Uppenberg, Kristian

Article

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EIB Papers

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European Investment Bank (EIB), Luxembourg

Suggested Citation: Uppenberg, Kristian (2009) : Innovation and economic growth, EIB Papers, ISSN 0257-7755, European Investment Bank (EIB), Luxembourg, Vol. 14, Iss. 1, pp. 10-35

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

Kristian Uppenberg

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.

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:

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

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 capital[1]. 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

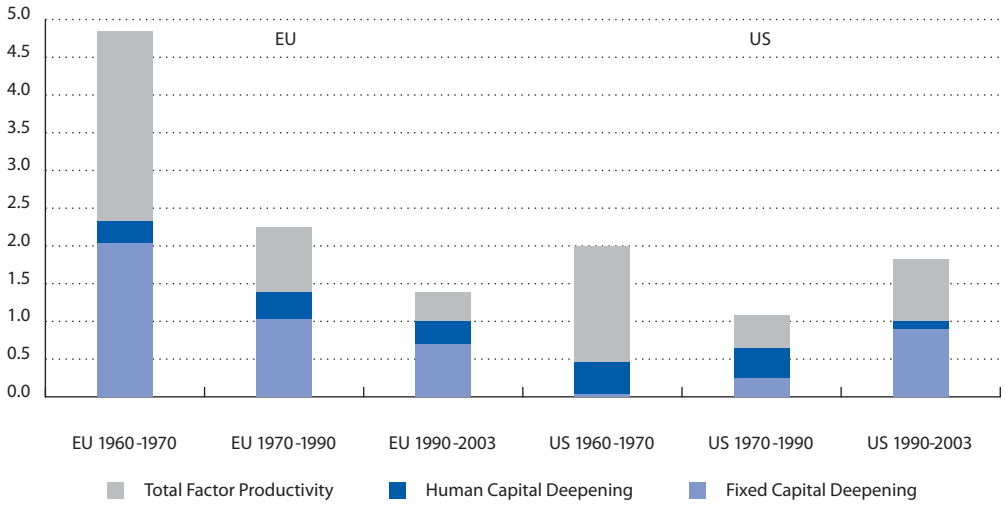
1 In order to do this using the relatively simple neo-classical production function and the limited set of data at his disposal, Solow had to make a few simplifying assumptions. First, he assumed that the US economy was on its equilibrium growth path, not unreasonably given its long history of having 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-α 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.

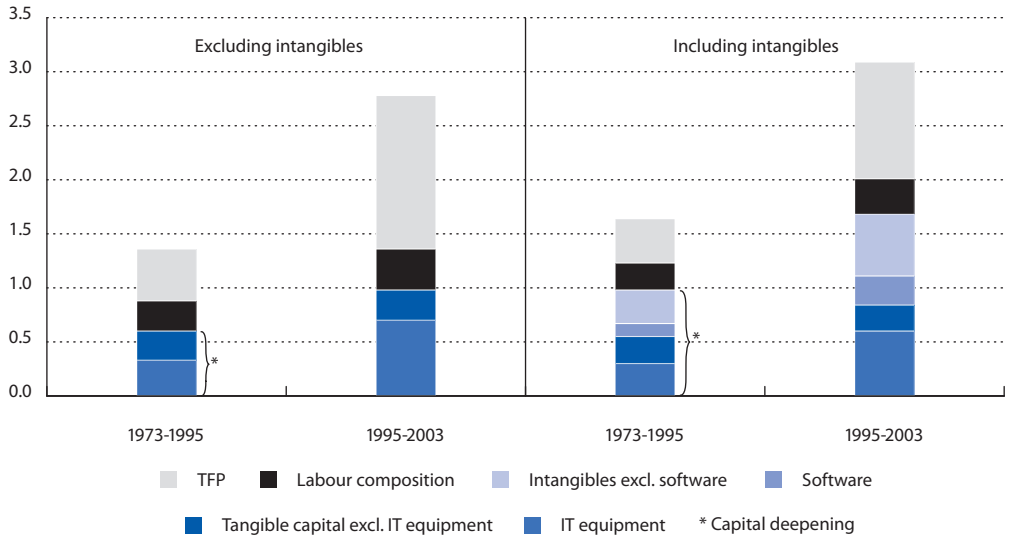
With capital deepening explaining a larger share of growth, the contribution from the TFP residual becomes correspondingly smaller, falling from around half to one-third for the post-1995 period when intangibles are included. The Solow residual also accounts for a smaller portion of the post-1995 *acceleration* 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

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

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 time[2]. 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:

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

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

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.

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 economies[3]. 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.

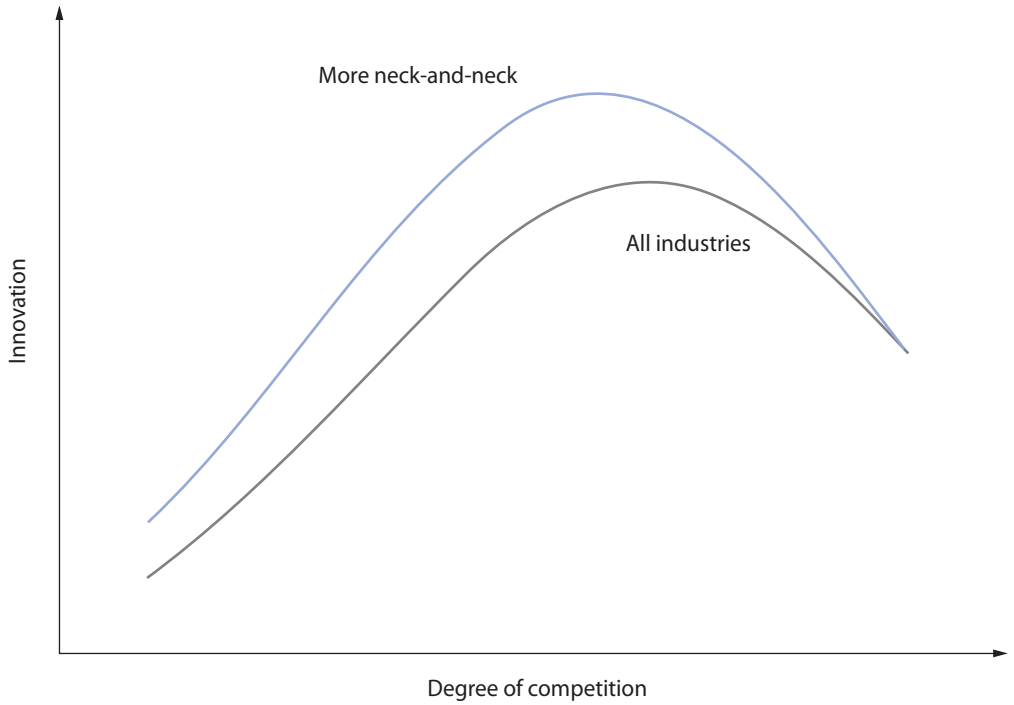
More competition does not boost innovation under all circumstances in this model, however. There is a difference between industries where firms are operating on a similar technological level – so-called "neck-and-neck" industries – and those where firms are more technologically uneven. In neck-and-neck 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.

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

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).

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 Mairesse** 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.

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