are probably not reliable in predicting the effects of radical policy changes. For example, it is likely that the marginal effect on R&D expenditures, and hence the BFTB multiplier, will decrease when the rate of the tax credit or its ceiling is strongly increased or when an incremental tax credit is replaced by a volume tax credit.

While the body of research on the tax credit's impact on firm R&D investment is rich, evidence is much scarcer for other outcomes of interest for economic policy, such as the probability to engage in R&D, innovation and productivity as well as social welfare. The few articles considering these outcomes are examples that should be followed in future policy evaluations. The BFTB multiplier is not a fully satisfactory measure of efficiency because it concentrates on how much additional R&D expenditures were generated per euro of tax credit but does not inform on higher-order goals of the tax credit policy.

There is a need for harmonizing evaluation methods, and more research should be devoted to effects on innovation and social welfare.

The fact that the BFTB is below or above the benchmark of one tells us whether the additional private R&D is entirely funded by the government or whether it is also funded by the firm and in what proportion. It does not tell to what extent firms' additional R&D contributes to increasing their own innovations and productivity and to fostering positive research externalities to the benefit of other firms and the economy at large. The more fundamental question is about the overall social return on the additional private R&D net of social costs. As the careful attempt of a full cost-benefit analysis for Canada by Parsons and Phillips (2007) shows, this is also the most difficult question to answer.

In any case, the need for harmonization and for increased comparability is obvious throughout this article, and maybe is its major conclusion. This objective could be reached through a consensus on the outcome variables to be studied, on the choice and implementation of evaluation methods and on the ways to present results. The development of a meta-analysis framework adapted to the R&D tax credit – and to fiscal incentives more generally – is a relevant and important direction for future research.

Annex

Table A1. Studies and estimates used in Figure 1 in the main text

Ref.	Authors	Year of publication	BFTB	Studied year	Country
1	McFetridge and Warda	1983	0.60	1972	Canada
2	Mansfield and Switzer	1985	0.39	1982	Canada
3	Mansfield	1985	0.34	1982	Sweden
4	Bernstein	1986	1.28	1985	Canada
5	Mansfield	1986	0.45	1982	US
6	Gen. Accounting Office	1989	0.26	1983	US
7	Cordes	1989	0.64	1983	US
8	Baily and Lawrence	1992	1.30	1985	US
9	Tillinger	1991	0.25	1983	US
10	Hall	1993	2.00	1986	US
11	Hines	1993	1.55	1987	US
12	Bureau of Ind. Eco.	1993	0.80	1988	Australia
13	Berger	1993	1.74	1984	US
14	McCutchen	1993	0.32	1984	US
15	Shah	1994	1.80	1973	Canada
16	Mamuneas and Nadiri	1996	0.95	1978	US
17	Lebeau	1996	0.98	1985	Canada
18	Abt Associates	1996	1.38	1994	Canada
19	Dagenais <i>et al.</i>	1997	0.98	1984	Canada
20	Bloom <i>et al.</i>	1997	0.54	1991	Australia
21	Bloom <i>et al.</i>	1997	0.28	1991	Canada
22	Bloom <i>et al.</i>	1997	0.18	1991	France
23	Bloom <i>et al.</i>	1997	0.82	1991	US
24	Van den Hove <i>et al.</i>	1998	1.20	1995	Netherlands
25	Brouwer <i>et al.</i>	2002	1.02	1997	Netherlands
26	Poot <i>et al.</i>	2003	1.02	1997	Netherlands
27	Klassen <i>et al.</i>	2004	1.30	1994	Canada
28	Klassen <i>et al.</i>	2004	2.96	1994	US
29	Mairesse and Mulkay	2004	2.80	1989	France
30	Cornet and Vroomen	2005	0.65	2001	Netherlands
31	Duguet	2007	2.17	1999	France
32	Hægeland and Møen	2007	2.10	2002	Norway
33	Lokshin and Mohnen	2009	0.90	2000	Netherlands

Table A2. Studies and estimates used in Figure 2 in the main text

Ref.	Authors	Year	Country	BFTB	Std Error
2	Mansfield and Switzer	1985	Canada	0.39	0.14
4	Bernstein	1986	Canada	1.28	0.23
6	Gen. Accounting Office	1989	US	0.26	0.05
9	Tillinger	1991	US	0.25	0.09
11	Hines	1993	US	1.55	0.18
12	Bureau of Industry Eco.	1993	Australia	0.80	0.10
14	McCutchen	1993	US	0.32	0.02
17	Lebeau	1996	Canada	0.98	0.04
24	Van den Hove <i>et al.</i>	1998	Netherlands	1.20	0.25
34	Bureau Bartels	1998	Netherlands	1.50	0.25
26	Poot <i>et al.</i>	2003	Netherlands	1.02	0.16
29	Mairesse and Mulkey	2004	France	2.80	0.40
30	Cornet and Vroomen	2005	Netherlands	0.65	0.08
31	Duguet	2007	France	3.33	0.28
31	Duguet	2007	France	1.01	0.26

References

- Abt Associates of Canada: Social Research Consultants (1996). "Survey of Scientific Research and Experimental Development Claimants". Report prepared for Finance Canada and Revenue Canada.
- Ashenfelter, O., Harmon, C. and Oosterbeek, H. (1999). "A Review of Estimates of the Schooling/Earnings Relationship, with Tests for Publication Bias". *Labour Economics*, (6:4), pp. 453-470.
- Baily, M.N. and Lawrence, R.Z. (1992). "Tax Incentives for R&D: What Do the Data Tell Us?" Study commissioned by the Council on Research and Technology, Washington, D.C., USA.
- Berger, P. G. (1993). "Explicit and Implicit Tax Effects of the R&D Tax Credit". *Journal of Accounting Research*, (31:2), pp. 131-171.
- Bernstein, J.I. (1986). "The Effect of Direct and Indirect Tax Incentives on Canadian Industrial R&D Expenditures". *Canadian Public Policy*, (12:3), pp. 438-448.
- Bloom, N., Chennells, L., Griffith, R. and Van Reenen, J. (1997). "How Has Tax Affected the Changing Cost of R&D? Evidence from Eight Countries". Institute for Fiscal Studies Working Paper 97/3.
- Brouwer, E., den Hertog, P., Poot, T. and Segers, J. (2002). "WBSO nader beschouwd. Onderzoek naar de effectiviteit van de WBSO". Opdracht van het Ministerie van Economische Zaken, DG Innovatie, Ministry of Economic Affairs, Den Haag, The Netherlands.
- Bureau Bartels (1998). "Evaluation of the WBSO R&D tax credit scheme", part I, Final report (only in Dutch) to the Ministry of Economic Affairs, Den Haag, The Netherlands.
- Bureau of Industry Economics (1993). "R&D, Innovation and Competitiveness: An Evaluation of the R&D Tax Concession". Australian Government Publishing Service, Canberra, Australia.
- Corchuelo, B. (2006). "Incentivos fiscales en I+D y decisiones de innovación". *Revista de Economía Aplicada*, XIV (40), pp. 5-34.
- Cordes, J. J. (1989). "Tax incentives and R&D spending: A review of the evidence". *Research Policy*, (18:3), pp. 119-133.
- Cornet, M. & Vroomen, B. (2005). "Extending the Dutch R&D Tax Credit Program: Does it Work?". Preliminary paper dated August 1, 2005, presented at ONS Analysis of Enterprise Microdata Conference, September 8, 2005, Cardiff, UK.
- Crépon, B., Duguet, E. and Mairesse, J. (1998). "Research, Innovation, and Productivity. An Econometric Analysis at the Firm Level". *Economics of Innovation and New Technology*, (7:2), pp. 115-158.
- Czarnitzki D., Hanel P. and Rosa, J.M. (2005). "Evaluating the Impact of R&D Tax Credits on Innovation: a Microeconomic Study on Canadian Firms". Centre interuniversitaire de recherche sur la science et la technologie, Note de recherche 2005-02, Montréal, Canada.
- Dagenais, M., Mohnen, P. and Thierrien, P. (1997). "Do Canadian Firms Respond to Fiscal Incentives to Research and Development?". G.R.E.Q.A.M. 97b05, Université Aix-Marseille III, France.
- Duguet, E. (2007). "L'effet du crédit d'impôt recherche sur le financement privé de la recherche: une évaluation économétrique". Working paper, Université d'Evry, France.
- European Commission (2006). "Evaluation and Design of R&D Tax Incentives". Report of the CREST Expert Group on Fiscal Measures.
- European Commission (2008). "Comparing Practices in R&D Tax Incentives Evaluation". Research Directorate - General, Report of an Expert Group on R&D Tax Incentives Evaluation.

- Eurostat (2008). *"Science, Technology and Innovation in Europe"*, Pocketbooks.
- General Accounting Office (GAO) (1989). "The research tax credit has stimulated some additional research spending". Tax Policy and Administration report, USA.
- Goolsbee, A. (1998). "Does government R&D policy mainly benefit scientists and engineers?" *American Economic Review*, (88:2), pp. 298-302.
- Hægeland, T. and Møen, J. (2007a). "The relationship between the Norwegian R&D tax credit scheme and other innovation policy instruments". Statistics Norway report 2007/45.
- Hægeland, T. and Møen, J. (2007b). "Input additionality in the Norwegian R&D tax credit scheme". Statistics Norway report 2007/47.
- Hall, B.H. (1993). "Tax policy during the eighties: success or failure?" *Tax Policy and the Economy*, (7), pp. 1-36.
- Hall, B.H. and van Reenen, J. (2000). "How Effective Are Fiscal Incentives for R&D? A Review of the Evidence". *Research Policy*, (29), pp. 449-469.
- Hall, R., and Jorgenson, D. (1971). "Application of the Theory of Optimum Capital Accumulation", in Fromm, G. (ed.), *Tax Incentives and Capital Spending*, Brookings Institution, Washington, USA.
- Hines, J.R. (1993). "Taxes, Technology Transfer, and the R&D Activities of Multinational Firms". National Bureau of Economic Research Working Paper No. 4932.
- Jorgenson, D. (1963). "Capital Theory and Investment Behaviour". Papers and Proceedings of the American Economic Association, *American Economic Review*, (52:2), pp. 247-259.
- Klassen, K.J., Pittman, J.A. and Reed, M.P. (2004). "A Cross-National Comparison of R&D Expenditure Decisions: Tax Incentives and Financial Constraints". *Contemporary Accounting Research*, (21:3), pp. 639-680.
- "Krueger, A.B. and Whitmore, D. (2001). "The Effect of Attending a Small Class in the Early Grades on College-Test Taking and Middle School Test Results: Evidence from Project STAR". *Economic Journal*, 111(468), pp. 1-28.
- Lebeau, D. (1996). "Les Mesures Fiscales d'Aide à la R-D et les Entreprises Québécoises, Conseil de la Science et de la Technologie", Gouvernement du Québec, Canada.
- Lokshin, B. and Mohnen, P. (2008). "Wage Effects of R&D Tax Incentives: Evidence from the Netherlands". UNU-MERIT Working Paper No. 34, University of Maastricht.
- Lokshin, B. and Mohnen, P. (2009). "How effective are level-based R&D tax credits? Evidence from the Netherlands". Updated UNU-MERIT Working Paper No. 29, University of Maastricht.
- Mairesse, J. and Mulkay, B. (2004). "Une évaluation du crédit d'impôt recherche en France / The effect R&D tax credit in France (1980-1997)". *Revue d'économie politique*, (114:6), pp. 747-778.
- Mairesse, J. and Mulkay, B. (2008). "Une évaluation du crédit d'impôt recherche en France / The effect R&D tax credit in France (1980-2003)". Updated Presentation.
- Mamuneas, T. and Nadiri, M.I. (1996). "Public R&D Policies and Cost Behavior of the U.S. Manufacturing Industries". *Journal of Public Economics*, (63:1), pp. 57-81.
- Mansfield, E. (1985). "Public Policy Toward Industrial Innovation: An International Study of Direct Tax Incentives for R and D", in Clark, K., Hayes, R. and Lorenz, C. (eds.), *The Uneasy Alliance: Managing the Productivity-Technology Dilemma*. Harvard Business School Press, Boston, USA.
- Mansfield, E. (1986). "The R&D Tax Credit and Other Technology Policy Issues". *American Economic Review*, (76:2), pp. 190-194.

- Mansfield, E., and Switzer, L. (1985). "How Effective Are Canada's Direct Tax Incentives for R and D?". *Canadian Public Policy/Analyse de Politiques*, (11:2), pp. 241-246.
- Marra, M.A. (2004). "Incentivos fiscales, inversión en actividades de I+D y estructura de costes. Un análisis por tamaño para una muestra representativa de empresas manufactureras españolas 1991-1999". *Hacienda Pública Española/Revista de Economía Pública*, (170), pp. 9-35.
- McCutchen, W.M., Jr. (1993). "Estimating the Impact of the R&D Tax Credit on Strategic Groups in the Pharmaceutical Industry". *Research Policy* (22), pp. 337-351.
- McFetridge, D.G. & Warda, J.P. (1983). "Canadian R & D Incentives: Their Adequacy and Impact". Canadian Tax Paper No. 70, Canadian Tax Foundation.
- Parsons, M. and Phillips, N. (2007). "An Evaluation of the Federal Tax Credit for Scientific Research and Experimental Development". Canada Department of Finance, Working paper 2007-08.
- Poot, T., Brouwer, E., den Hertog, P. and Grosfeld, T. (2003). "Evaluation of a Major Dutch Tax Credit Scheme (WBSO) Aimed at Promoting R&D", presented at FTEVAL Conference on the Evaluation of Government Funded R&D Activities, Vienna, May 15-16, 2003. English version of Brouwer *et al.* (2002).
- Romero, D. and Sanz, J.F. (2007). "Eficacia de los incentivos fiscales a la inversión en I+D en España en los años noventa". *Hacienda Pública Española/Revista de Economía Pública*, (183), pp. 9-32.
- Shah, A. (1994). "The Economics of Research and Development, How Research and Development Capital Affects Production and Markets and is Affected by Tax Incentives", World Bank, Policy Research Department, Working Paper 1325.
- Tillinger, J.W. (1991). "An Analysis of the Effectiveness of the Research and Experimentation Tax Credit in a q Model of Valuation". *Journal of the American Taxation Association*, (13:2), pp. 1-29.
- Van den Hove, N., de Lanoy Meijer, N. and Mohanlal, H. (1998). "Evaluation of the WBSO R&D tax credit scheme, part II, Final report to the Ministry of Economic Affairs", "Evaluatie van de effectiviteit van de Wet vermindering Afdracht, S&O-vermindering" (WVA/S&O, voorheen WBSO), Deel II", Centraal Bureau voor de Statistiek, Voorburg (in Dutch).

ABSTRACT

This paper re-visits the empirical failure to establish a clear link between R&D efforts and patent counts at the industry level. It is claimed that the “propensity-to-patent” concept should be split into an “appropriability propensity” and a “strategic propensity”. The empirical contribution is based on a unique panel dataset composed of 18 industries in 19 countries over 19 years. The results confirm that the R&D-patent relationship is affected by research productivity, appropriability propensity and strategic-propensity factors. The observed increase in the propensity to file patents is much stronger for supra-national (that is, triadic or regional) patents than for national priority filings, suggesting that the current patent hype is essentially the result of a globalization phenomenon.

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The R&D-patent relationship: An industry perspective

1. Introduction

Patent data are the most widely used indicators of technology output. They are used for instance to assess the rate of technological change, to gauge firms' competitive positions, to measure industrial structure, or to evaluate scientific progress and knowledge spillovers. The success of patent statistics is rooted in their wide availability, their intrinsic relatedness to inventions, and their relatively homogeneous standards across countries. International treaties such as the Paris Convention for the protection of industrial property of 1883 or the Patent Cooperation Treaty of 1978 have indeed set some degree of minimum legal and quality standards.

The quality of patents as indicators of technological change has however been criticized or challenged for several decades (see Griliches 1990). There are noticeable differences in the reliance on patents across firms, industries and countries, which make patent data rather difficult to interpret. It is well known that not all inventions are patentable and not all patentable inventions are actually patented. In addition, patented inventions differ in their quality or "inventive step". This latter shortcoming means that patents vary greatly in their technical and economic significance, with a majority apparently mirroring minor technological improvements. A growing stream of research has therefore analyzed the extent to which patents are a reliable indicator of technological change. Schmookler (1957) is probably the first formal attempt to investigate what patent statistics actually indicate. The literature has mainly focused on correlations between patent counts and one or several other variables that measure either innovative input, such as R&D expenditures, or ultimate output measures, such as productivity growth or the stock market value of firms.

Studies on the R&D-patent relationship performed on cross-sectional data lead to the conclusion that there is a strong and highly significant correlation between R&D inputs and patent counts across firms. However, this correlation almost vanishes when within-firm time-series are considered. Patents do react to firm changes in R&D expenditures, but much less than expected. Investigations at the industry level lead to even more incongruous results, with a weak or almost absent correlation between R&D and patents. Some industries have a high propensity to rely on the patent system but file much fewer patents than other industries with a weaker orientation towards patent protection (Levin *et al.* 1987). This conundrum is probably what led Zvi Griliches (1990) to conclude that it would be "misleading to interpret such [patent] numbers as indicators of either the effectiveness of patenting or the efficiency of the R&D process". The tacit convergence amongst research scholars has been that patent data would reflect a propensity behaviour, rather than innovation performance or research productivity.

Despite this wide empirical scepticism of landmark contributions to the economic literature on patent-based indicators, the latter are still intensely used nowadays to measure firms' or countries' innovation performance. In a recent contribution, de Rassenfosse and van Pottelsberghe (2009) produce cross-country empirical evidence in favour of patent statistics. In particular, they show that some patent indicators are more reflective of a research productivity effect whereas others indicate more varying propensities to patent. The authors show that the R&D-patent relationship is affected by a "research productivity" component and a "patent propensity" component, as illustrated by the impact of three types of policies on countries' patent performances: education, science and technology, and the design of patent systems. Yet, their study lacks a time dimension and is performed at the country level and therefore does not contribute to explaining the failures of the firm or industry-level attempts to identify a relationship between R&D and patents over time.



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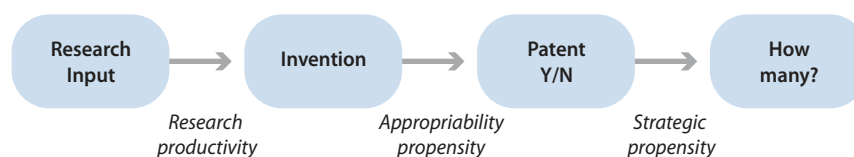
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R&D expenditure is related to patents through research productivity and the propensity to file for patent protection.

The present paper aims at re-visiting the failure to establish a clear empirical link between patent counts and changes in R&D expenditures at the industry level. The intended contribution to the literature is both conceptual and empirical. In addition to differentiating the “research productivity” effect from the “patent propensity” effect, the conceptual contribution claims that the latter effect should be disentangled into two main components: the “appropriability propensity” and the “strategic propensity”, as illustrated in Figure 1. The appropriability propensity relates to the share of inventions that are patented by firms, as measured in classical surveys (e.g. Levin *et al.* 1987, Arundel and Kabla 1998 or Cohen *et al.* 2000). The strategic propensity is defined as the number of patents filed to protect a given invention and has barely been measured so far. The failure to take into account both types of patent propensity is probably a major reason underlying the failure to identify a strong relationship between an increase in research activities and the evolution of patent applications at the industry level.

The empirical contribution of this paper consists in evaluating the R&D-patent relationship with a unique panel dataset covering 18 industries in 19 countries over 19 years. In addition, several patent-based indicators are used to test the robustness of the results: priority filings, “regional” filings and triadic filings.¹ Priority filings are first applications at national patent offices, which are potentially converted into regional patents later on (such as the European patent office (EPO) for Belgian applicants or the US Patent Office (USPTO) for Canadian applicants) or into triadic patent applications (patents filed simultaneously at the USPTO, the EPO and the Japanese Patent Office (JPO)). The average quality or value of patent indicators increases from priority filings to triadic applications, as witnessed by a larger geographical coverage and higher expenses due to legal and attorney fees, as well as translation costs.

Figure 1. The R&D-patent relationship



Our results confirm, first, that the research productivity dimension matters and explains part of the variation in the patent-to-R&D ratio over time. This productivity effect is captured by the share of basic research and of higher education in total R&D expenditures, and by an indicator of international-trade performance, which reflects the ultimate success of innovation efforts. Second, taking into account the two components of the propensity to patent – appropriability propensity and strategic propensity – helps to refine the relationship between R&D and patents at the industry level. If the long-term elasticity of patents with respect to R&D expenditures of about 0.12 is much lower than in cross-country or cross-firm estimates, it is nonetheless significant, suggesting that more R&D leads indeed to more patents. The low elasticity is probably due to the role of the strategic propensity, which is difficult to measure and is only partially captured by the strength of patent systems. The appropriability propensity has a positive and highly significant impact and sheds new light on the variability in the patent-to-R&D ratio across industries. A few industries (computers and communication technologies) and countries (South Korea, Spain and Poland) have strongly increased their propensity to file patents. The time dummies suggest that the propensity to file patents has increased much faster for regional applications (those at the USPTO or the EPO) and for triadic patents than for priority filings, suggesting that the current patent hype observed in regional patent offices is more the result of globalization than of a particularly stronger strategic propensity to file patents.

¹ “Regional” filings are filings at either the EPO or the USPTO or a mix of both indicators as explained in Section 3.2. These two offices, indeed, attract a large number of applications from non-domestic applicants, about half the total number of filings in the two offices.

The paper is structured as follows. The next section summarizes the results of selected empirical analyses of the R&D-patent relationship and discusses the two components of the propensity to patent. Section 3 presents the empirical model, the patent indicators and the explanatory variables. The empirical results are presented and interpreted in Section 4. Section 5 concludes and puts forward policy implications.

2. A missing link in the literature?

The estimated elasticity of patents with respect to R&D has been found to be large and significant in cross-sectional studies of firms, fluctuating around 1 (see Hall *et al.* 1986, Hausman *et al.* 1984, Jaffe 1986, Duguet and Kabla 1998, Crépon *et al.* 1998, Brouwer and Kleinknecht 1999 or Cincera 1997). Similarly large estimates of the elasticity of patents with respect to R&D are observed in cross-country or cross-region estimates (see for instance de Rassenfosse and van Pottelsberghe 2009 at the country level and Bottazzi and Peri 2003 at the regional level). When within-firm time-series data are used, the estimated parameters fall sharply and become less significant (see *e.g.* Hall *et al.* 1986, Hausman *et al.* 1984 or Czarnitzki *et al.* 2009). This low elasticity questions the relevance of patent measures as indicators of innovative output.

There are several possible reasons why the estimated R&D-patent elasticity is so weak when within-firms and/or time-series dimensions are taken into account. The first is that there are decreasing returns to research activities: the additional euro of research spent would be less “productive” than previous expenses. This explanation is problematic as it is not corroborated by the theoretical literature or by the existing evidence. The second potential explanation suggests that R&D indicators encompass much more than the very activity that consists in generating new ideas and inventions. In other words, R&D might not be a good indicator of innovative efforts. A third reason is related to the great randomness in the patent series, which greatly vary in their value, with most patents having low value and a few patents having very high value. Griliches (1990: p. 1678) clearly opts for the latter two hypotheses, arguing that “...the appearance of diminishing returns... could be an artefact of the incompleteness of the underlying data rather than a reflection of the characteristics of the innovation process itself.”

Industry level analyses lead to even less conclusive insights into the R&D-patent relationship. Cross-industry differences in the patent-to-R&D ratio do not correlate with their R&D intensity or their perception of the effectiveness of patents as a protection mechanism. For instance, some R&D-intensive industries that systematically rely on the patent system such as the pharmaceutical industry show low patent-to-R&D ratios. In other words, it suggests that patent metrics do not correlate well with innovative efforts across industries.

Scholars have long argued that patent counts reflect more the propensity to patent than innovative performance or research productivity. For instance, Scherer (1983, p. 116) explicitly assumes a constant productivity of research, for the sake of simplicity. While admitting the possibility of “differential creativity of an organization’s R&D scientists and engineers”, the author does not consider it important and chooses to concentrate on other “more systematic” factors. These more “systematic” factors which drive the patenting performance of firms are of two main types: strategic behaviour and alternative protection mechanisms.

Strategic patenting has been analyzed in-depth over the past 20 years (*e.g.* Teece 1998; Rivette and Kline 2000). Applying for a patent is indeed not always driven by the desire to protect innovation rents. Many facets of strategic patenting are listed in Guellec *et al.* (2007): Patents can be used as a tool for technological negotiations with competitors or with potential collaborators, to exclude rivals from a

Why is the R&D-elasticity of patents so low over time and across industries?

Patenting is only one way to appropriate the benefits from an invention and patents are used for other strategic purposes, too.

particular technological area, for communication purposes, to increase revenues through license agreements, to ensure freedom to operate and to attract capital. These strategic considerations all influence the observed patenting performance of firms. Patents are therefore not only an indicator of innovation output and technological success but also an indicator of strategic behaviour (see Blind *et al.* 2006; Cohen *et al.* 2000; de Rassenfosse and Guellec 2009 or Hall and Ziedonis 2001 for detailed investigations in this field).

The second reason that undermines the quality of patents as indicators of technological advance is embedded in the many alternative mechanisms of appropriation, such as secrecy, lead time, complementary sales and services, complementary manufacturing facilities, barriers to entry and the importance of tacit knowledge. Although all these mechanisms may coexist with patent protection, their availability might logically lower the need to rely on patent protection. According to the Carnegie Mellon Survey by Cohen *et al.* (2000) or the survey by Arundel and Kabla (1998), patents appear to be generally the last appropriability mechanism that is used, though its importance for some industries is noticeable, as reported in Table 1. This is particularly the case for medical equipment and drugs, special purpose machinery and computers. Secrecy and lead time are ranked overall as the two most effective appropriability mechanisms being top-ranked in 17 and 13 industries, respectively. Based on survey data of R&D executives in Switzerland, Harabi (1995) shows that the ability of competitors to “invent around” patents and the perception that patent documents disclose too much information are the most important factors that reduce the willingness to file patents.

Table 1. Share of product innovations that are patented (in percent)

	Arundel and Kabla (1998)	Cohen <i>et al.</i> (2000)
Mining	28	-
Food, beverages and tobacco	26	53
Textiles, clothing	8	43
Petroleum refining	23	73
Chemicals	57	77
Pharmaceuticals	79	74
Rubber and plastic products	34	65
Glass, clay, ceramics	29	50
Basic metals	15	54
Fabricated metal products	39	77
Machinery	52	74
Office and computing equipment	57	80
Electrical equipment	44	62
Communication equipment	47	59
Precision instruments	56	70
Automobiles	30	89
Other transport equipment	31	-
Power utilities	29	41
Transport and telecom services	20	-

Note: The industry classification corresponds to that presented in Arundel and Kabla (1998). The shares are rounded to the nearest integer.

In a nutshell, beside the innovation output that requires protection, the decision to file a patent is affected by alternative mechanisms of appropriation and by the strategic role that patents can play for a firm. These elements are typically industry-specific. It is striking that despite the many sources of variation and randomness in patent data, a strong increase in the use of patent-based indicators has been observed, including for economic and strategic analyses. The objective of this paper is to reconcile the *a priori* antagonism between the intensifying use of patent data and the pessimistic appraisal of these indicators in the academic literature. This reconciliation is done by identifying key milestones when dissecting the R&D-patent relationship.

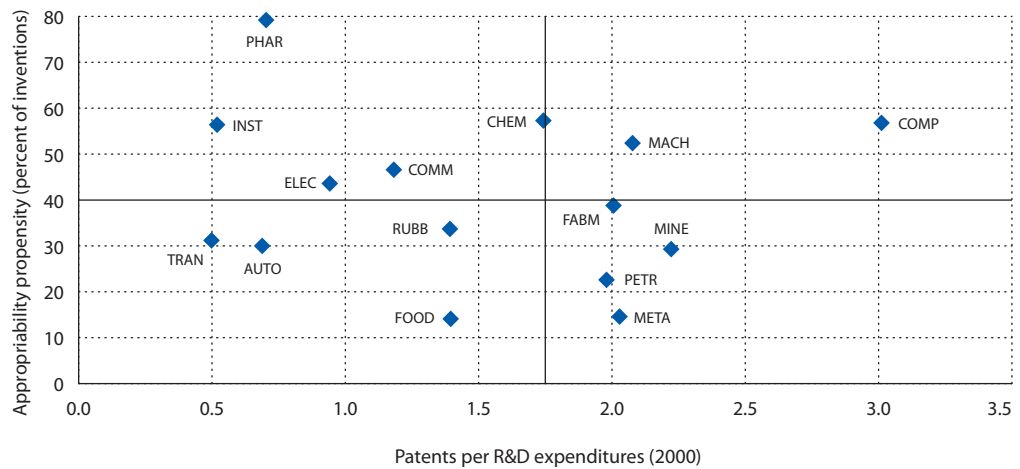
A first distinction can be made with respect to two important factors: research productivity and patent propensity. This distinction is investigated by de Rassenfosse and van Pottelsberghe (2009) who find that patent indicators reflect both research productivity and the propensity to patent. The authors exploit the cross-country variation in macroeconomic patent indicators for the year 2003. They relate the number of patents to total-economy R&D expenditure and to proxies for research productivity (e.g. the share of basic research in total R&D) and propensity to patent (e.g. the cost of filing a patent) and the strength of the patent system). Unlike the present study, however, de Rassenfosse and van Pottelsberghe (2009) have limited insights into cross-industry differences in the propensity to patent and do not investigate the time dimension, including the dynamic adjustment of patent outcomes to changes in research efforts.

The arguments made above as to why patent indicators are noisy, actually call for an additional distinction that should be made when conceptualising the R&D-patent relationship. The literature on this field has taken the implicit practice to define “patent propensity” in a (too) broad sense. We argue that it makes sense to split the propensity into two components: the “appropriability propensity” and the “strategic propensity”. The former captures the decision to protect an invention or not, and is proxied by the share of inventions that are patented, as reported in surveys like Levin *et al.* (1987), Cohen *et al.* (2000), or Arundel and Kabla (1998). The latter captures the patent-filing behaviour at a second stage. Once the decision is made to protect an invention, the applicant chooses the number of patents that are to be filed to protect it. These two dimensions surely affect the observed R&D-patent relationship. The failure to distinguish the appropriability propensity from the strategic propensity is probably what made Griliches claim that “the patent to R&D ratios appear to be dominated by what may be largely irrelevant fluctuations in the R&D numbers”. This paper argues – and provides empirical evidence of the claim – that taking into account these two dimensions provides a better understanding of the R&D-patent relationship.

‘Appropriability propensity’ refers to whether or not a firm opts for patenting at all, while ‘strategic propensity’ captures the behaviour at the filing stage.

Figure 2 illustrates somewhat the issue at stake. It depicts the appropriability propensity against the ratio of patents to R&D expenditure, with the former shown on the vertical axis and the latter on the horizontal axis. For instance, the instrument and the computer industries both have a high appropriability propensity but the latter has a much higher patent-to-R&D ratio than the former, probably due to a higher strategic propensity (patent thickets are known to be prevalent in this particular industry). Note that differences along the horizontal axis are probably not solely due to heterogeneous strategic propensities. The pharmaceutical industry has a very high appropriability propensity but a very low patent-to-R&D ratio due to the huge amount of R&D efforts devoted to a single invention. Similarly, the relatively low share of patented inventions in food and basic metals does not prevent these industries from having a relatively high number of patents per R&D. This should be borne in mind when interpreting statistics such as patents over R&D expenditures. The quantitative approach adopted in the next section aims at taking into account, and measuring, these three components of the R&D-patent relationship.

Figure 2. Appropriability propensity versus strategic propensity by industry



Source: Arundel and Kabla (1998) and own calculations

Note: The horizontal axis corresponds to the ratio of priority filings to R&D expenditures (in million of USD PPP at constant prices).

3. Empirical framework

In analyzing the R&D-patent link, we take into account determinants of research productivity and determinants of the propensity to patent.

The aim of the empirical analysis is to investigate the link between R&D and patents at the industry level taking into account the factors that affect the propensity to patent and those that affect the productivity of research efforts. In an ideal set-up, one would be able to observe both the “raw” technology output (*i.e.* the number of inventions) and the number of patents. Yet, since the only observable measure of inventive output is the count of patents, one should be cautious in the interpretation of the parameters of the patent production function because differences in patent numbers reflect both productivity and propensity effects.

3.1 Estimation methodology

The dataset has three dimensions: time, industry and country. The estimations, however, are performed on two dimensions: the time period (t) and the country-industry pair (ij) – each “individual” is thus an industry in a country.² The patent production function is estimated in an error correction framework to differentiate short-run from long-run effects of the explanatory variables on the number of patents. More specifically, the following equation is estimated (see Box 1 for a detailed description of the model):

$$\Delta p_{ijt} = \psi_i + \psi_j + \psi_t + \Delta r_{ijt} \gamma + \Delta z_{ijt} \beta + \Delta x_{ijt} \alpha - (\lambda p_{ijt-1} - c - r_{ijt-1} \gamma - z_{ijt-1} \beta - x_{ijt-1} \alpha) + v_{ijt}$$

where p stands for the log of the number of patents, r is the log of the research efforts, x and z are vectors of variables capturing the productivity of research efforts (leading from research efforts to inventions) and the propensity to patent (leading from inventions to patents), respectively. Δ is the first difference operator, v is the error term, ψ_i is the vector of country dummies ($i=1, \dots, 19$), ψ_j is the vector of industry dummies ($j=1, \dots, 18$), and ψ_t is the vector of time dummies for the years 1987 to 2005 ($t=1, \dots, 19$).

² An alternative approach would have been to estimate the parameters of a patent production function for each industry, thereby allowing for differentiated impacts across industries. The “pooled” approach is nevertheless chosen because it is based on a larger number of observations and provides averages across industries and countries. In addition, it is the very purpose of this paper to grasp cross-industry determinants of patent-to-R&D variations.

Note that since the dependent variable is the first difference of the log of patents ($\ln P_t - \ln P_{t-1}$), it is a rough approximation of the growth rate of patents.

The term in parentheses is usually referred to as the error correction term. It can be interpreted as the deviation from equilibrium in the previous period. The variables expressed in first difference (i.e. those preceded by the operator Δ) capture the short-term impact on the number of patents and indicate how a change in any explanatory variable contemporaneously affects the number of patents. The parameter λ usually fluctuates between 0 and 1 and measures the speed of adjustment to the long-term equilibrium (the closer to 1, the quicker the adjustment process). The long-run elasticities are calculated by dividing each parameter associated with the lagged variables by the adjustment parameter λ . For instance, the long-run elasticity of the productivity variable is equal to $-\alpha_j \cdot \lambda^{-1}$ (for a discussion, see Alogoskoufis and Smith 1991).

The growth-rate-of-patents equation is estimated with an error-correction model.

Box 1. Derivation of the estimation framework

Since research efforts (R) lead to inventions (I) which, in turn, may lead to patent applications (P), we can express the R&D-patent relationship for the N individuals in the sample as follows (forgetting momentarily the time dimension):

$$(B.1) \quad I = \Omega R^\gamma \quad \text{and} \quad P = \Phi I$$

where Ω and Φ are diagonal matrices of size N capturing the productivity and the propensity effects for each individual, respectively. In this framework, Φ captures both the appropriability propensity and the strategic propensity. The parameter γ is a scalar measuring the average return to R&D across individuals.¹ Φ can be expressed as a function of the two propensity components (the appropriability propensity and the strategic propensity) but this would unnecessarily clutter the notation. If we let X and Z , respectively denote the matrices of variables that affect Ω and Φ , and α and β the column vectors of parameters, we can write:

$$(B.2) \quad i = c_1 + x\alpha + r\gamma \quad \text{and} \quad p = c_2 + z\beta + i$$

where lower-case roman letters denote the log of the variables. Expanding the patent production function gives:

$$(B.3) \quad p = c + r\gamma + z\beta + x\alpha$$

where c equals $c_1 + c_2$ and is a scale parameter capturing the rate at which research efforts lead to patent applications (c_1 reflects the average productivity of research across individuals and c_2 the average propensity to file patents). It is well documented in the literature (see references in the introduction and in Section 2) that the propensity to patent has most probably constantly increased since the eighties, due to an unobservable greater reliance on the patent system for various "strategic" reasons, i.e., c_2 might have increased over time, even when accounting for the observable characteristics Z . In a similar vein, the productivity of research has also probably improved over the years (Kortum and Lerner 1999). Therefore, the extent to which the scale variable c would capture an average growth rate of the productivity of research or of the two propensity effects is unclear. It actually depends on the proxies for research productivity and the propensity to patent, respectively. As the variables used in the empirical analysis tend to better capture cross-industry and cross-country variations in the productivity of research, there are more reasons to suspect that unobserved changes are due to variation in the propensity to

¹ The expression R^γ indicates that each of the N elements r_i of R is taken to the power of γ .

patent rather than in the productivity of research. It is therefore likely that the dummies would be more reflective of a change in propensity than a change in productivity. The patent production function for a given industry-country pair in a single point in time (ijt) to be estimated empirically can be written as:

$$(B.4) \quad p_{ijt} = c_{ijt} + r_{ijt} \gamma + z_{ijt} \beta + x_{ijt} \alpha + \varepsilon_{ijt}$$

where ε_{ijt} is the error term. It is good practice to estimate panel data in first-difference to avoid potential spurious-regression problems. Letting “ Δ ” denote the first-difference operator, we can write:

$$(B.5) \quad \Delta p_{ijt} = \Delta c_{ijt} + \Delta r_{ijt} \gamma + \Delta z_{ijt} \beta + \Delta x_{ijt} \alpha + \Delta \varepsilon_{ijt}$$

Assuming that c_i is constant,

$$(B.6) \quad \Delta c_{ijt} = c_{ijt} - c_{ijt-1} = (c_{1,ijt} + c_{2,ijt}) - (c_{1,ijt-1} + c_{2,ijt-1}) \approx \Delta c_{2,ijt}$$

such that we can write

$$(B.7) \quad \Delta p_{ijt} = \Delta c_{2,ijt} + \Delta r_{ijt} \gamma + \Delta z_{ijt} \beta + \Delta x_{ijt} \alpha + u_{ijt}$$

with $u_{ijt} = \Delta \varepsilon_{ijt}$. Since the variables are expressed in logs, Equation (B.7) is an approximation of the growth rate of patenting. The term $\Delta c_{2,ijt}$ is the growth rate of the propensity to patent that is not accounted for by the explanatory variables. Equation (B.7) implies that a change in any of the explanatory variable has a contemporaneous impact on the number of patents applied for. In other words, the parameters of the first-differenced variables capture the short term elasticities.

However, past R&D expenditures might also influence current patenting activity because research projects usually require quite some time before leading to a patentable invention. In order to account for a gradual adjustment, the patent production function is estimated by means of an error correction model (ECM) with a one-year lag structure. The choice of a one-year lag is motivated by de Rassenfosse and Guellec (2009) and Hall *et al.* (1986). Using firm-level survey data, de Rassenfosse and Guellec (2009) notice that the lag between initial R&D expenditures and patent applications is of the order of one year, even though it can reach as much as five years. Hall *et al.* (1986) estimate several panel data models at the microeconomic level and obtain a strong contemporaneous relationship between R&D expenditures and patenting, and a small effect of R&D history on patent applications. This is consistent with the practice of filing patents early enough in the life of a research project.

ECMs allow estimating both the short-run and the long-run impacts that exist between the endogenous and the exogenous variables. It consists in estimating the model in first difference together with previous year's deviation from equilibrium (in brackets), leading to the equation given in the main text.

$$(B.8) \quad \Delta p_{ijt} = \psi_i + \psi_j + \psi_t + \Delta r_{ijt} \gamma + \Delta z_{ijt} \beta + \Delta x_{ijt} \alpha - (\lambda p_{ijt-1} - c - r_{ijt-1} \gamma - z_{ijt-1} \beta - x_{ijt-1} \alpha) + v_{ijt}$$

Finally, remember that the individual is defined as a country-industry pair. The term $\Delta c_{2,ijt}$ of Equation (B.7) can be decomposed into a fixed country effect (ψ_i), a fixed industry effect (ψ_j) and with a common time-effect (ψ_t).

3.2 The dependent variable: patent indicators

There are many different ways of counting patents.

There exist many ways to count patents, each carrying its own meaning (see *e.g.* Dernis *et al.* 2001 and OECD 2009). It is therefore particularly important to carefully select the patent indicator that will be used to monitor countries' innovation performance so as to reduce the potential biases as much as possible. For this reason, five alternative indicators are used in the empirical analysis in order to gauge

the robustness of the results to the chosen dependent variable. These indicators are the number of national priority filings, the number of patents filed at the EPO, the number of patents filed at the USPTO, a measure combining EPO and USPTO patents, and the number of patents filed simultaneously in Japan, the US and Europe. Whereas the first indicator is composed of many patents with a much skewed distribution of value, the triadic filings are less numerous but are supposed to be of a much higher economic value. Figure 3 illustrates some of the differences between these indicators.

The patent indicators are computed from the OECD-EPO PATSTAT database (April 2009) for each manufacturing industry, following the International Standard Industry Classification scheme (ISIC, Revision 3) as indicated in Table A1 of Annex 1. Patents, however, are not characterised by the ISIC scheme, but rather by the codes of the International Patent Classification (IPC), representing different areas of technology to which they pertain. Patents have therefore been assigned to the appropriate industries using the concordance table between IPC and ISIC codes provided by Schmoch *et al.* (2003) who have estimated the empirical concordance table by investigating the patenting activity by technology-based fields (IPC) of more than 3,000 firms classified by industrial sector (ISIC). When a patent contains more than one IPC code, the industry allocation is performed on a fractional basis.³

The first indicator is the corrected count of national priority filings (NPF CORR) recently introduced by de Rassenfosse *et al.* (2009). It captures all the patents filed by the inventors based in a country, regardless of the patent office of application. The count for, say, Austria is thus equal to the number of priority filings by Austrian inventors filed at the Austrian patent office plus the priority filings from Austrian inventors directly filed at other patent offices such as the EPO, the USPTO or the German patent office.⁴ The inclusion of these priority filings abroad allows reducing the bias against small countries such as Belgium and the Netherlands which file a higher share of their patents abroad as compared with, say, France and Germany. This indicator is a very broad measure of patenting, encompassing both low-value and high-value patents. It is biased in favour of Japan and South Korea, with the share of these countries in the total of national priority filings being much higher than their share in R&D expenditures (see Figure 3). This is due to the large differences in patent systems, particularly in South Korea and Japan, where patents are much smaller but more numerous (see de Rassenfosse and van Pottelsberghe 2008). For this reason, the count for Japanese and Korean priority filings has been divided by three (for a discussion, see Kotabe 1992 and Archontopoulos *et al.* 2007).

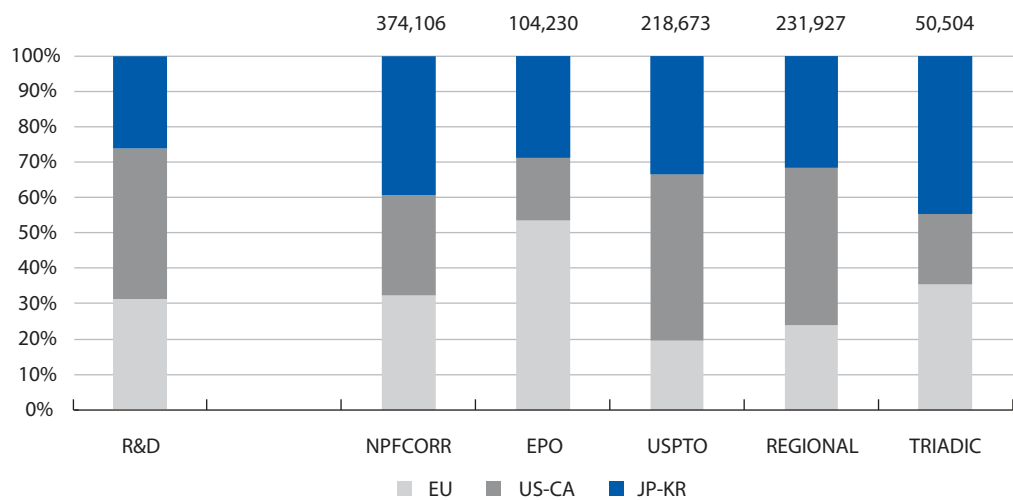
We use a corrected measure of national priority filings, applications filed at the EPO, ...

The second indicator is the count of patent applications filed at the EPO. It is composed of the patents that were filed directly at the EPO or that were later extended to the EPO as second filings. As the patenting procedure at the EPO is expensive, EPO patents are supposedly of a higher value. This indicator is nevertheless biased for two main reasons. The first is related to the home bias, which is well illustrated in Figure 3, whereby companies in Europe tend to rely more heavily on the EPO than companies from non-European countries. Second, the reliance on the EPO has increased over time, for all countries and especially European ones. De Rassenfosse and van Pottelsberghe (2007) show that a systematic bias in statistics based on European patents must be acknowledged: the share of priority filings transferred to the EPO is increasing with the age of membership to the European Patent Convention. This calls for a cautious interpretation of the evolution of the number of EPO patents over time.

3 Some patents had no IPC codes, and some IPC codes were not in the concordance table. All these “unassigned” patents were allocated to the industries according to the observed share of successfully allocated patents.

4 The nationality of filings was identified by the country of residence of inventors so as to capture all the inventive output in a given country. That is, a patent from Austrian inventors is considered as an Austrian application even if it is filed by a US assignee (or patentee). This methodology assures the best match between R&D expenditures and patent applications.

Figure 3. Research effort and patenting activity, 2004



Source: Own calculations. See Table A.1 for more details

...patents granted at the US patent office, a mixed EPO-USPTO measure and the count of triadic patent families.

The third indicator is similar to the second, except that the patent office of reference is the USPTO and that statistics are available for granted patents only. Given that a large number of countries in the sample are European countries, this indicator probably reflects the value of patents better (a European applicant will file more easily at the EPO than at the USPTO, and will seek for a US patent only for the most valuable inventions).⁵ However, this indicator is subject to an important, and logical, home bias for North American applicants (see Figure 3).

The fourth indicator (REGIONAL) is a mix between EPO and USPTO patents. Since European applicants have a higher tendency to file at the EPO and other countries preferably file at the USPTO, the indicator is composed of EPO patents for European countries and USPTO patents for other countries. The approach mitigates the home biases characterising the EPO and the USPTO indicators, with a geographical distribution that is closer to the distribution of research efforts.

The count of triadic patent families is the fifth indicator (TRIADIC). It was developed a decade ago by the OECD to select patents of a high quality standard that were comparable across countries. According to the OECD definition, the triadic patent family is defined as a set of patent applications filed simultaneously at the EPO, the JPO, and granted by the USPTO, sharing one or more priority applications (OECD 2009a, p 71). The indicator is more robust to differences in patent regulations across countries and changes in patent laws over time. Triadic patents are of high value given the high cost incurred with patent applications in the three patent offices. On average, only between 10 and 15 percent of priority filings ultimately become triadic patents. The 19 countries included in the sample have a total of 374,106 priority filings in 2004 for 50,504 triadic patent applications. The absolute count of patents and the relative shares is presented in Tables A2 and A3 of Annex 1 for countries and industries, respectively.

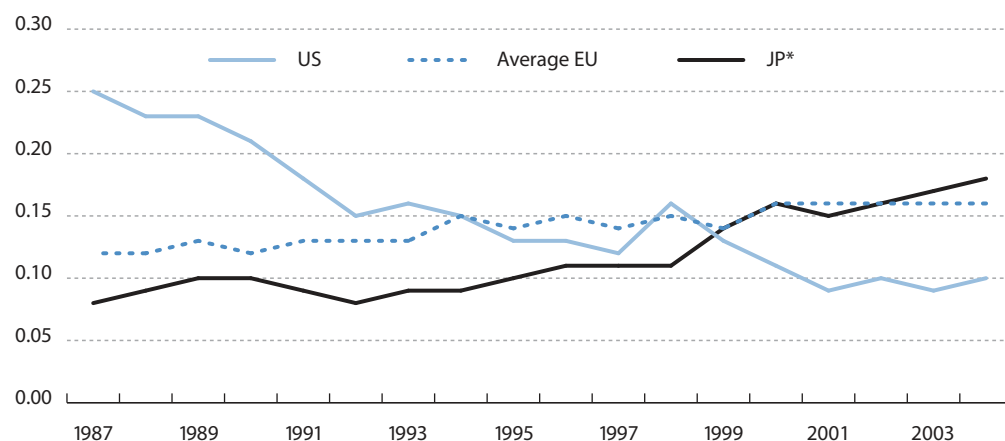
Figure 4 represents the share of priority filings that eventually became triadic patents. De Rassenfosse and van Pottelsberghe (2009) have shown that triadic patents are a good measure of research productivity and are more suited than priority filings to capture the quality of research efforts. Yet, an increase in the share of triadic patents over time does not necessarily reflect an increase in patent quality, as other factors such as the internationalisation of economic activity and a higher familiarity

⁵ To mitigate the effect of the grant lag on US patent statistics, which was especially strong in 2004 and 2005, the data are adjusted for each country-industry pair using the ratio of EPO patents to US patents for the year 2003.

with international patenting procedures possibly play a role, too. The figure shows that the share of triadic patents has been slightly increasing in Europe and Japan and decreasing in the US. The increase in Europe and Japan could be more due to a higher tendency of applicants to seek protection in foreign markets than to an increase in the average value of inventions. As for the US, it is likely that the drop in the share of triadic patents is due to a strong increase in the number of priority filings that did not lead to many triadic patent applications. According to van Pottelsberghe (2009) this is due to the very low cost of patenting in the US and a weak rigour of the examination process. Cheap patents facing a soft examination practice would logically lead to a high propensity to file low value patents, which are not later translated into triadic applications.

Triadic patents tell more about research productivity than other patent counts but their faster increase also reflects the internationalization of production.

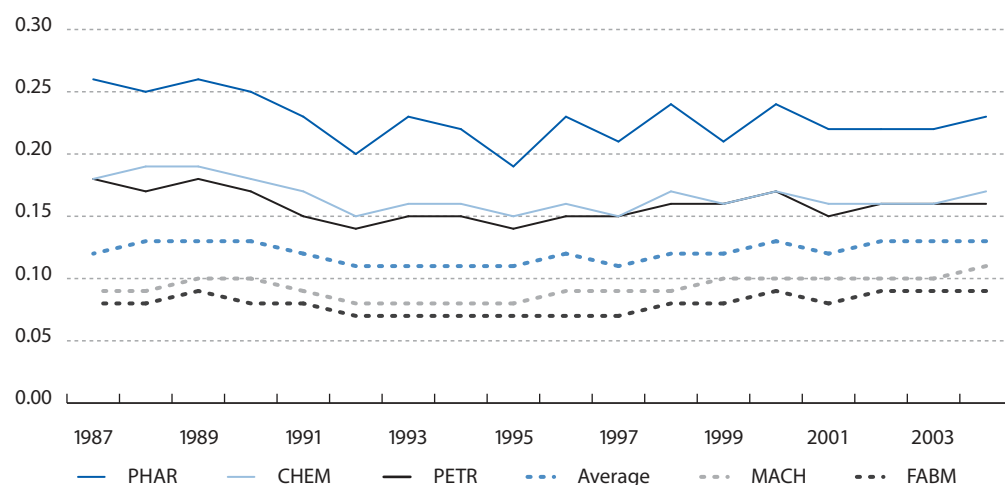
Figure 4. Share of triadic patents in total priority filings, in Europe, Japan and the USA



Source: Own calculations

Figure 5 depicts the evolution over time of the share of triadic patents for a selected number of industries. On average, 10 to 15 percent of priority filings are extended in the Triad, but some industries, in particular the pharmaceutical industry have a much higher share of triadic patents. This figure should be contrasted with the low ranking achieved by the pharmaceutical industry in Figure 2. This industry typically produces a low number of patents per unit of R&D, but these patents are of a relatively high value.

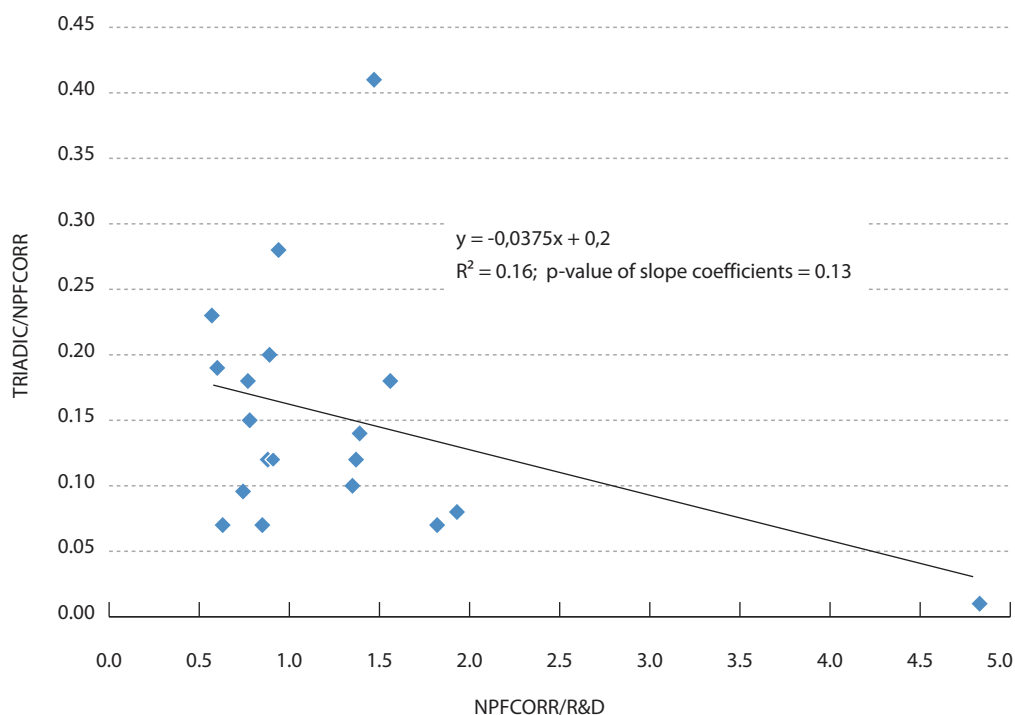
Figure 5. Share of triadic patents in total priority filings, in Europe, Japan and the USA



Source: Own calculations

To test whether a high propensity to patent is associated with a lower quality per patent, Figure 6 presents the share of triadic filings in total priority filings by country as a function of the number of priority filings per million dollars invested in R&D. There is a clear negative relationship, indicating that countries with a high propensity to patent have portfolios that are of lower average quality or economic value.

Figure 6. Quality of applications versus propensity to file, by country, (2004)



Source: Own calculations

3.3 Explanatory variables

The key explanatory variable is R&D expenditure as a measure of an industry's research efforts.

The most important explanatory variable is R&D expenditures by industry ("R&D") as a measure of the industry's research efforts. It is taken from the OECD's ANBERD database (2009), and is expressed in constant US dollars (USD) at purchasing power parity (PPP). The estimated patent elasticity with respect to R&D provides an incomplete evaluation of the research productivity. A more complete picture would be easy to draw if inventions (not patents) could be measured with accuracy and if the two types of propensity to patent were properly measured across countries and over time. Since there is no such indicator, an indirect approach such as the one developed by de Rassenfosse and van Pottelsberghe (2009) is needed. It consists in finding variables that arguably reflect (or induce) differences in the productivity of research activities and variables that arguably affect the propensity to patent.

Finding potential explanatory variables affecting the propensity and the productivity components for a large group of countries, varying over industries and available over a long period is a challenging task. Three candidates that could affect the productivity of research and two potentially affecting the propensity to patent are identified. Some vary over time and across countries and industries whereas some others vary only across countries or industries, as indicated in Table 2.

Table 2. Overview of the explanatory variables

	Component		Variation			Number of observations
	<i>Propensity (z)</i>	<i>Productivity (x)</i>	<i>Country</i>	<i>Industry</i>	<i>Year</i>	
R&D			x	x	x	4937
APPROPRIABILITY	x			x		4131
IP INDEX	x		x		x	4937
INTL COMP		x		x	x	4451
SHARE BASIC		x	x		x	1811
SHARE HIGHER EDU		x	x		x	4353

Source: OECD STAN R&D Expenditure in Industry (ISIC Rev. 3) ANBERD ed2009 for R&D; Arundel and Kabla (1998) for APPROPRIABILITY; Park (2008) for IP INDEX, with yearly data computed on the basis of a compound annual growth rate two available data points; OECD (2009b) for INTL COMP; and OECD (2009a) for SHARE BASIC and SHARE HIGHER EDU

The three variables that are supposed to affect – or correlate with – research productivity are defined and measured as follows. The variable “SHARE BASIC” is the basic-research expenditure as a percentage of gross domestic expenditure on R&D (OECD 2009a). The variable is expected to lead to a greater productivity of research efforts as basic research typically pushes forward the knowledge frontier and generates new opportunities for further development. The second productivity variable is “SHARE HIGHER EDU.” It is defined as the percentage of gross domestic expenditure on R&D performed by the higher education sector (OECD 2009a). The expected impact on the number of patents is mixed. On the one hand, the higher education sector develops and uses frontier knowledge that companies can use, suggesting a positive relationship. On the other hand, the propensity to patent is lower among universities, such that a negative impact is possible, too. The third productivity variable is “INTL COMP” and captures an industry’s exposure to international trade. It is defined for each country-industry pair as the ratio of net exports to the sum of imports and exports (OECD 2009b). The higher the variable, the more the industry exports in comparison to its imports, hence the more it is internationally competitive. A positive impact is expected as internationally competitive industries must be innovative in terms of new product performance or reduced production costs. In analyzing the determinants of patenting across a set of OECD countries, Furman *et al.* (2002, p. 899) find that “an extremely important role is played by factors associated with differences in R&D productivity [such as] openness to international trade.”

Two proxies are available for the propensity effects. As for the strategic propensity, the variable “IP INDEX” is a measure of the strength of the intellectual property (IP) system at the country level developed by Ginarte and Park (1997). We expect countries with a stronger IP regime to have a higher strategic propensity to patent as a strong protection increases the value of patent rights. This is an imperfect proxy however, as it is only published every five years.⁶ The second variable, “APPROPRIABILITY”, captures the appropriability propensity and is based on Arundel and Kabla (1998) who have surveyed the share of innovations that were patented in the French manufacturing industry. This observation allows reducing the noise in the R&D-patent relationship by directly correcting for a fundamental link between inventions and patents. This data source is preferred over others because it is the closest to the industry classification of the ANBERD database.

⁶ We compute annual data on the basis of the compound annual growth rate.

The shares of basic and/or university research and international competitiveness matter for research productivity.

It is worth mentioning that those variables that supposedly influence (or correlate with) the productivity of research are more diverse and comprehensive than the propensity variables: the exposure-to-trade variable varies across countries, industries and over time and the other two variables vary over time and across countries). By contrast, the proxy for the appropriability propensity varies only across industries, while the proxy for the strategic propensity varies essentially across countries and slightly over time. It is therefore fair to assume that the fixed effects in the regression mainly capture changes in the propensity to patent across the various dimensions of the panel (industry, country and time).

4. Empirical results

The empirical results are analyzed and interpreted in three main stages. First, the basic R&D-patent model is estimated with the alternative patent indicators. Then the productivity and propensity variables are added simultaneously to the model. The third stage consists in analyzing the various sets of dummies (industry, country and time), as they witness the remaining “dynamic” propensity to patent.

4.1. The basic R&D-patent model

The estimated parameters of the error correction model described in Equation (B.8) are presented in Table 3 for the five patent indicators. The only explanatory variable taken into account is R&D expenditure.

Table 3. Results of the error-correction model of the R&D-patent relationship

	NPFCORR	TRIADIC	EPO	USPTO	REGIONAL
$\Delta \log(\#patents)$	(1)	(2)	(3)	(4)	(5)
$\Delta \log(R\&D)$	0.009 (0.007)	0.013 (0.015)	0.009 (0.009)	-0.013 (0.010)	0.014 (0.009)
$\log(\#patents) (t-1)$	-0.119*** (0.007)	-0.290*** (0.010)	-0.155*** (0.008)	-0.145*** (0.008)	-0.149*** (0.008)
$\log(R\&D) (t-1)$	0.014*** (0.002)	0.032*** (0.005)	0.018*** (0.003)	0.017*** (0.003)	0.019*** (0.003)
Country dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Industry dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Time dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Number of observations	4943	4943	4943	4943	4943
Adjusted R-squared	0.197	0.187	0.156	0.171	0.129
Long-run impact of R&D	0.118	0.110	0.116	0.123	0.128

Notes: Standard errors in parentheses; ***, **, * denote significance at the 1, 5 and 10-percent levels, respectively. The rows “country dummies”, “industry dummies” and “time dummies” report the significance level of the joint effect of these dummies. The long-run impact of R&D is computed by dividing the coefficient of $\log(R\&D) (t-1)$ by the coefficient of $\log(\#patents) (t-1)$.

On average, a 10-percent increase in R&D expenditure leads to a 1.2-percent increase in patent applications.

The short-term elasticity is not significantly different from zero (see the coefficient of $\Delta \log(R\&D)$). This result confirms that patents are a poor indicator of short-term changes in the output of inventive activity. The long-term elasticity of R&D fluctuates around 0.12, regardless of the patent indicator that is used. In other words, a 10-percent increase in R&D outlays leads to a 1.2-percent increase in patent applications, on average. These point estimates are strikingly low but compatible with estimates performed with firm-level panel data sets. The adjustment parameter λ (coefficient of variable $\log(\#patents)$) is lowest for priority filings and highest for triadic patents indicating greater inertia of

priority filings. In other words, the R&D history matters more for priority filings whereas changes in R&D expenditures have a faster impact on triadic patents.

Depending on the patent indicator that is used, R&D expenditures and the three sets of dummy variables explain between 13 and 20 percent of the growth in patent applications. The best fits are achieved with priority filings and triadic patents, *i.e.* the patent indicators that are at the opposite ends on the average-value scale: for these specifications the adjusted R-squared is 20 percent. This explanatory power is quite satisfactory given the nature of the data and the simplicity of the patent production function considered. Country, industry and time effects are all jointly significant. They are described and analyzed at the end of this section. Note that tests for autocorrelation of residuals reject the presence of correlated errors.⁷

4.2. Productivity

The low estimated elasticity of patents with respect to R&D raises the question whether other factors may help to explain industry or country variations in patent applications. This issue is investigated in Table 4 where the productivity and the two propensity components are jointly included in the model. The estimations are presented only with indicators NPFCORR, the TRIADIC and the REGIONAL as dependent variables. Regressions based on EPO and USPTO lead to similar results.

Given this low R&D-elasticity, what else drives variations in patent applications?

Table 4. Results of the full error-correction model

$\Delta \log(\#patents)$	NPFCORR	TRIADIC	REGIONAL
	(1)	(2)	(3)
APPROPRIABILITY	0.004*** (0.000)	0.012*** (0.001)	0.005*** (0.000)
IP INDEX	0.031** (0.012)	0.053** (0.023)	0.073*** (0.015)
$\Delta \log(R\&D)$	-0.003 (0.008)	-0.010 (0.016)	-0.008 (0.010)
Δ INTL COMP	-0.002 (0.016)	0.098*** (0.030)	0.052*** (0.019)
Δ SHARE HIGHER EDU	-0.010*** (0.002)	-0.002 (0.004)	-0.008*** (0.002)
$\log(\#patents)$ (t-1)	-0.142*** (0.008)	-0.279*** (0.012)	-0.137*** (0.009)
$\log(R\&D)$ (t-1)	0.014*** (0.003)	0.013** (0.006)	0.007* (0.004)
INTL COMP (t-1)	0.028*** (0.009)	0.100*** (0.017)	0.056*** (0.011)
SHARE HIGHER EDU (t-1)	0.0002 (0.001)	-0.002 (0.002)	0.005*** (0.001)
Countries dummies	Yes ***	Yes ***	Yes ***
Industry dummies	Yes ***	Yes ***	Yes ***
Time dummies	Yes ***	Yes ***	Yes ***
Number of observations	3696	3696	3696
Adjusted R-Square	0.237	0.190	0.140

Notes: Standard errors in parentheses; ***, **, * denote significance at the 1, 5 and 10-percent levels, respectively. Each of the rows "country dummies", "industry dummies" and "time dummies" report the significance level of the joint effect of the respective dummies.

⁷ Tests for autocorrelation are available upon request from the authors.

Three indicators likely to affect (or to be correlated with) research productivity are used. They include the share of higher education in total R&D expenditure, the share of basic research in total R&D expenditure and an indicator of international competitiveness. The first two indicators are not perfect because they only vary across countries and over time but not across industries. The third fluctuates in the three dimensions. The impact of the share of total R&D performed by the higher education sector (SHARE HIGHER EDU) has a positive and significant impact on the regional patent indicator only, suggesting that university-performed R&D leads to more valuable patents in the long-run. The negative short-term impact of this variable is probably due to a transitional effect caused by the diversion of resources towards less patent-minded entities. It can also be explained by longer delays in the R&D process at universities as compared with the private sector. In any case, it suggests that allocating more resources to academic research is a long-term policy aimed at securing the seeds of future innovations.

The share of basic research, an indicator of potential breakthrough inventions, is tested separately. It is not included in the main specification due to a much smaller number of data points available. The results are presented in Table A4 of Annex 1. The share of basic research has a strong productivity effect on all patent indicators, with a long-term premium of about 11 percent. In other words, the higher the share of basic research in total R&D expenditures, the higher the number of patent applications induced by an increase in the productivity of research efforts.

The exposure to international trade (INTL COMP) has a positive and significant impact on the number of patent filings, both in the short run and in the long run. This result confirms the impact on research productivity that Furman *et al.* (2002) obtain with their variable OPENNESS. Note that the effect is twice as high with international patents as with priority filings.

4.3. Propensities

The number of patents tends to be higher in countries with stringent IP protection and in industries with high appropriability propensity.

The distinction between appropriability and strategic propensities put forward in the present paper is not easy to implement empirically. The two proxies that are used to gauge these propensities are imperfect measures because they only vary across countries or across industries and are quite stable over time. Still, the appropriability propensity variable (APPROPRIABILITY) is highly significant and confirms the relevance of using information on the share of inventions that are patented in order to better understand how an increase in R&D efforts would translate into more patents. This is evidence of the key role of the appropriability propensity in the R&D-patent relationship.

The variable that aims at capturing some facets of the strategic propensity is the strength of the patent system (IP-INDEX). It turns out to be a significant determinant of the number of patents. Countries with a higher IP-INDEX are also likely to have more patent filings per unit of R&D effort. For instance, the US has a very high index because there are many patentable subject matters (as opposed to Europe where many restrictions apply) and because the enforcement system is well developed and historically supporting patented inventions.

This propensity variable is only one factor influencing the strategic propensity to patent. Despite its significant impact, which validates the intuition expressed in this paper, we recognise that “strategic propensity” is imperfectly measured since no indicator with cross-industry variations is available to the best of our knowledge. A similar criticism can be made on the appropriability variable.

4.4. Remaining “dynamic” propensity

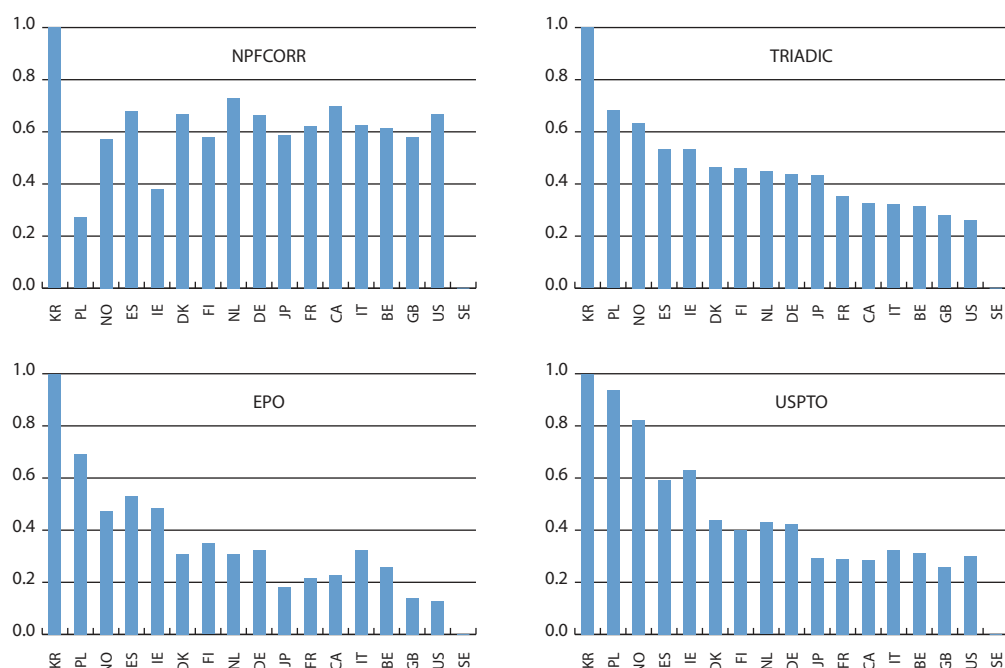
The country, industry and time effects from the full model can be used to assess the average evolution of the propensity to patent along the three dimensions (see Annex 2 for methodological details). Since

the model explains the growth rate of patent filings, the control dummies capture the increase in the propensity to patent – or the “dynamic” propensity – net of the impact of all other observable characteristics. The fixed effects probably capture unobserved changes in productivity and in the two measures of propensity. But since the R&D productivity component is definitely better measured than the two propensity components, it is fair to assume that the fixed effects capture more the propensity than the productivity components.

The remaining propensity to patent is dissected into its country, industry and time dimensions.

Figure 7 shows the normalized coefficients of the country dummies. The rankings for the international indicators (TRIADIC, EPO and USPTO) are roughly similar and clearly underline a strong catching-up effect for South Korea, Poland, Norway and Spain. Countries such as France, Canada, Great Britain and the US rank last on triadic and regional patent statistics (EPO and USPTO), suggesting that they have lost some ground in their patenting performance as measured by international indicators.

Figure 7. Dynamic propensity to patent across countries

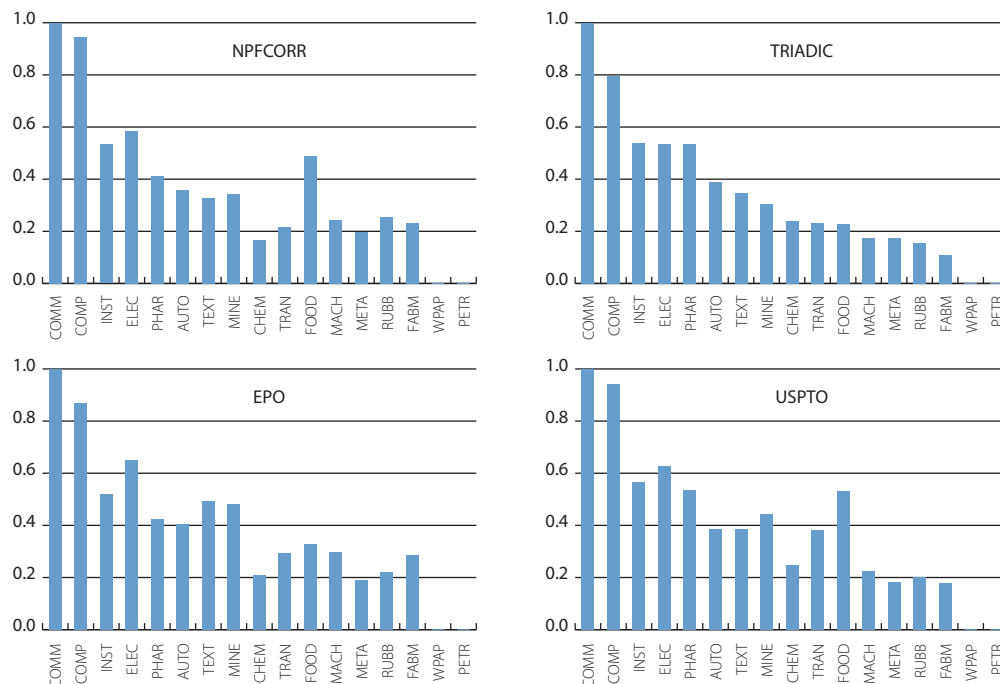


Source: Own calculations

Note: The values are coefficients of country dummies taken from the full model and are normalized from 0 to 1. They are interpreted as normalized dynamic propensity to patent. See Annex 2 for details.

The change in the propensity to patent varies as well across manufacturing industries, and to a significant extent, as illustrated in Figure 8. The industries including communication, computers and instruments are associated with the strongest increase in the propensity to patent whereas fabricated metals or rubber and plastics products had the lowest increase. There is a clear ICT (information and communication technologies) effect here. The industries in this area already scored high in at least one of the two propensity components (see Figure 2), and they have apparently further increased their willingness to patent. This observation is true for all patent indicators. Contrary to the country dummies, which illustrate a catching-up effect from newcomers, the industry dummies seem to reinforce the trends towards a higher propensity to patent. As we control for the industry-specific appropriability propensity, this effect is most probably due to a sharp increase in the strategic propensity to patent in the two industries.

Figure 8. Dynamic propensity to patent across industries

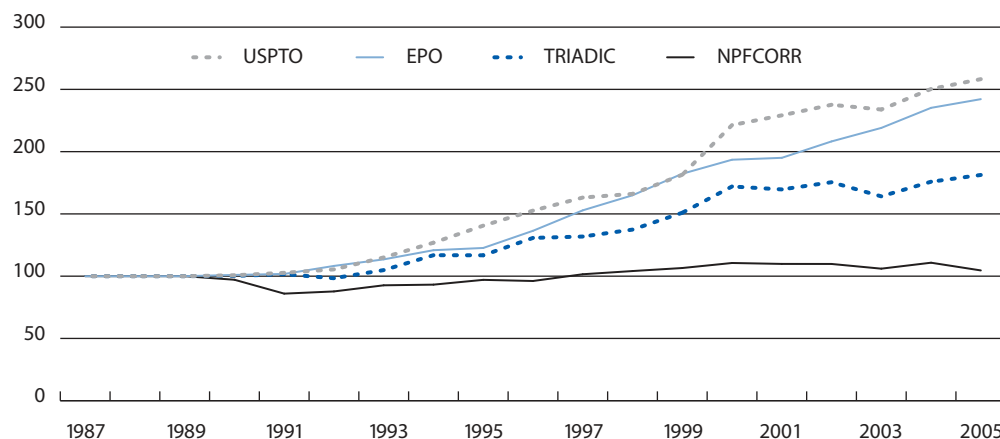


Source: Own calculations
 Note: The values are coefficients of industry dummies taken from the full model and are normalized from 0 to 1. They are interpreted as normalized dynamic propensity to patent. See Annex 2 for details.

The global 'patent warming' is mainly due to companies' willingness to extend patent protection to foreign markets.

Finally, Figure 9 depicts the evolution of the propensity to patent over time for the principal patent indicators. The most striking observation is that the propensity to file priority filings has been roughly constant over time whereas the propensity to file international/regional applications has steadily increased. Taken together, these trends lead to the conclusion that there has been no particular "burst" in the underlying inventiveness (beyond the increase in R&D efforts and beyond the improvement in research productivity measured in the empirical analysis) and that the "patent warming" observed at major patent offices is mostly due to a globalization effect: companies do not file particularly more patents, but have a higher willingness to extend them abroad. The USPTO (and to a lesser extent the EPO) is particularly intensely targeted in this respect.

Figure 9. Evolution of the propensity to patent over time



Source: Own calculations (see Annex 2 for details)

5. Concluding remarks and policy implications

The literature on the R&D-patent relationship reports a weak correlation between R&D efforts and patents in two main configurations: time-series analyses and cross-industry investigations. This weakness has not reduced the emerging hype towards the use of patent statistics for many purposes, including economic research on technological progress and knowledge diffusion. The objective of this paper is to provide further conceptual and empirical insights into the apparent failure to find a strong relationship between R&D efforts and patent applications. The empirical investigation relies on a unique panel data set composed of 18 manufacturing industries in 19 countries over the period 1987 to 2005, for which three broad patent indicators are developed. Six main methodological and policy implications summarize the main contributions of this paper.

The first is conceptual. The literature has implicitly or explicitly assumed that the patent-to-R&D ratio is driven by a research productivity stage (the extent to which additional units of R&D generate additional inventions) and a propensity-to-patent stage. This paper claims that in order to better understand how an increase in R&D expenditure translates into patent applications, the propensity to patent must be split into two main components: the “appropriability propensity” which indicates whether or not an invention is protected with patents; and the “strategic propensity” which measures the number of patents used to protect the invention. While the former component can be proxied by existing survey data on the share of inventions that are patented (e.g. Arundel and Kabla 1998) in each industrial sector, the latter can so far be gauged only with quantitative analysis. This theoretical insight has a major implication: Large-scale surveys like the Community Innovation Survey in Europe should regularly assess the two propensity components for many countries. Data on the evolution of the share of inventions that are patented as well as on the average number of patents used to protect an invention would drastically improve our understanding of the R&D-patent relationship. So far only single-country information is available for a given year or period.

Second, the econometric results based on the cross-industry, cross-country and time series dataset confirm that the patent elasticity with respect to R&D is positive and significant but small. It fluctuates around 12 percent and is very robust to the patent indicator used as dependent variable (national priority filings *versus* the more restrictive and valuable triadic patents). R&D and the various fixed effects (country, industry and time dummies) explain about 20 percent of the variance in the growth rate of patents. The results therefore confirm the existing dynamic time series estimates at the microeconomic level: The elasticity is much smaller than “hoped” for (Griliches 1990) and captures only a small share of the patent variance, which is arguably due to two important missing links unrelated to the productivity of research, namely appropriability and strategic propensities.

Third, the empirical analysis confirms that a significant productivity effect takes place and does explain part of the variations in the R&D-patent ratio, as witnessed by the positive and significant premium associated with basic research and academic research, or by the noticeable impact of the international-competitiveness variable, an indicator of ultimate innovation performance. The positive impact of basic and academic research suggests that allocating more resources to university-performed research and to basic projects is a long-term policy aimed at securing the seeds of future innovations.

Fourth, the empirical results lead to the conclusion that the appropriability propensity plays a positive and highly significant role in the patent production function, despite the fact that its measure only varies across industries. The implicit assumption that it is similar across countries and does not vary over time is probably too strong, but there is no convincing alternative to the best of our knowledge. The strategic propensity to patent is measured by one variable supposed to affect it, the strength of the patent system in the inventor country. This variable has a positive and significant impact on the propensity to patent, but probably only partially captures the strategic propensity to patent.

The number of patents depends on R&D efforts, research productivity, the wish to appropriate inventions and on strategic behaviour.

Fifth, the country and industry dummies allow to identify in some depth the origins of the increase in the propensity to file patents. This “dynamic propensity” is logically composed of an appropriability component and a strategic component. Two manufacturing industries, which were already characterized by a high patent-to-R&D ratio, communications and computers, turn out to be associated with the sharpest increase in the propensity to patent. This is precisely the technological area where a patent “paradox” was identified by Hall and Ziedonis (2001). In this respect our result shed some additional light on the R&D-patent relationship and its industry dimension. The pharmaceutical industry has a high appropriability propensity but is not associated with a particularly strong increase in its propensity to patent. The countries that are associated with the sharpest increase in their propensity to patent are South Korea, Poland and Spain, which witnesses a clear catching up effect. These results exemplify the pitfalls and advantages associated with patent data. Whereas they witness fundamental economic changes such as catching-up effects, they are also greatly impacted by nations’ industrial structure, hence the need to improve our understanding of the “propensity” components.

The global ‘patent warming’ would justify stronger coordination of national/regional patent offices if their views on patent system design converged.

Finally, the time dummies provide a broad measure of the dynamic increase in patent propensity, net of country and industry specificities, and of R&D expenditure. Here the results depend on the patent indicators that are used. The sharpest increases are associated with regional patent offices (EPO and USPTO) followed by triadic applications. As far as national priority filings are concerned, hardly any increase in the unaccounted propensity to patent is observed. In other words, the “global patent warming” that is currently taking place is essentially the result of a stronger internationalization of national patent applications, and not a consequence of increased propensity to rely on patent systems with national priority applications. Innovating firms are increasingly targeting global markets and hence have a higher tendency to seek for protection in regional patent offices, world-wide. This tendency would justify a stronger coordination of patent offices at the global level, provided their views of how a patent system should be designed converge noticeably, as suggested in van Pottelsberghe (2009).

Annex 1. Additional background tables

Table A1. Abbreviations of countries and industries

Abbr.	Country	Abbr.	ISIC Rev.3	Industry definition	Technological classification*
AT	Austria	FOOD	15-16	Manufacture of food products, beverages and tobacco products	LOTE
BE	Belgium	TEXT	17-19	Manufacture of textiles, wearing apparel; dressing and dyeing of fur; Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	LOTE
CA	Canada	WPAP	20-22	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials; manufacture of paper and paper products; publishing, printing and reproduction of recorded media	LOTE
CH	Switzerland	PETR	23	Manufacture of coke, refined petroleum products and nuclear	MLTE
DE	Germany	CHEM	24 less 2423	Manufacture of chemicals and chemical products	MHTE
DK	Denmark	PHAR	2423	Pharmaceuticals and medicinal chemicals	HTE
ES	Spain	RUBB	25	Manufacture of rubber and plastics products	MLTE
FI	Finland	MINE	26	Manufacture of other non-metallic mineral products	MLTE
FR	France	META	27	Manufacture of basic metals	MLTE
GB	United Kingdom	FABM	28	Manufacture of fabricated metal products, except machinery and equipment	MLTE
IE	Ireland	MACH	29	Manufacture of machinery and equipment not elsewhere classified (n.e.c.)	MHTE
IT	Italy	COMP	30	Manufacture of office, accounting and computing machinery	HTE
JP	Japan	ELEC	31	Manufacture of electrical machinery and apparatus n.e.c.	MHTE
KR	Korea	COMM	32	Manufacture of radio, television and communication equipment and apparatus	HTE
NL	Netherlands	INST	33	Manufacture of medical, precision and optical instruments, watches and clocks	HTE
NO	Norway	AUTO	34	Manufacture of motor vehicles, trailers and semi-trailers	MHTE
PL	Poland	TRAN	35	Manufacture of other transport equipment	MHTE
SE	Sweden	MISC	36	Manufacture of furniture; manufacturing n.e.c.	MHTE
US	United States				

Note: * Based on the OECD technological classification, LOTE, MLTE, MHTE and HTE stand for low technology, medium-to-low technology, medium-to-high technology and high technology, respectively.

Table A2. Absolute and relative number of patents by country (2004)

Country	NPFCORR	%	TRIADIC	%	EPO	%	USPTO	%	REGIONAL	%
AT	2,356	0.6	284	0.6	1,259	1.2	825	0.4	1,259	0.5
BE	1,742	0.5	394	0.8	1,265	1.2	927	0.4	1,265	0.5
CA	5,569	1.5	381	0.8	1,147	1.1	3,750	1.7	3,750	1.6
CH	3,480	0.9	988	2.0	2,656	2.5	1,874	0.9	2,656	1.1
DE	49,502	13.2	6,865	13.6	24,130	23.2	17,126	7.8	24,130	10.4
DK	1,579	0.4	311	0.6	1,015	1.0	906	0.4	1,015	0.4
ES	2,525	0.7	177	0.4	886	0.9	519	0.2	886	0.4
FI	2,640	0.7	314	0.6	1,175	1.1	1,199	0.5	1,175	0.5
FR	14,635	3.9	2,675	5.3	7,839	7.5	5,541	2.5	7,839	3.4
GB	19,665	5.3	1,944	3.8	5,181	5.0	5,782	2.6	5,181	2.2
IE	559	0.1	82	0.2	237	0.2	282	0.1	237	0.1
IT	10,007	2.7	696	1.4	3,962	3.8	2,195	1.0	3,962	1.7
JP*	113,488	30.3	19,890	39.4	25,382	24.4	56,968	26.1	56,968	24.6
KR*	33,282	8.9	2,736	5.4	4,573	4.4	16,084	7.4	16,084	6.9
NL	5,742	1.5	2,329	4.6	3,879	3.7	3,362	1.5	3,879	1.7
NO	1,045	0.3	127	0.3	356	0.3	410	0.2	356	0.2
PL	2,226	0.6	13	0.0	135	0.1	99	0.0	135	0.1
SE	3,599	1.0	685	1.4	1,817	1.7	1,491	0.7	1,817	0.8
US	100,465	26.9	9,613	19.0	17,336	16.6	99,334	45.4	99,334	42.8
Total	374,106	100	50,504	100	104,230	100	218,673	100	231,927	100

Source: Own calculations

Notes: *The number of priority filings for Japan and Korea has been divided by 3. The "%columns report the share of each country in the total of each patent count, expressed in percent.

Table A3. Absolute and relative number of patents by industry (2004)

Industry	NPFCORR	%	TRIADIC	%	EPO	%	USPTO	%	REGIONAL	%
FOOD	7,939	2.1	997	2.0	2,172	2.1	4,156	1.9	4,258	1.8
TEXT	2,521	0.7	268	0.5	613	0.6	1,258	0.6	1,369	0.6
WPAP	4,698	1.3	605	1.2	1,324	1.3	2,418	1.1	2,649	1.1
PETR	4,632	1.2	739	1.5	1,496	1.4	2,497	1.1	2,664	1.1
CHEM	37,325	10.0	6,307	12.5	12,306	11.8	20,427	9.3	22,077	9.5
PHAR	21,229	5.7	4,872	9.6	8,762	8.4	13,831	6.3	14,734	6.4
RUBB	7,282	1.9	840	1.7	2,030	1.9	3,410	1.6	3,878	1.7
MINE	6,654	1.8	810	1.6	1,767	1.7	3,380	1.5	3,695	1.6
META	7,774	2.1	1,003	2.0	2,148	2.1	3,948	1.8	4,319	1.9
FABM	10,142	2.7	925	1.8	2,579	2.5	4,532	2.1	5,239	2.3
MACH	44,986	12.0	4,741	9.4	11,938	11.5	22,169	10.1	24,578	10.6
COMP	53,304	14.2	7,012	13.9	12,922	12.4	36,830	16.8	37,443	16.1
ELEC	14,209	3.8	1,794	3.6	3,736	3.6	8,527	3.9	9,016	3.9
COMM	81,450	21.8	11,453	22.7	21,622	20.7	55,051	25.2	56,313	24.3
INST	15,260	4.1	2,148	4.3	4,211	4.0	9,400	4.3	9,821	4.2
AUTO	34,274	9.2	4,088	8.1	9,983	9.6	16,838	7.7	18,995	8.2
TRAN	10,916	2.9	1,329	2.6	3,112	3.0	5,893	2.7	6,441	2.8
MISC	9,511	2.5	573	1.1	1,510	1.4	4,107	1.9	4,439	1.9
Total	374,106	100	50,504	100	104,230	100	218,673	100	231,927	100

Source: Own calculations

Note: The "%columns report the share of each country in the total of each patent count.

Table A4. Partial model with share of basic research in total R&D

$\Delta \log(\#patents)$	NPFCORR	TRIADIC	EPO	USPTO	REGIONAL
	(1)	(2)	(3)	(4)	(5)
$\Delta \log(R\&D)$	0.019 (0.013)	-0.004 (0.029)	0.007 (0.019)	-0.031* (0.019)	0.020 (0.018)
$\Delta \text{ SHARE BASIC}$	0.016*** (0.003)	-0.0002 (0.007)	-0.008* (0.004)	0.028*** (0.004)	-0.005 (0.004)
$\log(\#patents) (t-1)$	-0.114*** (0.011)	-0.365*** (0.019)	-0.191*** (0.014)	-0.207*** (0.014)	-0.192*** (0.014)
$\log(R\&D) (t-1)$	0.016*** (0.005)	0.041*** (0.011)	0.020*** (0.007)	0.020*** (0.007)	0.022*** (0.007)
$\text{SHARE BASIC} (t-1)$	0.019*** (0.003)	0.029*** (0.006)	0.026*** (0.004)	0.021*** (0.004)	0.023*** (0.004)
Countries dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Industry dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Time dummies	Yes ***	Yes ***	Yes ***	Yes ***	Yes ***
Number of observations	1811	1811	1811	1811	1811
Adjusted R-Square	0.331	0.241	0.192	0.245	0.170

Notes: ***, **, * denote significance at the 1, 5 and 10-percent levels, respectively. The rows "country dummies", "industry dummies" and "time dummies" report the significance level of the joint effect of these dummies.

Annex 2. Construction of the dynamic propensities

The variables presented in Figures 7, 8 and 9 are based on ψ_i , ψ_j and ψ_t in Equation (B.8) that is, the industry, country and time-effects, respectively. Since the dependent variable is the difference of the log of patent filings, the fixed effects can be interpreted as the growth rate in propensity to patent taking into account all the potential explanatory variables. We refer to these parameters as the dynamic propensities.

Note that the fixed effects cannot be recovered immediately from Equation (B.8). Indeed, the fact that that error correction term is left open in Equation (B.8) of Box 1 means that the estimated fixed effects also include the parameter c (recall from Equation (B.3) that c captures the rate at which research efforts lead to patent applications). For this reason, the fixed effects presented in Figures 7, 8 and 9 have been recovered in the following way. We have first estimated the residuals from Equation (B.4) and injected them into Equation (B.7) in lieu of the lagged long-term relationship (the expression in parentheses in Equation (B.7)). The fixed effects of this modified specification can be interpreted as the country, industry and time components of the change in the propensity to patent. Figures 7, 8 and 9, respectively, present the parameters ψ_i and ψ_j , which are normalized to lie between 0 and 1 for ease of readability. Figure 9 presents the cumulative growth of the time dummies, net of industry and country effects.

References

- Alogoskoufis, G. and Smith, R. (1991). "On error correction models: Specification, interpretation, estimation". *Journal of Economic Surveys*, (5:1), pp. 91-128.
- Archontopoulos, E., Guellec, D., Stevnsborg, N., van Pottelsberghe de la Potterie, B. and van Zeebroeck, N. (2007). "When small is beautiful: Measuring the evolution and consequences of the voluminosity of patent applications at the EPO". *Information Economics and Policy*, (19:2), pp. 103-132.
- Arundel, A. and Kabla, I. (1998). "What percentage of innovations are patented? Empirical estimates for European firms". *Research Policy*, (27:2), pp. 127-141.
- Blind, K., Edler, J., Frietsch, R. and Schmoch, U. (2006). "Motives to patent: Empirical evidence from Germany". *Research Policy*, (35:5), pp. 655-672.
- Bottazzi, L. and Peri, G. (2003). "Innovation and spillovers in regions: Evidence from European patent data". *European Economic Review*, (47:4), pp. 687-710.
- Brouwer, E. and Kleinknecht, A. (1999). "Innovative Output and a Firm Propensity to Patent. An Exploration of CIS Micro Data". *Research Policy*, (28:6), pp. 615-624.
- Cincera, M. (1997). "Patents, R&D and Technological Spillovers at the Firm Level: Some Evidence from Econometric Count Models for Panel Data". *Journal of Applied Econometrics*, (12:3), pp. 265-280.
- Cohen, W., Nelson, R. and Walsh, J. (2000). "Protecting their intellectual assets: Appropriability conditions and why U.S. manufacturing firms patent or not". NBER Working Paper No. 7552.
- Crépon, B., Duguet, E. and Mairesse, J. (1998). "Research, Innovation, and Productivity: An Econometric Analysis at the Firm Level". *Economics of Innovation and New Technology*, (7:2), pp. 115-158.
- Czarnitzki, D., Kraft, K. and Thorwarth, S. (2009). "The knowledge production of 'R' and 'D'". *Economics Letters*, (105:1), pp. 141-143.
- de Rassenfosse, G., Dernis, H., Guellec, D., Picci, L. and van Pottelsberghe de la Potterie, B. (2009). "A corrected count of priority filings". Paper presented at the 4th OECD-EPO conference on patent statistics, Vienna.
- de Rassenfosse, G. and Guellec, D. (2009). "Quality versus quantity: Strategic interactions and the patent inflation". Paper presented at the 4th annual conference of the EPIP association.
- de Rassenfosse, G. and van Pottelsberghe de la Potterie, B. (2007). "Per un pugno di dollari: A first look at the price elasticity of patents". *Oxford Review of Economic Policy*, (23:4), pp. 588-604.
- de Rassenfosse, G. and van Pottelsberghe de la Potterie, B. (2008). "On the price elasticity of demand for patents". ECARES Working Paper, 2008-031.
- de Rassenfosse, G. and van Pottelsberghe de la Potterie, B. (2009). "A policy insight into the R&D-patent relationship". *Research Policy*, (38:5), pp. 779-792.
- Dernis, H., Guellec, D. and van Pottelsberghe de la Potterie, B. (2001). "Using patent counts for cross-country comparisons of technology output". *Science Technology and Industry Review*, (27), pp. 128-146.
- Duguet, E. and Kabla, I. (1998). "Appropriation strategy and the motivations to use the patent system: An econometric analysis at the firm level in French manufacturing". *Annales d'Economie et de Statistique*, (49/50), pp. 289-327.
- Furman, J., Porter, M. and Stern, S. (2002). "The determinants of national innovative capacity". *Research Policy*, (31:6), pp. 899-933.
- Ginarte, J. and Park, W. (1997). "Determinants of patent rights: A cross-national study". *Research Policy*, (26:3), pp. 283-301.

- Griliches, Z. (1990). "Patent statistics as economic indicators: A survey". *Journal of Economic Literature*, (28), pp. 1661-1707.
- Guellec, D., van Pottelsberghe de la Potterie, B. and van Zeebroeck, N. (2007). "Patents as a market instrument", in Guellec, D. and van Pottelsberghe de la Potterie, B. (eds.), *The economics of the European Patent System*. Oxford University Press, Oxford, UK, pp. 85-113.
- Hall, B.H., Griliches, Z. and Hausman, J.A. (1986). "Patents and R and D: Is there a lag?". *International Economic Review*, (27:2), pp. 265-283.
- Hall, B.H. and Ziedonis, R.H. (2001). "The patent paradox revisited: An empirical study of patenting in the US semiconductor industry, 1979-1995". *RAND Journal of Economics*, (32:1), pp. 101-128.
- Harabi, N. (1995). "Appropriability of technical innovations: An empirical analysis". *Research Policy*, (24:6), pp. 981-992.
- Hausman, J.A., Hall, B.H. and Griliches, Z. (1984). "Econometric Models for Count Data with an Application to the Patents-R&D Relationship". *Econometrica*, (52:4), pp. 909-938.
- Jaffe, A. (1986). "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value". *American Economic Review*, (76:5), pp. 984-1001.
- Kortum, S. and Lerner, J. (1999). "What is behind the recent surge in patenting?". *Research Policy*, (28:1), pp. 1-22.
- Kotabe, M. (1992). "A comparative study of U.S. and Japanese patent systems". *Journal of International Business Studies*, (23:1), pp. 147-168.
- Levin, R., Klevorick, A., Nelson, R., Winter, S., Gilbert, R., Griliches, Z. (1987). "Appropriating the returns from industrial research and development". *Brookings Papers on Economic Activity*, (3), pp. 783-832.
- OECD (Organisation for Economic Co-operation and Development) (2009). *OECD Patent Statistics Manual*, Paris.
- OECD (2009a). *Main Science and Technology Indicators*, Paris.
- OECD (2009b). *Stan Bilateral Trade Database*.
- Park, W. (2008). "International patent protection: 1960-2005". *Research Policy*, (37:4), pp. 761-766.
- Rivette, K.G. and Kline, D. (2000). *Rembrandts in the Attic*, Harvard Business School Press, Boston, MA, USA.
- Scherer, F.M. (1983), "The Propensity to Patent". *International Journal of Industrial Organization*, (1:1), pp. 107-128.
- Schmoch, U., Laville, F., Patel, P. and Frietsch, R. (2003). "Linking technology areas to industrial sectors". Final report to the European Commission - DG Research.
- Schmookler, J. (1957). "Inventors Past and Present". *The Review of Economics and Statistics*, (39:3), pp. 321-333.
- Teece, D.J. (1998). "Capturing Value from Knowledge Assets: The New Economy, Markets for Know-How, and Intangibles Assets". *California Management Review*, (40:3), pp. 55-79.
- van Pottelsberghe de la Potterie, B. (2009). *Lost property: The European patent system and why it doesn't work*, Bruegel Blueprint, Brussels, Belgium.

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