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More Effective?
Some Guidelines for European Research Policy**

Raquel Ortega-Argilés
Mariacristina Piva
Lesley Potters
Marco Vivarelli

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Raquel Ortega-Argilés

European Commission, JRC, IPTS

Mariacristina Piva

Università Cattolica del Sacro Cuore, Milan

Lesley Potters

*European Commission, JRC, IPTS
and Utrecht School of Economics*

Marco Vivarelli

*European Commission, JRC, IPTS,
Università Cattolica del Sacro Cuore, Milan, and IZA*

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IZA

P.O. Box 7240
53072 Bonn
Germany

Phone: +49-228-3894-0

Fax: +49-228-3894-180

E-mail: iza@iza.org

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ABSTRACT

Is Corporate R&D Investment in High-Tech Sectors More Effective? Some Guidelines for European Research Policy

This paper discusses the link between R&D and productivity across the European industrial and service sectors. The empirical analysis is based on both the European sectoral OECD data and on a unique micro longitudinal database consisting of 532 top European R&D investors. The main conclusions are as follows. First, the R&D stock has a significant positive impact on labour productivity; this general result is largely consistent with previous literature in terms of the sign, the significance and the magnitude of the estimated coefficients. More interestingly, both at sectoral and firm levels the R&D coefficient increases monotonically (both in significance and magnitude) when we move from the low-tech to the medium and high-tech sectors. This outcome means that corporate R&D investment is more effective in the high-tech sectors and this may need to be taken into account when designing policy instruments (subsidies, fiscal incentives, etc.) in support of private R&D. However, R&D investment is not the sole source of productivity gains; technological change embodied in gross investment is of comparable importance on aggregate and is the main determinant of productivity increase in the low-tech sectors. Hence, an economic policy aiming to increase productivity in the low-tech sectors should support overall capital formation.

JEL Classification: O33

Keywords: R&D, productivity, high-tech sectors, innovation, industrial policy

Corresponding author:

Marco Vivarelli
Facoltà di Economia
Università Cattolica
Via Emilia Parmense 84
I-29100 Piacenza
Italy
E-mail: marco.vivarelli@unicatt.it

I. INTRODUCTION

As of the '90s, from a macroeconomic viewpoint the US and the EU have diverged in terms of both economic and labour productivity growth rates (see Figs. A1 and A2 respectively in the Appendix). In particular, what emerges clearly is that the historical process of the EU15's catching up to the higher US levels of labour productivity stopped around the mid '90s (see O'Mahony and Van Ark, 2003; Blanchard, 2004; Turner and Boulhol, 2008).

Most scholars agree that in order to explain the transatlantic productivity gap and the differences within Europe, one has to take into account the R&D and innovation divides which emerged with the spread of the ICT technologies (see Daveri, 2002; Crespi and Pianta 2008). Indeed, R&D expenditures in general, and ICT technologies in particular, have been shown to play an important role in explaining this persistent and broadening gap in productivity between the industrialised countries (see Oliner and Sichel, 2000; Stiroh, 2002¹).

In this context, the role of private R&D investment by corporate firms (Business Enterprise Research and Development: BERD) has been recognised as a fundamental engine for productivity growth at both the macro and microeconomic levels (see Baumol, 2002; Jones, 2002).

The EU15 has lagged considerably and persistently behind the US in this respect (see Fig. 1). Hence the private R&D gap might be the main culprit of the transatlantic growth and productivity gaps mentioned above.

Indeed, the increasing of R&D investment is an issue of major concern for long-term European policy strategy. It informs the rationale behind both the "Lisbon agenda 2000" aiming to make Europe the most dynamic knowledge economy in the world by 2010, and the more specific "Barcelona target", which two years later committed the EU to reaching an R&D/GDP

¹ New technologies also affect the employment intensity of economic growth (see Padalino and Vivarelli, 1997) and the skill upgrading of the labour force (see Piva and Vivarelli 2002 and 2004); the study of these important impacts of technological change are out of the scope of the present paper.

level of 3%, two thirds of which in the private sector (European Council, 2002; European Commission 2002)².

If increasing R&D investment is envisaged as being the main strategy tool for closing the productivity gap between the US and the EU, R&D-intensive sectors are especially important. One could argue that the European delay in terms of private R&D investment is mainly due to a sectoral composition effect, since the R&D-intensive, high-tech sectors are under-represented in the European economy in comparison with that of U.S. (European Commission, 2008).

However, this interpretation is controversial in the light of very recent theoretical and empirical debate. For instance, Mathieu and van Pottelsberghe de la Potterie (2008), running a panel analysis of the R&D intensity of 21 economic sectors in 10 European countries over the period 1991-2002, conclude that BERD intensity is mainly driven by the degree of specialization in R&D-intensive industries. This evidence in favour of the role of the sectoral composition effect is limited to analysis within European countries and to a sectoral breakdown where manufacturing is divided into 20 sectors while services are treated as a single aggregate.

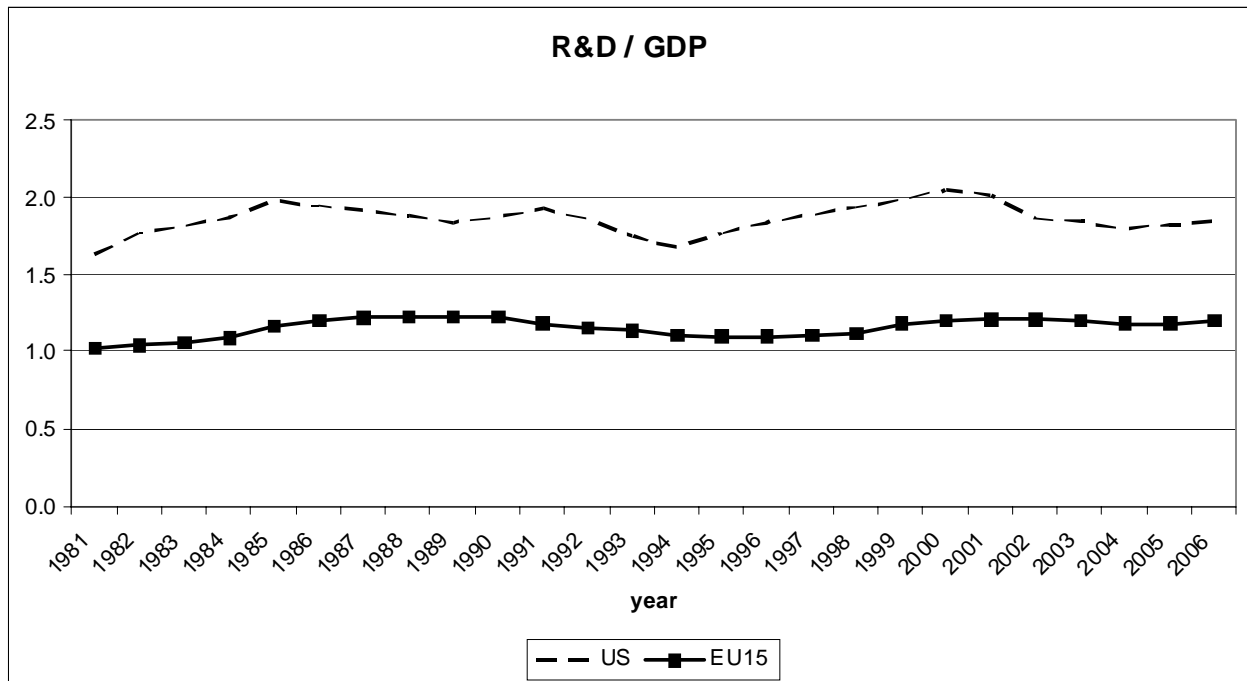
Erken and Van Es (2007) put forward a similar statistical exercise based on OECD-STAN and OECD-ANBERD data concerning 14 European countries and the US and 36 industries (with a proper disaggregation of services) over the period 1987-2003. In contrast with the previous paper, their striking result is that the EU/US gap in private R&D intensity is mainly due to an intrinsic effect (European firms do less R&D within each sector) rather than to the sector composition effect.

If the sectoral composition of the European economy provides only a marginal explanation for R&D divergence between the EU and the US, the argument in favour of targeting high-tech sectors is partially weakened. Although it remains true by definition that one way to increase European private R&D is to insist on the high-tech sectors, the sectoral composition of

² In particular, the 7th Framework Programme for Research, Technological Development and Demonstration activities, the 7th Euratom Framework Programme for Nuclear Research and Training Activities, the Competitiveness and Innovation Framework Programme (CIP), and the Structural Funds are the four EU funding sources for supporting research, development and innovation.

the European economy does not emerge as the main hindrance to catching up with the US as regards the private R&D/GDP ratio.

Fig. 1: Private R&D/GDP in the EU15 and the US: 1981-2006



Source: OECD – Main Science and Technology Indicators (2008 edition)

Indeed, the overall lower European productivity can be explained not only by a lower level of private R&D investment, but also by a lower capacity to translate R&D investment into productivity gains, which in turn then foster competitiveness and economic growth. With regard to this explanation, the European economies may be still affected by a sort of Solow's (1987) paradox, i.e. by a difficulty to translate their own investments in technology into increases in productivity.

In contrast with other studies, in this paper we gather available evidence and analyses with the aim of putting forward an original perspective, such that high-tech sectors may be crucial not

only because they invest more in R&D but because within high-tech sectors corporate R&D investment may be more fruitful in terms of achieving productivity gains.

If the private R&D/labour productivity link is stronger in the high-tech sectors, we would thus find an additional argument in favour of industrial and innovation policies targeted at reinforcing high-tech sectors in Europe. These policies would be advisable not only because high-tech sectors invest more in R&D, but also because in these sectors private R&D investment is more effective in achieving those productivity gains which are in turn necessary for closing the transatlantic gap in terms of competitiveness and economic growth.

The rest of the paper is organised as follows. In the next section a review of the previous literature is provided. In the following Section 3, the analysis using OECD data is carried out at the sectoral level, showing that the highest productivity gains can be achieved in European high-tech sectors. This outcome will be further supported by the microeconomic evidence put forward in Section 4. The conclusive Section 5 will be devoted to the possible implications of these empirical outcomes for the design of public instruments supporting R&D and for targeted European industrial and innovation policies.

II. PREVIOUS EVIDENCE

Since the publication of the seminal contributions by Zvi Griliches (1979, 1995 and 2000), the R&D-productivity relationship has been studied at the national, sectoral and firm levels, using different proxies for productivity according to the data available (labour productivity measured as the ratio between value added and employment; labour productivity as the ratio between value added and hours worked; total factor productivity; Solow's residual; etc.). In general, previous literature has found robust evidence for a positive and significant impact of R&D on productivity (see, for instance, Klette and Kortum, 2004; Janz, Lööf and Peters, 2004; Rogers, 2006; Lööf and Heshmati, 2006). In this literature, the estimated overall elasticity of productivity with respect to R&D is positive, generally statistically significant and with a magnitude depending on the level of analysis (country, sector or firm), on the econometric

methodology, and on the data. In this literature, the estimated overall average elasticity of productivity in respect to R&D ranges from 0.05 to 0.25 (see Mairesse and Sassenou, 1991 for a survey; Griliches 1995 and 2000; Mairesse and Mohnen, 2001).

Turning the attention to a sectoral breakdown, previous empirical evidence from the microeconomic literature is scarce; however, it seems to suggest a greater impact of R&D investment on productivity in the high-tech sectors than in the low-tech ones.

For instance, Griliches and Mairesse (1982), using both US and French data, and Cuneo and Mairesse (1983), using only French data, performed two comparable studies using micro-level data, distinguishing between firms belonging to science-related sectors and firms belonging to other sectors. They found that the impact of R&D on productivity for scientific firms (elasticity equal to 0.20) was significantly greater than for other firms (0.10).

In a more recent paper, Verspagen (1995) used OECD sectoral-level data on value added, employment, capital expenditures and R&D investment in a standard production function framework. His major finding was that the influence of R&D on output was significant and positive only in high-tech sectors, while for medium and low-tech sectors no significant effects could be found.

Wakelin (2001) applied a Cobb–Douglas production function in which productivity was regressed on R&D expenditures, capital and labour using data on 170 UK quoted firms during the period 1988-1992. She found R&D expenditure had a positive and significant role in influencing productivity growth; however, firms belonging to sectors defined as "net users of innovations" turned out to have a higher rate of return on R&D.

Finally, Tsai and Wang (2004) also applied a Cobb-Douglas production function to a stratified sample of 156 large firms quoted on the Taiwan Stock Exchange over the period 1994 - 2000. They found that R&D investment had a significant and positive impact on the growth of a firm's productivity (with an elasticity equal to 0.18). When a distinction was made between high-tech and other firms, this impact was much greater for high-tech firms (0.3) than for other firms (0.07).

III. SECTORAL EVIDENCE

The framework and the data

We will test the hypothesis that R&D expenditures are more effective in the high-tech sectors using comprehensive and recent databases both at the sectoral (this section) and at the firm level (next section). In this and the following section, we will use the same specification, based on an augmented production function:

$$(1) \quad \ln(VA/E) = \alpha + \beta \ln(K/E) + \gamma \ln(C/E) + \lambda \ln(E) + \varepsilon$$

Our proxy for productivity is labour productivity (Value Added, VA , over total employment, E); our pivotal impact variables are the R&D stock (K) per employee, and physical capital expenditures (C) per employee. Taking per capita values permits both standardisation of our data and elimination of possible size effects (see, for example, Crépon, Duguet and Mairesse, 1998, p.123). In this framework, total employment (E) is a control variable: if λ turns out to be greater than zero, it indicates increasing returns. All the variables are taken in natural logarithms and deflated according to the different national GDP deflators.

While K/E (R&D stock per employee) captures that portion of technological change which is related to the cumulated R&D investment, C/E (physical capital per employee) is the result of extensive (using the same technology) and intensive investment, implementing new technologies. This latter component of C represents the so-called *embodied technological change* with its great potential to positively affect productivity growth. The embodied nature of technological progress and the effects related to its spread in the economy were originally discussed by Salter (1960); in particular, vintage capital models describe an endogenous process of innovation in which the replacement of old equipment and machinery is the main way by

which firms update their own technologies (see Freeman, Clark and Soete, 1982; Freeman and Soete, 1987).

As is common in this type of literature (see Hulten, 1990; Jorgenson, 1990; Hall and Mairesse, 1995; Parisi, Schiantarelli and Sembenelli, 2006), stock indicators rather than flows are considered as impact variables; indeed, productivity is affected by the cumulated stocks of capital and R&D expenditures and not only by current or lagged flows³. In this framework, R&D and physical capital stocks have been computed using the *perpetual inventory method*, according to the following formulas:

$$(2) \quad K_{t0} = \frac{R \& D_{t0}}{(g + \delta)} \text{ and } K_t = K_{t-1} \cdot (1 - \delta) + R \& D_t \text{ where R\&D} = \text{R\&D expenditures}$$

$$(3) \quad C_{t0} = \frac{I_{t0}}{(g + \delta)} \text{ and } C_t = C_{t-1} \cdot (1 - \delta) + I_t \text{ where I} = \text{gross investment}$$

Moreover, the use of cumulated stock enables us to avoid the arbitrary choice of a particular structure of lags in measuring the impact of current and previous R&D investments. Finally, in using the perpetual inventory method and computing both g and δ , sectoral and country peculiarities in the available data have been taken into account.

In this section the data sources are the OECD-STAN and the OECD-ANBERD databases. Given the aims of this study, separate estimates for the high, medium and low-tech European sectors will be put forward, using the standard OECD sectoral splitting (Hatzichronoglou, 1997)⁴.

³ Dealing with stocks, rather than flows, has two additional advantages: on the one hand, since stocks incorporate the cumulated R&D investments in the past, the risks of endogeneity is minimised; on the other hand, there is no need to deal with the complicate (and often arbitrary) choice of the appropriate structure of lags of the regressors.

⁴ In this section, the analysis is limited to the sole manufacturing sector available and to the period 1987-2002 because of data limitations in terms of availability, reliability and homogeneity. In the next section, the analysis will include the service sectors.

Given the limitations in the availability of comparable OECD sectoral data, regressions were run over the period 1987-2002, and compounded average growth rates (g) were computed over at least the three year period before the reference period.

Depreciation rates (δ) were differentiated, taking into account what is commonly assumed in the reference literature (see Nadiri and Prucha, 1996 for physical capital; Hall and Mairesse, 1995 and Hall, 2007 for the R&D stock): namely, on the one hand, depreciation rates for the R&D stocks were assumed to be higher than the corresponding rates for physical capital (i.e. it was assumed that technological obsolescence is more rapid than the scrapping of physical capital); on the other hand, depreciation rates for the high-tech sectors were assumed to be higher than the corresponding rates for medium and low-tech sectors (under the assumption that technological development is faster in the high-tech sectors). Specifically, depreciation was assumed equal to 4%, 6% and 8% with regard to physical capital depreciation in the low, medium and high-tech sectors respectively, while the corresponding δ for R&D stocks was assumed equal to 12%, 15% and 20% respectively.

Empirical findings at the sectoral level

Taking into account the availability, reliability and comparability of data in the OECD STAN and ANBERD sectoral databases, the EU overall estimation totals (on average, with some missing values) 15 manufacturing sectors in 9 European countries over 12 years, resulting in a total number of observations equal to 1,591.⁵ Pooling estimates (POLS) have been controlled for national and annual fixed effects through country and yearly dummies (both highly significant) and computed using heteroskedasticity robust standard errors.

In addition to POLS estimates, we also ran random effect specifications in order to control for possible idiosyncratic sectoral effects such as special developments in the sectoral cost structure and in sectoral demand. We chose a random rather than a fixed effects specification because the within-sector component of the variability of the dependent variable turned out to be overwhelmed by the between-sectors one (0.18 vs 0.46). Moreover, the Hausman test comparing

the random and fixed effects models for the whole sample clearly supported the former ($\chi^2=17.23$, $p\text{-value}=0.24$). Heteroskedasticity problems were checked for and corrected according to the Eicker/Huber/White sandwich estimator.

Table 1. Sectoral estimates; Dependent variable: log(Labour Productivity) – 9 European countries, 1987-2002 (column (1) Total; column (2) High-tech sectors (ISIC 2423, 30, 32, 33); column (3) Medium-tech sectors (ISIC 23, 24-2423, 25, 26, 27+28, 29, 31, 34, 35); column (4) Low-tech sectors (ISIC 15+16, 17+18+19, 20+21+22, 36+37))

| Model Specification | Whole Sample | | High-tech | | Medium-tech | | Low-tech | |
|---|-------------------|-------------------|------------------|-------------------------|-------------------|-------------------------|-------------------------|-------------------------|
| | POLS | RE | POLS | RE | POLS | RE | POLS | RE |
| Log (R&D stock per employee) | 0.096 (0.007) | 0.085 (0.021) | 0.130 (0.034) | 0.234 (0.055) | 0.039 (0.009) | <u>0.010</u> (0.031) | <u>0.017</u> (0.017) | -0.120 (0.017) |
| Log (physical capital stock per employee) | 0.266 (0.012) | 0.086 (0.019) | 0.283 (0.046) | <u>0.073</u> (0.066) | 0.244 (0.022) | 0.072 (0.023) | 0.249 (0.025) | 0.127 (0.029) |
| Log (Employment) | -0.072 (0.016) | 0.031 (0.062) | 0.212 (0.056) | 0.372 (0.114) | -0.171 (0.020) | -0.279 (0.061) | 0.162 (0.015) | <u>0.001</u> (0.039) |
| Constant | 2.924 (0.085) | 3.429 (0.223) | 1.979 (0.255) | 2.463 (0.401) | 3.428 (0.116) | 4.399 (0.275) | 2.083 (0.120) | 3.379 (0.249) |
| Wald time-dummies (p-value) | 2.37 (0.007) | 197.33 (0.000) | 0.93 (0.514) | 20.74 (0.036) | 2.17 (0.014) | 180.84 (0.000) | 1.17 (0.307) | 147.30 (0.000) |
| Wald- country-dummies (p-value) | 15.98 (0.000) | 11.61 (0.169) | 28.49 (0.000) | 53.72 (0.000) | 13.60 (0.000) | 22.76 (0.003) | 46.84 (0.000) | 28.09 (0.000) |
| R-squared (overall) | 0.518 | 0.396 | 0.550 | 0.357 | 0.555 | 0.488 | 0.623 | 0.280 |
| observations | 1591 | | 308 | | 863 | | 420 | |
| sectors | 133 | | 26 | | 72 | | 35 | |

Note: robust standard errors in brackets; all coefficients are significant at the 99% level of confidence apart from those underlined (not significant).

Looking at the evidence presented in Table 1, it is obvious that both cumulated physical capital and cumulated technological capital (the R&D stock) have a positive and significant impact on labour productivity on aggregate⁶; however, the role of R&D is particularly important in the high-tech sectors with an elasticity (highly statistically significant) ranging from 0.13 to 0.23. The impact of the cumulated R&D stock in the medium-tech sectors goes down to 0.04

⁵ See Table A1 for the countries and periods covered; the sectors involved are indicated in the headings of Table 1.

according to POLS and even becomes not significant according to the RE estimates. Finally, if we turn our attention to the low-tech sectors, the R&D stock has a non-significant or even a counter-productive impact on productivity⁷. Hence, high-tech sectors emerge as the only ones where the R&D/productivity link is significant and robust to the different specifications.

The physical capital stock also positively and significantly affects productivity on aggregate, and this effect is homogeneously significant across sectors (with the only exception being the RE model in the high-tech sectors). Hence, embodied technological change emerges as an important source of productivity gains in all sectors of the European economy; since R&D seems to be ineffective in the low-tech sectors, capital formation turns out to be the sole driver of increases in productivity in these sectors.

IV. MICROECONOMETRIC EVIDENCE

The framework and the data

In order to further investigate whether the revealed relationship between R&D and productivity is more obvious in firms belonging to certain sectors than to others, we built up an unbalanced longitudinal database consisting of 532 top European R&D investors over the six-year period 2000-2005. This unique database was constructed by merging the UK-DTI R&D Scoreboard data and the UK-DTI Value Added Scoreboard data⁸. By merging the two databases

⁶ Both these results were expected and consistent with the previous literature discussed above.

⁷ However, the negative and significant R&D coefficient in the RE model concerning the low-tech sectors (last column in Table 1) should be taken cautiously since (in contrast with the whole sample, high-tech and low-tech cases) the RE estimates dramatically depart from those for POLS, revealing both instabilities in the single coefficients and a disappointing fitness of the overall regression (see the low R-squared).

⁸ The UK Department of Trade and Industry (DTI) collects detailed and tracked data on the larger European firms, both in manufacturing and services, in terms of their R&D investment and value added (VA); the two separate DTI datasets contain information at the firm level, distinguishing by country and sector. Although data come from 14 European countries (Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Norway, Spain, Sweden, Switzerland, the Netherlands and the UK), British firms are over-represented in the DTI databases.

we obtained the necessary information to compute our dependent variable (labour productivity, VA/E), our main impact variable (K/E) and our additional variables (C/E and E)⁹.

We split our panel into three subgroups of comparable size: high-tech, medium-tech and low-tech sectors¹⁰. *Ex ante*, we endogenously grouped the sectors according to their overall R&D intensity ($R\&D/VA$), assuming the thresholds of 5% and 15%¹¹. *Ex post*, we compared the outcome of our taxonomy with the OECD classification, and we registered a high degree of consistency at least as far as the comparable manufacturing sectors were concerned¹². The service sectors were allocated accordingly (see Tables A2 and A3 in the Appendix).

As in the previous section and in accordance with the related microeconomic literature (see Hall and Mairesse, 1995; Bönnte, 2003; Parisi, Schiantarelli and Sembenelli, 2006), stock indicators (rather than flows) were inserted as impact variables; indeed, a firm's productivity is affected by the cumulated stocks of capital and R&D expenditures and not only by current or lagged flows.

In this framework, R&D and physical capital stocks were computed again using the perpetual inventory method. As far as the growth rates for the physical capital and R&D are concerned, we used the OECD-STAN and the OECD-ANBERD databases respectively. In particular, we computed the compounded average rates of change in real R&D expenditures and

⁹ Out of the original 577 firms, 27 firms belonging to marginal sectors with fewer than five firms were dropped, 6 outliers were excluded according to the results of Grubbs' tests centred on the sectoral average growth rates of firms' R&D stock intensity (K/VA) over the investigated period, and 12 additional firms were dropped for reasons related to the computation of the R&D and capital initial stocks in the year 2000. Finally, M&A were treated in a way that does not compromise the comparability of longitudinal data; specifically, when an M&A occurs, a new entry appears in the database, while the merged firms exit. An important caveat regarding the following analysis concerns the nature of this sample, which is made up of the top European performers with regard to R&D investments. In other words, while the previous sectoral analysis based on OECD BERD data can be considered fully representative of the European economy, here only the European "champions" are considered. However, notwithstanding this fact, we can still provide interesting insights into possible differences in the R&D/productivity relationship across top R&D investors belonging to different industrial sectors.

¹⁰ Compared with the OECD classification, we grouped low-tech and middle-low-tech sectors together, in order to have enough observations in each of the sectoral groups.

¹¹ Note that these thresholds are significantly higher than those adopted by the OECD for the manufacturing sectors only (2% and 5%, see Hatzichronoglou 1997); this is the obvious consequence of dealing with the top European R&D investors.

¹² Only two sectors (automobile and food) turned out to be up-graded; this is also a consequence of dealing with top R&D investors.

fixed capital expenditures in the relevant sectors and countries over the period 1990-1999 (the ten-year period preceding the period investigated in this section).

As far as the depreciation rates for K and C are concerned we chose to apply different rates to each of our three sectoral groups. As in the previous section, we applied sectoral depreciation rates of 20%, 15% and 12% to the R&D stock and 8%, 6% and 4% to the physical capital stock (respectively for the high-tech, medium-high-tech and medium-low/low-tech sectors). The resulting weighted averages were 15.6% for the R&D stock and 6.0% for the capital stock respectively; these values are very close or identical to the 15% and 6% commonly used in the literature.

Empirical findings at the firm level

The results from the microeconomic estimates are reported in Table 2. Specification (1) was tested through two econometric methodologies: pooled ordinary least squares (POLS) and random effects (RE).

We chose a random rather than a fixed effects specification for various reasons. Firstly, the nature of our unbalanced short panel (six years with an average of 3.4 observations available per firm) severely affects the within-firm variability component of our data. Secondly, and consistently with the previous observation, the within-firm component of the variability of the dependent variable turns out to be overwhelmed by the between-firms component (the standard deviations being 0.15 and 0.58 respectively). Thirdly, the Hausman test comparing the random and fixed effects models for the whole sample clearly supports the former ($\chi^2=4.65$, p -value=0.79). Fourthly, in the fixed effects model the estimation of the coefficient of any time-invariant regressor – such as an indicator of sectoral belonging – is not possible as it is absorbed into the individual-specific effect; this is particularly unfortunate in our case, where the two-digit sectoral dummies always turn out to be both jointly significant (see the corresponding Wald tests in Table 2) and individually significant in the vast majority of cases (for instance, in 25 cases out of 27 sectoral dummies for the whole sample).

As was the case in the sectoral estimates, we used the Eicker/Huber/White sandwich estimator; diagnosis tests revealed the satisfactory fitness of the chosen models and the usefulness of including country, time and sectoral dummies.

As can be seen, the R&D stock has a significant positive impact on a firm's productivity with an overall elasticity of about 0.10; this general result is largely consistent with the previous literature both in terms of the sign, the significance and the estimated magnitude of the relevant coefficient (see Section 2).

More interestingly, the coefficient increases monotonically when we move from the low-tech to the medium and the high-tech sectors, ranging from a minimum of 0.03-0.05 in the low-tech industries (and turning barely significant in both the models) to 0.11-0.13 in the medium-tech sectors (achieving 99% significance) and to a maximum of 0.14-0.17 in the high-tech ones (also fully significant). These outcomes are consistent with the previous empirical results at the sectoral level (see Section 3): on the whole, high-tech sectors not only invest more in R&D¹³, but also achieve more in terms of productivity gains from their own research activities. At the other end of the spectrum, a clear link between private R&D and productivity was not found as far as the low-tech industries are concerned.

The physical capital stock also increases a firm's productivity, with an overall elasticity which turned out to be around 0.12-0.13; however, this effect is stronger in the low-tech sectors, lower but still significant in the medium tech sectors, while it turned out to be not significant in the high-tech sectors¹⁴. Consistently with what emerged in the previous section, this evidence seems to suggest that embodied technological change is crucial in the low-tech sectors¹⁵, while in the high-tech sectors technological progress is mainly introduced through R&D investments.

¹³ See Table A2 in the Appendix for some descriptive statistics, where the higher average R&D intensity (K/E) characterising the firms belonging to the high-tech sectors emerges clearly.

¹⁴ At the micro level, it may well be the case that a high-tech firm is always "avant-garde" as far as installed capital is concerned (for instance, using the latest vintage of machineries incorporating the most recent process innovations). In this context, marginal productivity gains only come from the R&D activities and the correlated product innovations. In the low-tech sectors, the opposite can happen, with productivity gains mainly being associated with process innovations linked with a gradual renewal of the installed capital (embodied technological change).

¹⁵ On the crucial role played by embodied technological change in traditional sectors, see Santarelli and Sterlacchini (1990); Conte and Vivarelli (2005).

Table 2. Firm level estimates; Dependent variable: log(Labour Productivity)

| Model Specification | Whole Sample | | High-tech | | Medium-tech | | Low-tech | |
|------------------------------------|-------------------------|-------------------|-------------------------|-------------------------|-------------------|-------------------|-------------------------|-------------------------|
| | POLS | RE | POLS | RE | POLS | RE | POLS | RE |
| log(R&D stock per employee) | 0.104 (0.009) | 0.104 (0.017) | 0.169 (0.019) | 0.138 (0.030) | 0.115 (0.014) | 0.126 (0.031) | <i>0.029</i> (0.015) | <i>0.048</i> (0.026) |
| log(physical capital per employee) | 0.132 (0.013) | 0.123 (0.018) | <u>0.002</u> (0.019) | <u>0.017</u> (0.024) | 0.154 (0.019) | 0.147 (0.031) | 0.245 (0.021) | 0.223 (0.032) |
| log(Employment) | -0.078 (0.009) | -0.115 (0.017) | -0.059 (0.014) | -0.118 (0.028) | -0.086 (0.014) | -0.089 (0.027) | -0.092 (0.018) | -0.127 (0.028) |
| Constant | <u>0.088</u> (0.195) | 0.809 (0.293) | -1.533 (0.196) | -0.532 (0.263) | -0.977 (0.167) | -0.919 (0.299) | -0.497 (0.195) | 1.130 (0.297) |
| Wald time-dummies (p-value) | 7.67 (0.000) | 95.68 (0.000) | 2.97 (0.012) | 29.93 (0.000) | 3.87 (0.002) | 32.37 (0.000) | 6.46 (0.000) | 54.63 (0.000) |
| Wald sector-dummies (p-value) | 46.04 (0.000) | 382.93 (0.000) | 28.16 (0.000) | 43.91 (0.000) | 14.05 (0.000) | 19.98 (0.003) | 36.35 (0.000) | 161.23 (0.000) |
| Wald country-dummies (p-value) | 8.11 (0.000) | 32.70 (0.002) | 21.28 (0.000) | 85.55 (0.000) | 30.11 (0.000) | 79.34 (0.000) | 6.38 (0.000) | <u>19.06</u> (0.087) |
| R-squared (overall) | 0.663 | 0.651 | 0.581 | 0.556 | 0.515 | 0.507 | 0.802 | 0.789 |
| observations | 1787 | | 600 | | 671 | | 516 | |
| firms | 532 | | 170 | | 196 | | 166 | |

Note: robust standard errors in brackets; all coefficients are significant at the 99% level of confidence apart from those either underlined (not significant) or in *italics* (barely significant at the 90% level).

V. CONCLUSIONS AND POLICY IMPLICATIONS

Consistently with the evidence from previous literature, this study further confirms that the relationship between R&D stock and productivity is positive and statistically significant, with an overall elasticity of around 0.10. Moreover, this study provides the following further original findings:

1. The positive and significant impact of R&D on productivity is confirmed at both sectoral and firm levels.

2. R&D is clearly and significantly linked to productivity in the high-tech sectors and to a lesser extent in the medium-tech industries; in contrast, a significant impact is not to be found within the low-tech sectors. Hence, firms in high-tech sectors not only invest more in R&D, but also achieve more in terms of the productivity gains connected with research activities.
3. Investment in physical capital is significantly linked to productivity gains, confirming the belief that "embodied technological change" is a crucial driver of productivity evolution. This relationship is particularly strong in the low-tech sectors, where investment activities are the sole significant sources of productivity gains.

The implications in terms of European research and innovation policy are straightforward.

1. Considering that higher productivity gains can be achieved in the high-tech sectors, the allocation of R&D efforts is as important as an increase in R&D; hence, high-tech sectors should be targeted by R&D policy.
2. Considering that the relationship between R&D and productivity is stronger in the high-tech sectors, another way to increase European productivity consists in an industrial policy based on incentives in favour of the expansion of high-tech sectors in the European economies. In other words, European industrial structure - although fixed in the short-term - should be reshaped in the long-run.
3. Considering that productivity gains within low-tech sectors are better achieved through the implementation of embodied technological change, a proper policy aiming to increase productivity in those sectors should foster investment in physical capital.

On the whole, the findings of this report support a targeted research policy rather than an "*erga omnes*" type of public intervention. This consideration applies both to the distribution of subsidies and to the design of fiscal incentives targeting corporate R&D investment.

As far as fiscal policy is concerned, most of European governments (Germany being a notable exception) have adopted tax incentives to foster R&D expenditure, leaving the private sector to decide which is the most productive way to invest the fiscal gain (see CREST, 2004 and 2006). However, most of the adopted fiscal measures are "*erga omnes*" and related to general R&D costs and investment. Exceptions can be found in particular fiscal schemes addressed either to innovative SMEs (such as, for instance, the EUROSTARS scheme¹⁶), start-ups or research cooperation. However, sectoral discrimination in fiscal measures does not seem to be on the agenda of European governments, apart from specific measures to support the so-called new technology based firms (NTBFs; see Nill, 2006). As will now be obvious to the reader, the strategy implication that emerges from this report is supporting fiscal measures targeted at fostering R&D in the high-tech sectors, instead of the adoption of fiscal incentives on a general basis.

To summarise, it is now necessary to move a step ahead of current conventional wisdom, which states that increasing R&D is crucial to fostering European productivity and competitiveness. While this is the commonly-accepted background to the Lisbon-Barcelona targets, the evidence provided in this study not only confirms the need to increase corporate R&D investment, but supports the view that this effort should be concentrated in the high-tech sectors. Overall, the targeting of R&D effort is as important as its increase.

¹⁶ The EUROSTARS programme will offer funding to those European SMEs with less than 250 employees who invest at least 10% of their annual turnover in R&D activities.

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APPENDIX

Fig. A1: Real GDP growth in the US and the EU15: 1980-2007 (Source: OECD)

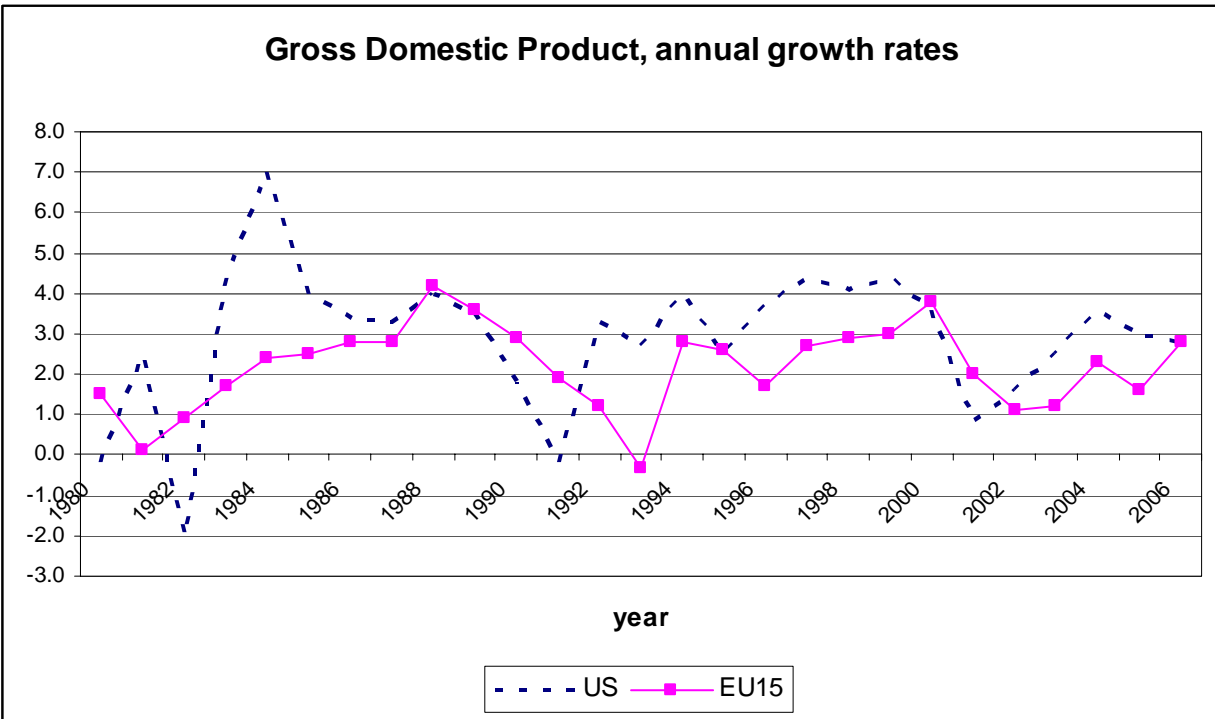


Fig. A2: Labour productivity growth in the US and the EU15: 1996-2006 (Source: OECD)

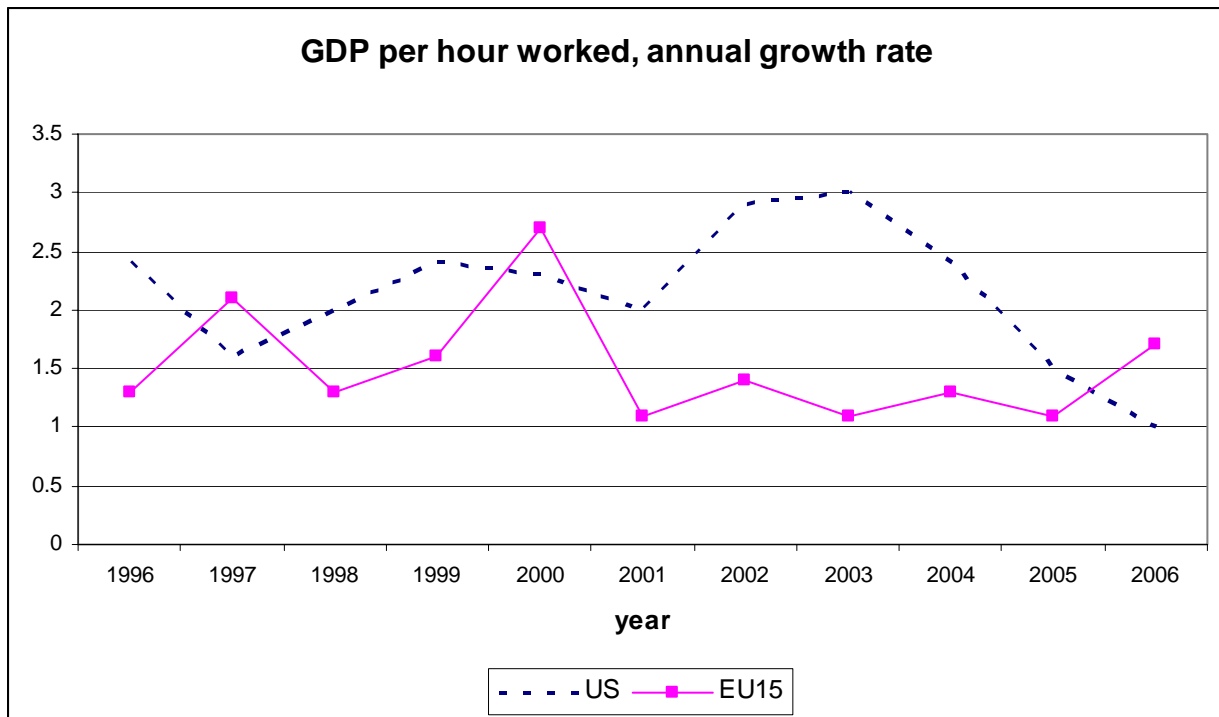


Table A1: The OECD sectoral dataset

| Country | N° of manufacturing sectors | Period |
|----------------|-----------------------------|-----------|
| Finland | 17 | 1987-2002 |
| France | 13 | 1987-2002 |
| Germany | 17 | 1991-2002 |
| Ireland | 14 | 1991-2002 |
| Italy | 17 | 1991-2002 |
| Netherlands | 12 | 1987-2002 |
| Spain | 9 | 1987-2002 |
| Sweden | 17 | 1987-2002 |
| United Kingdom | 17 | 1987-2002 |

Table A2: Descriptive statistics (532 UK Scoreboard firms)

| <i>Variable</i> | <i>All firms</i> | | <i>High-tech</i> | | <i>Medium-high</i> | | <i>Low-tech</i> | |
|-----------------|------------------|-----------|------------------|-----------|--------------------|-----------|-----------------|-----------|
| | <i>Mean</i> | <i>SD</i> | <i>Mean</i> | <i>SD</i> | <i>Mean</i> | <i>SD</i> | <i>Mean</i> | <i>SD</i> |
| VA/E | 0.068 | 0.062 | 0.063 | 0.037 | 0.053 | 0.024 | 0.095 | 0.100 |
| K/E | 0.032 | 0.049 | 0.062 | 0.069 | 0.021 | 0.026 | 0.012 | 0.013 |
| C/E | 0.473 | 1.756 | 0.158 | 0.400 | 0.135 | 0.176 | 1.280 | 3.091 |
| E | 36120 | 62434 | 40626 | 73890 | 22736 | 38350 | 48258 | 69635 |

Table A3: Sectoral classification and composition of the UK Scoreboard sample

| | R&D intensity | firms | observations |
|--|---------------|------------|--------------|
| High-tech | 0.21 | 170 | 600 |
| Technology hardware & equipment | 0.41 | 22 | 77 |
| Pharmaceuticals & biotechnology | 0.28 | 30 | 120 |
| Leisure goods | 0.25 | 7 | 25 |
| Aerospace & defence | 0.20 | 21 | 82 |
| Automobiles & parts | 0.16 | 37 | 140 |
| Software & computer services | 0.16 | 21 | 56 |
| Electronic & electrical equipment | 0.15 | 32 | 100 |
| Medium-tech | 0.08 | 196 | 671 |
| Chemicals | 0.12 | 42 | 154 |
| Industrial engineering | 0.08 | 58 | 209 |
| Health care equipment & services | 0.08 | 14 | 43 |
| Household goods | 0.06 | 18 | 51 |
| General industrials | 0.05 | 20 | 69 |
| Food producers | 0.05 | 31 | 105 |
| Media | 0.05 | 13 | 40 |
| Low-tech | 0.02 | 166 | 516 |
| Fixed line telecommunications | 0.03 | 14 | 43 |
| Industrial metals | 0.02 | 14 | 39 |
| Electricity | 0.02 | 13 | 43 |
| Oil equipment, services & distribution | 0.02 | 7 | 22 |
| General retailers | 0.02 | 9 | 29 |
| Support services | 0.02 | 22 | 67 |
| Construction & materials | 0.02 | 15 | 65 |
| Banks | 0.02 | 6 | 6 |
| Gas, water & multiutilities | 0.01 | 23 | 75 |
| Oil & gas producers | 0.01 | 13 | 48 |
| Mobile telecommunications | 0.01 | 6 | 17 |
| Industrial transportation | 0.01 | 11 | 23 |
| Beverages | 0.01 | 8 | 20 |
| Mining | 0.00 | 5 | 19 |
| Total | 0.09 | 532 | 1787 |