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Article

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Suggested Citation: McMorrow, Kieran; Röger, Werner (2009) : R&D capital and economic growth: The empirical evidence, EIB Papers, ISSN 0257-7755, European Investment Bank (EIB), Luxembourg, Vol. 14, Iss. 1, pp. 94-118

This Version is available at:

<https://hdl.handle.net/10419/44909>

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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:

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

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:

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

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

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

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

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

We can rewrite (A.2):

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

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):

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

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.

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