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R&D and Productivity in the US and the EU: Sectoral Specificities and Differences in the Crisis

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Abstract

Using data on the US and EU top R&D spenders from 2004 until 2012, this paper investigates the sources of the US/EU productivity gap. We find robust evidence that US firms have a higher capacity to translate R&D into productivity gains (especially in the high-tech industries), and this contributes to explaining the higher productivity of US firms. Conversely, EU firms are more likely to achieve productivity gains through capital-embodied technological change at least in medium and low-tech sectors. Our results also show that the US/EU productivity gap has worsened during the crisis period, as the EU companies have been more affected by the economic crisis in their capacity to translate R&D investments into productivity. Based on these findings, we make a case for a learning-based and selective R&D funding, which – instead of purely aiming at stimulating higher R&D expenditures – works on improving the firms' capabilities to transform R&D into productivity gains.

Keywords

R&D, productivity, economic crisis, US, EU

JEL Classifications

O33, O51, O52

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1 Introduction

While productivity trends were broadly stable between the 1980s and the first half of the 1990s, both in Europe and the US, a substantial change has been observed since the second half of the 1990s. In particular, during the last two decades, there has been a widening productivity gap between European countries and the United States that has now reached considerable size. Indeed, OECD macroeconomic data (OECD, 2015) report that in 2014 the labor productivity (measured as GDP per hour worked) in EU-28 was $ (2010 PPP) 46.6, meanwhile it was $ (2010 PPP) 63 in the US (see Fig.1).

As shown by Broadberry and O'Mahony (2004) and van Ark *et al.* (2008), the source of this widening gap has been a slowdown in the European productivity growth, implying that the post-WW2 European catch-up process has not only stopped but is actually now reversing (see Fig.1). Even for the latest figures, this gap appears to be widening. The OECD data report an annual productivity growth rate (2014 *vs*. 2013) of 0.5% for US against 0.3% for the European Union (OECD, 2015).

Consensus on the causes of these trends is not achieved, which is also due to the fact that most analyses refer to aggregate data. The literature has pointed out to different possible reasons probably jointly contributing to determine this result, ranging from the different level of flexibility in labor markets (Gomez-Salvador *et al.*, 2006; Grimalda, 2016), the quality of human capital (Gu *et al*., 2002) or the better North-American managerial practices (Bloom *et al*., 2005; Bloom and Van Reenen, 2010).

However, the main strand of the literature drew attention to the role of the differentials in the introduction and diffusion of new technologies between the two side of the Atlantic (Oliner and Sichel, 2000; Daveri, 2002; Wilson, 2009; Bacchiocchi and Montobbio, 2010). In particular, corresponding to the widening productivity gaps, there is a well-documented gap in the relative level of R&D spending, which may have played a king role in explaining the former (Rogers, 2010). Considering the EU-28, the BERD/GDP[1] ratio was 1.11% in 2002, it has remained almost constant until 2008 (1.14%), while slightly increasing in the following years up to 1.24% in 2012; meanwhile, the US R&D intensity was 1.77% in 2002, reached 1.97% in 2008, slowed down in the following years to get back to 1.95% in 2012 (the latest available value, OECD, 2014).

On the one hand, some scholars have argued that the lower European R&D spending is mainly due to the so-called *structural composition effect* and have provided evidence supporting their thesis. This sectoral composition effect arises because the R&D-intensive manufacturing and R&D-intensive service sectors are under-represented in the European economy in comparison to the US (European Commission, 2007; Mathieu and van Pottelsberghe de la Potterie, 2008; Lindmark *et al*., 2010; Ortega-

[1] BERD = Business Enterprise Expenditure on R&D.

Argilés and Brandsma, 2010). This view therefore treats the differences in R&D spending rather as an artifact of differences in sector composition.

On the other hand, other authors have stressed the so-called *intrinsic effect* and they have also provided convincing empirical evidence in support of their view. These authors pointed out that a general difficulty of European firms in investing in R&D and in achieving productivity gains can be detected. According to this view, EU firms *within* each industrial sector are characterized by a lower R&D intensity in comparison with their US counterparts (Erken and van Es, 2007; Ortega-Argilés *et al*., 2010, 2011). In addition, Ortega-Argilés *et al*. (2014) argue that there is also a lower capacity to translate R&D investment into productivity gains. In a sense, European companies might be still affected by a sort of modern Solow's (1987) paradox, *i.e.* by a difficulty to translate their own investments in R&D into increases in productivity. In summary, there could be an issue both in the *level* and in the productivity *impact* of R&D spending within European firms, irrespective of their sectoral belonging.

However, much of the scientific and policy discussion seems to be focused on the level effect. *E.g.*, European policy makers recently made explicit that it is necessary to augment R&D investments to foster productivity and, therefore, to support the recovery of growth and jobs in a 'knowledge-based' economy (European Commission 2010a and 2010b). However, precisely knowing the mechanisms sustaining the productivity gap is crucial for policy-making. In particular, if there are differential abilities to translate R&D into productivity gains, the lower levels of R&D spending may be a rational response by the firms, because their expected pay-off is lower. This may imply that policies aiming purely at increasing R&D spending – the 3% target is a prime example – may be inefficient when they are not simultaneously aiming at increasing the capabilities to make efficient use of R&D inputs.

Testing this hypothesis requires the ability to control for sectoral composition in Europe and the US, as well as for R&D and productivity at the level of the firm. Most existing analyses of the European-US productivity gap have, however, made reference to aggregate data. We therefore propose an empirical analysis based on a unique longitudinal database comprising comparable samples of European and US companies for a total of 1,112 top-R&D performing firms. Together with comparisons for the overall sample of firms, we will also split our analysis by two macro-sectors (high and medium-low tech), in order to better investigate the nature and source of the transatlantic productivity gap, with particular reference to the respective roles of the *structural* and the *intrinsic* effect. Moreover, the time-period available (2004–2012) also allows us to investigate the R&D-productivity dynamics before and after the recent worldwide economic crisis. Thus, our paper also sheds light on a particular critical period of the economic development in Europe, which has not been investigated by earlier studies.

The rest of the paper is organized as follows. Section 2 discusses the previous microeconometric evidence on the subject. Section 3 outlines how the dataset was constructed and presents the empirical methodology used to pursue the analysis. Section 4 discusses results, while the final section concludes and puts forward some policy implications.

2 Previous evidence

Back in 1979, Zvi Griliches started a prosperous empirical literature devoted to investigate the relationship between R&D and productivity (for a comprehensive survey, see Mohnen and Hall, 2013). On the whole, this microeconometric literature has provided robust evidence of a positive and significant impact of R&D on productivity at the firm-level, with an elasticity ranging from 0.05 to 0.25. Indeed, the consensus about the existence of a positive and significant impact of R&D on productivity remains strong across almost all studies and methodologies, even if comparable data in more countries are not common and results might be subject to discussion (Hall and Mairesse, 1995; Klette and Kortum, 2004; Loof and Heshmati, 2006; Heshmati and Kim, 2011; Ortega-Argiles *et al.*, 2011; Gkypali *et al.*, 2015).

However, when considering the structural dimension of an economic system, its industrial composition might affect the overall aggregate result since technological opportunities and appropriability conditions are very different across sectors (see Freeman, 1982; Winter, 1984; Malerba, 2004). This may also involve substantial differences in the sector-specific R&D-productivity links.

Indeed, previous sectoral studies (mainly on manufacturing industries) clearly suggest a greater impact of R&D investment on productivity in the high-tech sectors rather than in the low-tech ones.

Griliches and Mairesse (1982) and Cuneo and Mairesse (1983), who performed two companion studies on French and US firms, found that the impact of R&D on productivity for scientific firms (elasticity equal to 0.20) was significantly greater than for non-scientific firms (0.10). By the same token, Verspagen (1995) carried out a multi-country study involving 9 countries, singling out three macro industries: high-tech, medium-tech and low-tech, according to the OECD classification (Hatzichronoglou, 1997). The major finding of his study was that the impact of R&D was significant and positive only in high-tech sectors. Los and Verspagen (2000) found – for a sample of US manufacturing firms – that the average elasticity of the R&D investment to company productivity was 0.014; however, when they run the same analysis for the high-tech sectors only, the elasticity increased to 0.1.

A recent study by Ortega-Argilés *et al.* (2010), looking at the top 577 EU R&D investors, concluded that the coefficient of this impact increases monotonically when moving from the low-tech over the medium-high to the high-tech sectors, ranging from a minimum of 0.03/0.05 to a maximum of 0.14/0.17.

Moving closer to the topic investigated in this study, Ortega-Argilés *et al.* (2014 and 2015) analyze the transatlantic productivity gap providing evidences of differences among industries. Estimates are based on a COMPUSTAT-based database covering the period 1990-2008 and comprising 1,809 US and EU companies for a total of 16,079 observations. Robust evidence of a significant impact of R&D on productivity is provided. Moreover, the R&D coefficients for the US firms always turn out to be significantly higher. To see to what extent these transatlantic differences in the R&D-productivity relationship may be related to the different sectoral structures in the US and the EU, the analysis is differentiated by sectors. The result is that both in manufacturing, services and high-tech manufacturing sectors US firms are more able to translate their R&D investments into productivity increases.

Previous literature also suggests that more complex and radical product innovation generally relies on formal R&D, while process innovation is much more related to embodied technical change achieved by investment in new machinery and equipment (Parisi *et al*., 2006; Conte and Vivarelli 2014). Consistently with this framework, another result from Ortega-Argilés *et al*. (2014 and 2015) is that in traditional low-tech sectors – which focus on process innovation – productivity gains turn out to be more related to capital accumulation rather than to R&D expenditures.

Building on this microeconometric literature focusing on the relationship between R&D and productivity, our empirical study uses more updated microdata and analyzes a critical time span including pre- and post- world crisis sub-periods. Although the European and the US-economy have been severely plagued by the economic crisis, large parts of the European economy have found it harder to recover. Thus, it does not seem unreasonable to assume that the crisis might have amplified the factors contributing to widening the productivity gap rather than closing it. If this pattern became apparent, this would constitute worrying evidence that European R&D policy has been quite unsuccessful in achieving one of its major objectives, *i.e.* significantly increasing the competitiveness of the European economy vis-à-vis the US as one of its main competitors.

3 Data and methodology

3.1 The data

Previous literature has been partly limited by the extreme difficulty to obtain reliable and comparable micro datasets across countries. The microdata used in this study were provided by the JRC–IPTS (Joint Research Centre-Institute for Prospective Technological Studies, Sevilla) of the European Commission[2].

[2] This longitudinal dataset has been prepared and analyzed in the context of a project on 'European Innovative Companies and Global Value Chains: The Productivity Impact of Heterogeneous Strategies' funded by the JRC-IPTS (European Commission).

The dataset is mainly based on the EU Industrial R&D Scoreboard and aggregates information on top R&D spenders worldwide from 2004 until 2012. In particular, the EU Industrial R&D Investment Scoreboard provides the main economic and financial data of the top corporate R&D investors from the EU and from abroad. It uses data extracted directly from each company's Annual Report (data are consolidated at group level, *i.e.* including all the subsidiaries). Additional balance sheet information from the Bureau Van Dijk's ORBIS database for the same period is also considered. Even if the population of innovative companies is not covered completely, the companies listed in Scoreboard account for more than 90% of worldwide Business Enterprise Expenditure on R&D (BERD).

Overall, the data are organized as a panel of over 2,000 companies worldwide over the years 2004–2012. The data refer to basic firm economic features, such as sales, employment, capital expenditures, and R&D. In order to focus on EU vs. US, we excluded companies belonging to different geographical areas. The final sample is unbalanced in nature and comprises 1,355 companies (732 European firms and 623 US firms) with data from a minimum of two years, to a maximum of 9 years. Moreover, outlier observations have been dropped following the Grubbs test – as discussed in Section 3.2 – and leading to a final sample of 1,112 companies (504 European firms and 608 US firms) and 8,763 observations.

Table 1 reports the distribution of the retained firms and observations across countries, showing a dominant role of Germany and United Kingdom in Europe, but letting the other major European countries to be adequately represented in the sample[3].

<INSERT TABLE 1>

3.2 Econometric specification and descriptive statistics

Following Hall and Mairesse (1995), we test an augmented production function, derived from a standard Cobb-Douglas function in three inputs: knowledge capital, physical capital and labour:

$$\ln\left(\frac{VA}{E}\right)_{i,t} = \alpha + \beta\ln\left(\frac{K}{E}\right)_{i,t} + \gamma\ln\left(\frac{C}{E}\right)_{i,t} + \vartheta\ln(E)_{i,t} + \varepsilon_{i,t} \qquad (1)$$

with $i = 1,\ldots, 1{,}112$; $t = 2004,\ldots, 2012$; ln = natural logarithm.

Our ideal proxy for productivity is labour productivity (Value Added, VA, over total Employment, E), while our pivotal impact variables are the R&D stock (K, for knowledge) per employee and the physical capital stock (C) per employee.[4] Taking per capita values permits both standardisation of our data and

[3] Obviously enough, R&D and innovation activities are heterogeneously distributed across EU countries and regions (see Maurseth and Verspagen, 2002); however, investigating the differences in the innovative efforts within the EU is out of the scope of the present study.

[4] All the monetary variables are expressed in Euro after applying appropriate exchange rates for companies based in non-Euro countries (i.e. Denmark, Hungary, Sweden, United Kingdom, United States) and in cases of firms whose financial data where expressed in pounds or dollars even if located in the Euro-area.

elimination of possible company's size effects (see, for example, Crépon *et al*., 1998, p.123). In this framework, total employment (E) is a control variable that indicates increasing returns, if θ turns out to be greater than zero and decreasing returns otherwise.

In particular, K/E (R&D stock per employee) captures that portion of technological change which is related to the cumulated R&D investments, C/E (physical capital stock per employee) is the result of the accumulated investment, implementing different vintages of technologies. So, this variable encompasses the so-called embodied technological change, possibly affecting productivity growth.

Considering our dataset in more detail, one can appreciate that unfortunately the Value Added variable has a huge number of missing values due to particular accounting procedures adopted in the US. In order to maintain a reasonable number of observations, we decided to use Net Sales (NS)[5] instead of Value Added to construct the productivity variable. Over the available 3,866 observations the pairwise correlation coefficient between Value Added and Net Sales turns out to be 0.88. This high correlation makes us confident in using Net Sales/Employment as a proper proxy for labor productivity.

Given the crucial role assumed by the R&D variable in this study, it is worthwhile to discuss in detail what is intended by R&D in our database, since R&D measurement might follow different accounting practices in different countries over the world. In particular, the R&D investment included in the Scoreboard is the cash investment which is funded by the companies themselves, while it excludes R&D undertaken under contract for customers such as governments or other companies. Therefore, our R&D indicator is consistent and homogeneous across all the considered countries and refers to the genuine flow of current additional resources.

As it is common in this type of literature (see Hulten, 1990; Jorgenson, 1990; Hall and Mairesse, 1995; Parisi *et al*., 2006), stock indicators rather than flows are considered as impact variables; indeed, productivity is affected by the accumulated stocks of R&D and physical capital and not only by current or lagged flows.

Moreover, dealing with stocks – rather than flows – has two additional advantages: on the one hand, since stocks incorporate the accumulated investments in the past, the risks of endogeneity are minimised; on the other hand, there is no need to deal with the complex (sometimes arbitrary) choice of the appropriate lag structure for the flows.

[5] Net Sales variable follows the usual accounting definition of sales, excluding sales taxes and shares of sales of joint ventures and associates.

In our paper, R&D stock (K) is computed using a standard perpetual inventory method (PIM) approach according to the following formula (equation (2)[6]):

$$K_t = \frac{K_{t-1}}{(1+\delta)} + R\&D_t \qquad (2)$$

Where R&D = R&D expenditures; δ = depreciation rate (0.15)

The physical capital stock (C) was instead directly provided in the dataset, as a public information from balance sheets.[7]

In order to eliminate outliers, we undertook an outlier detection procedure using the Grubbs (1969) test over NS/E, K/E and C/E. After the outlier detection process, 243 companies were dropped. More in detail, 138 observations for the NS/E variable, 313 for the K/E variable and 294 observations for the C/E variable were deleted. The final dataset permits to retain almost the 75% of overall European and US R&D covered by the Scoreboard in 2012. This value represents almost the 65% of total European and US Business Enterprise Expenditure on R&D (BERD).

Specification (1) was estimated through different econometric techniques. Firstly, pooled ordinary least squared (POLS) regressions were run to provide preliminary evidence. Although very basic, in these POLS regressions we were able to control for heteroskedasticity (using the Eicker/Huber/White sandwich estimator to compute robust standard errors) and for a complete set of country (17 European countries + US), time (9 years), sector (29 ICB 3-digit code[8]) dummies.

Secondly, firm fixed effect (FE) regressions were performed in order to take into account firm specific unobservable time-invariant characteristics. The advantage of the FE estimates is that different firms are not pooled and therefore the estimates control for both unobserved heterogeneity and the intra-firm dependence structure. The disadvantage is that time constant variables (in our case in particular

[6] In year 0, $K_0 = \frac{R\&D_0}{(g+\delta)}$ (where g is computed as the average growth rate of the corresponding flow variable in the first three years available and δ is the depreciation rate).

[7] We also computed the physical capital stock starting from the investment flows using the same PIM procedure adopted in the case of the R&D stock. Nevertheless, due to a large number of missing values, we opted for the already available capital stock variable. Overall, the pairwise correlation coefficient between the physical capital stock from balance sheets and the physical capital stock computed with the PIM is 0.72 (over the available 7,056 observations), which supports our choice.

[8] The Industry Classification Benchmark (ICB) is a definitive system categorizing over 70,000 companies and 75,000 securities worldwide, enabling the comparison of companies across four levels of classification and national boundaries. The ICB system is supported by the ICB Database, an unrivalled data source for global sector analysis, which is maintained by FTSE International Limited (http://www.icbenchmark.com/).

country and sector dummies) are not individually identified, since they are encompassed by the individual firm-level fixed effects.[9]

Table 2 reports the means and standard deviations of the four relevant variables in specification (1). As we are also interested in singling out sectoral differences in the R&D/productivity relationship, we split our panel into two subgroups: high-tech vs medium- and low-tech sectors, ranking sectors according to their R&D intensity (measured in terms of R&D/employment, see Ortega-Argilés *et al*., 2011).[10] Furthermore, we also consider the descriptive statistics in the pre and post-world crisis sub-periods.

As can be seen, our sample comprises very large and established corporations, with an average employment of more than 20,000 employees (the median value is 4,683). On average, US companies are characterized by a larger knowledge stock per employees as compared to EU companies (+60%); moreover, US companies are more productive (NS/E) than EU firms, although being smaller on average. This very preliminary evidence is consistent both with a view that relates the transatlantic productivity gap to differences in the level of R&D investments and one which emphasize the different impact of R&D investments. The econometric analysis (see next section) will allow us to properly investigate this issue.

Considering the sectoral taxonomy, average values suggest that the productivity per employees decreases from high to medium/low-tech sectors together with the knowledge capital per employee (not surprisingly), meanwhile the physical capital per employee increases, suggesting a larger endowment of embodied technologies in the medium-low tech sectors.

Turning our attention to the pre and post-crisis subsamples, the statistical evidence suggests that the US/EU divides in both productivity and knowledge stock have persisted after the crisis.

< INSERT TABLE 2 >

4 Results

Table 3 provides the overall econometric results concerning the whole sample of 1,112 companies (8,763 observations). We find robust evidence of a positive and significant impact of the R&D stock on productivity with an elasticity ranging from 0.148 to 0.178, according to the different adopted

[9] Random effect (RE) regressions were also run and tested against the FE specification through the Hausman test. According to the outcomes of the test, in all the following investigated cases the FE estimates turned out to be preferable to the RE ones (results available from the authors upon request).

[10] The resulting high-tech group is made by: Aerospace & Defence, Automobiles, Automobiles & Parts, Computer Hardware, Computer Services, Consumer Electronics, Electrical Components & Equipment, Electronic Equipment, Electronic Office Equipment, Health Care Equipment & Services, Internet, Leisure Goods, Pharmaceuticals, Recreational Products, Semiconductors, Software, Telecommunications Equipment, Tires.

estimation techniques (POLS vs. FE). These estimates are within the bounds set by previous empirical studies (0.05/0.25; see Section 2).

As far as physical capital is concerned, we assess a positive and significant impact ranging from 0.112 (FE) to 0.236 (POLS); capital formation – embodying vintages of new technologies – emerges as a still important driver of productivity growth.

< INSERT TABLE 3 >

Turning our attention to the comparison between the US and the EU, the same model is run separately in US companies and European firms (608 vs. 504 companies). As can be seen in Table 3, our results fully confirm the previous outcomes from the extant literature. Although uniformly positive and statistically significant, the R&D coefficients for the US firms turn out to be consistently larger than the corresponding coefficients for the European firms. Indeed, the two estimation techniques consistently provide European elasticities which are merely about 35% of their US counterparts. Focusing on the more reliable fixed-effects (FE) specification, the US/EU gap is 99% statistically significant, as reported in the last but one column of Table 3 where a t-test measures if the FE coefficients referred to the two areas are significantly different. We interpret these unambiguous results as a clear evidence of the better ability of US firms to translate R&D investments into productivity gains and as a signal of the persistence of a structural gap that European firms and European policy have to deal with.

As far as the productivity impact of the physical capital is concerned, POLS and FE estimates tell us a different story: they both show that EU has a relative (although only marginally significant) advantage in productivity from investing in physical capital. In particular, the FE elasticity for the EU is 30% higher than its US counterpart. This evidence suggests that in 2004–2012, European companies have mainly relied on embodied technological change in order to foster their levels of productivity.

Looking at employment, FE results suggest a negative size impact on productivity. This evidence of decreasing returns is more accentuated for European than for US companies, given that the coefficient associated with the number of employees is more than 2.5 time larger for EU firms; this outcome can be related to the larger size of EU firms in our sample (see Table 2).

As a further step, we split our sample into a high-tech and a medium/low-tech industries subsample, and we investigate the different R&D-productivity relationship in these two industry-groups. As already discussed in Section 2, previous literature suggests that a greater impact of R&D investment on productivity is expected in the high-tech sectors rather than in the medium and low-tech ones. Therefore, the US advantage in terms of R&D impact may be due to a sectoral composition effect: in the aggregate, US firms may exhibit higher R&D/productivity elasticities just because they are relatively more concentrated in high-tech industries where the returns to R&D are higher.

< INSERT TABLES 4 AND 5>

Table 4 displays the US/EU comparison with regard to the high-tech industries. As expected – comparing Table 4 with Table 3 – high-tech companies turn out to be able to have the largest productivity gains from investments in R&D (0.255 *vs* 0.178 in the FE estimates). However, the European lag is fully confirmed: as it was the case for the whole economy, in the high-tech sectors the US coefficients are larger than their European counterparts (0.333 *vs* 0.128). Moreover, focusing on the FE estimates, the R&D gap turns out to be statistically significant at the 99% level of confidence (t-test in the last but one column). Differently, the capital gap in favor of the European firms is not confirmed at all. This evidence suggests that the advantage of US companies in translating knowledge into productivity gains is not only driven by their higher concentration in high-tech industries, but also by their higher ability to translate R&D into productivity within those industries. Moreover – in these sectors – the European companies do not show a better ability of their American counterparts to obtain productivity gains from physical capital and embodied technological change.

In Table 5, results for companies in the medium and low-tech sectors are presented. The picture is similar but paler than in the high-tech case. Overall, the elasticity for knowledge capital ranges from 0.054 to 0.100, revealing – not surprisingly – the lowest values in our estimates. In other words, productivity improvements at the firm-level, are relying on R&D investments relatively more in high-tech industries than in medium and low-tech sectors. Taking the fixed-effects estimates as a benchmark, a 10% increase in R&D capital stock per employee increases productivity by 2.55% in the high-tech sectors and only 1% in the medium/low-tech sectors. Conversely, in medium and low-tech sectors, investments in the physical stock of capital, which includes technology embodied in capital goods, is largely more productive than in high-tech industries (0.195 *vs* 0.082).

Turning our attention to the EU/US comparison, the medium- and low-tech European companies show (both in the POLS and FE estimates) a lower elasticity of productivity to R&D in comparison with their US counterparts. However, this differential is smaller than in the case of high-tech industries: looking at the FE coefficients, the European one it is about two-thirds (0.65) the one estimated for US firms (while in the case of high-tech it was about two-fifths, 0.38) – and only significant at the 95%-level. On the other hand, European companies in medium and low-tech sectors seem to be better in transforming investment in physical capital into productivity gains, although the t-test provides only marginal support of a statistical significant difference.

On the whole, the transatlantic productivity divide can be explained not only by a lower level of R&D investment of EU firms as opposed to their US counterparts (as obvious in Table 2), but also by a lower capacity to translate R&D investments into productivity gains. This is rather clear for the whole sample, but it is particularly accentuated in the high-tech industries and also significant, although smaller in magnitude, in the medium- and low-tech sectors.

In order to check if the previous evidence is confirmed over the economic cycle, we re-run the previous estimates, splitting the time-period into a pre-crisis sub-period from 2004 to 2008, and a post-crisis sub-period, from 2009-2012. As can be seen in the next Tables 6 and 7 our data allow us to have adequate and comparable sub-samples to be used for this evaluation exercise[11].

Results – comparing the whole sample evidence from the FE in the first panel of the two tables – reveal that in the post-crisis period the top-R&D spenders had a lower capacity to translate investment in R&D into productivity gains (0.158 *vs* 0.243); while showing a slightly better performance in terms of getting productivity improvements from physical capital (0.089 *vs* 0.070). This result may suggest that firm R&D capital is less pro-cyclical than output, so in times of crisis output may suffer from higher volatility than R&D.

Focusing on the comparison between the EU and the US, the evidence that US companies outperform the EU ones in terms of productivity gains from knowledge capital persists before and after the crisis, (the t-tests supports at the 95% level of significance the difference among the two coefficients both in 2004-2088 and in 2009-2012). In particular, the gap is still obvious in the post-crisis period, even if for both the US and the EU the magnitude of the elasticity lowers (from 0.294 to 0.199 for the US and from 0.194 to 0.093 for the EU). However, the EU companies have been more affected than their US counterparts in their capacity to translate R&D investments into productivity: –52% *vs.* –32%. This has implied that after the crisis the return from R&D investments of EU firms has dropped to 46% of the return of US firms, compared with 66% before the crisis. Indeed, the US/EU efficiency gap in linking R&D and productivity has worsened as a consequence of the global economic crisis.

< INSERT TABLES 6 AND 7 >

5 Conclusions and policy implications

In this paper, we test the hypothesis that the transatlantic productivity gap may be due not only to a lower level of corporate R&D expenditures by European firms, but also to a possible lower capacity to translate corporate R&D expenditures into productivity gains.

Consistent with previous literature, we find robust evidence of a positive and significant impact of the R&D stock on productivity. However, the R&D coefficients for the US firms turn out to be consistently and significantly larger than the corresponding coefficients for the European firms: on the aggregate,

[11] On the contrary, running estimates that jointly apply the time splitting and the sectoral splitting is prevented by the scarce number of observations in each of the six resulting subsamples.

European elasticities amount to about one third of their US counterparts. We interpret this unambiguous outcome as a clear evidence of the better ability of US firms in translating R&D investments into productivity gains and as a signal of a structural gap that European firms and European policy have to deal with.

To see to what extent these transatlantic differences may be related to the different sectoral structures in the US and the EU (the US economy being disproportionally characterized by high-tech industries), we have differentiated the US/EU comparative empirical exercise by macro-sectors, according to their technological level. Indeed, our results show that the US firms are more capable to translate their R&D investments into productivity gains both in the high-tech and in the medium/low-tech sectors, albeit the US lead is particularly obvious in the former set of industries. Therefore, not only US firms are more concentrated in high-tech industries, contributing to a positive structural effect on aggregate productivity, but in those industries they can extract higher productivity gains from their R&D investments. Given the key role of high-tech and emerging sectors in fostering productivity and the overall economic growth, this evidence can be considered particularly worrying in terms of the overall perspectives of the European economy.

Furthermore, our results show that the EU companies have been more affected by the economic crisis in their capacity to translate R&D investments into productivity: indeed, the US/EU gap investigated in this study has worsened as a consequence of the global economic crisis.

These findings have a considerable impact for the organization of policy support. A major implication of the even relatively decreasing ability of EU firms to translate R&D into productivity during the crisis suggests that EU support for R&D has not proven to be particularly effective in reaching one of its major goals, *i.e.* turning the EU into a more competitive economy in the long-run. Rather the opposite seems to have occurred and this can be due to a myopic EU policy.

Indeed, we find robust evidence of both a quantity effect (relatively lower R&D spending of European firms) and a quality effect (lower ability to transform R&D spending into productivity gains). However, most policy attention has been devoted to the lower levels of R&D spending rather than the lower capabilities to make efficient use of it. This is exemplified by the 3% target – in terms of the R&D/GDP ratio – set by the EU, making reference primarily to increasing the level of R&D spending. Yet, our results suggest that the overall lower level of intramural R&D spending might be a rational response to lower abilities to transform R&D into productivity gains. If this were true, policies and R&D support schemes should focus on increasing the firm's capabilities to turn R&D inputs into productivity gains rather than increasing business R&D spending, irrespective of whether it pays off or not.

Effective policies should, instead of primarily focusing on the symptom (*i.e.* R&D investments that are perceived as too low), rather take into account the reasons why EU firms choose to spend less on R&D

than US-firms. One possible option is to make policies more learning-oriented by including fostering knowledge-transfer and learning between firms (Rammer and Schubert 2016), another option is shifting the EU funding schemes in a direction of a greater excellence orientation (Frietsch *et al*., 2015).

This paper leaves however a series of open questions, related to why EU firms are less capable than their US counterparts to translate R&D into productivity. Is it due to the quality of human capital employed in R&D and/or – more generally– to firms' workforce composition? Or is it a matter of incentives, organization and managerial practices? Does globalization play a role in the ability to translate R&D into productivity, maybe in association with other characteristics of the firm? Due to data constraints, these questions cannot be addressed in this paper, but they are certainly key issues for promising future avenues of research.

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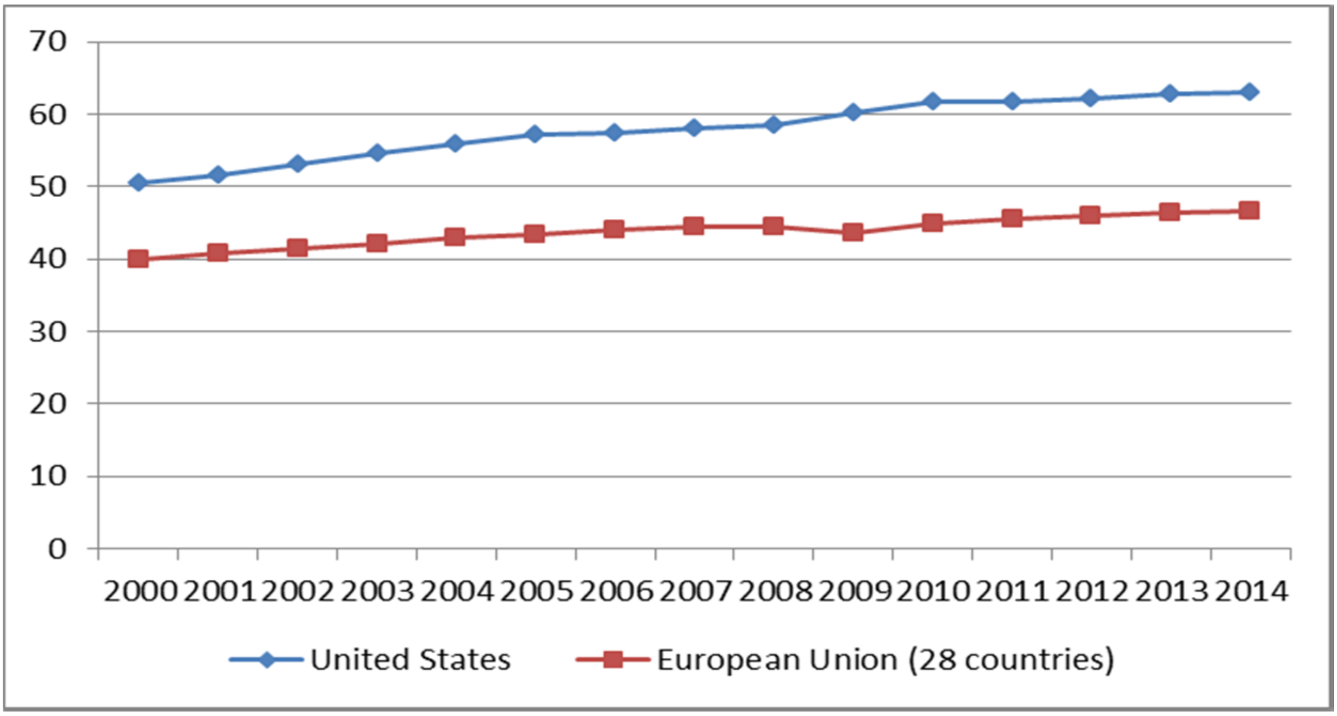
Figure 1: GDP per hour worked (USD, 2010 PPP)



Source: OECD data – Level of GDP per capita and productivity (OECD, 2015)

Table 1: Distribution of firms and observations across countries

COUNTRY	FIRMS	OBSERVATIONS
AUSTRIA	19	165
BELGIUM	18	140
DENMARK	22	176
FINLAND	31	272
FRANCE	79	642
GERMANY	113	990
GREECE	1	8
HUNGARY	1	9
IRELAND	10	82
ITALY	19	109
LUXEMBOURG	3	15
MALTA	1	8
SLOVENIA	1	9
SPAIN	10	88
SWEDEN	47	360
THE NETHERLANDS	29	235
UNITED KINGDOM	100	791
EUROPEAN UNION	**504**	**4,099**
US	**608**	**4,664**
TOTAL	**1,112**	**8,763**

Table 2: Descriptive statistics

Sample (N. of observations)	NS/E		K/E		C/E		E	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Whole sample (8,763)	252.18	199.20	66.98	85.98	130.94	120.08	21,371.09	50,965.21
US (4,664)	261.72	191.50	81.31	92.35	133.29	113.60	16,973.35	40,843.24
EU (4,099)	241.32	207.10	50.68	74.86	128.27	127.01	26,375.02	60,070.24
High-tech (5,583)	248.21	184.22	82.75	88.49	122.02	108.57	17,069.86	43,928.71
Medium and low-tech (3,180)	239.15	222.95	39.31	73.66	146.60	136.60	28,922.59	60,672.77
Whole sample *2004–2008* (4,949)	244.23	192.36	53.31	77.13	122.96	116.25	20,455.02	48,766.52
US (2,652)	253.54	194.05	64.51	82.16	124.51	107.84	16,333.93	38,902.62
EU (2,297)	233.49	189.88	40.39	68.65	121.17	125.26	25,213.03	57,753.02
Whole sample *2009–2012* (3,814)	262.49	207.30	84.72	93.34	141.30	124.12	22,559.77	53,667.32
US (2,012)	272.51	187.59	103.46	100.06	144.86	119.81	17,816.15	43,263.81
EU (1,802)	251.29	226.83	63.80	80.23	137.32	128.69	27,856.20	62,885.47

Table 3: Dependent variable: log(Net Sales/Employees)

	WHOLE SAMPLE	UNITED STATES	EUROPE	WHOLE SAMPLE	UNITED STATES	EUROPE	EU – US^	EU/US
	POLS	POLS	POLS	FE	FE	FE	FE	FE
Log(R&D stock per employee)	0.148*** (0.007)	0.234*** (0.010)	0.083*** (0.012)	0.178*** (0.013)	0.267*** (0.019)	0.094*** (0.018)	–0.173*** [0.000]	0.35
Log(Physical stock per employee)	0.236*** (0.009)	0.174*** (0.011)	0.293*** (0.015)	0.112*** (0.007)	0.099*** (0.009)	0.129*** (0.012)	0.030* [0.060]	1.30
Log(Employees)	0.027*** (0.005)	0.031*** (0.006)	0.032*** (0.007)	–0.143*** (0.012)	–0.082*** (0.016)	–0.223*** (0.019)	–0.141*** [0.000]	2.71
Constant	3.773*** (0.170)	5.872*** (0.095)	3.437*** (0.165)					
Wald time-dummies (p-value)	5.2*** (0.000)	6.5*** (0.000)	2.3** (0.017)	21.8*** (0.000)	15.3*** (0.000)	11.9*** (0.000)		
Wald country-dummies (p-value)	13.5*** (0.000)		10.8*** (0.000)					
Wald sectoral-dummies (p-value)	41.9*** (0.000)	198.3*** (0.000)	22.3*** (0.000)					
R^2 (overall) R^2 (within)	0.35	0.38	0.38	 0.20	 0.22	 0.19		
Obs.	8,763	4,664	4,099	8,763	4,664	4,099		
N. of firms	1,112	608	504	1,112	608	504		

Notes: (Robust in POLS) standard errors in brackets; * significance at 10%, ** 5%, *** 1 %.
For time-dummies, country-dummies and sectoral-dummies, Wald tests of joint significance are reported.
^ The absolute difference between the EU and US coefficients (from the FE estimates) is reported, together with the p-value (in squared brackets) of the t-test on the significance of this difference. In the last column the ratio of the EU coefficient with respect to the US one is reported.

Table 4: Dependent variable: log(Net Sales/Employees) – HIGH-TECH

	WHOLE SAMPLE	UNITED STATES	EUROPE	WHOLE SAMPLE	UNITED STATES	EUROPE	EU-US^	EU/US
	POLS	**POLS**	**POLS**	**FE**	**FE**	**FE**	**FE**	**FE**
Log(R&D stock per employee)	0.229*** (0.010)	0.277*** (0.011)	0.154*** (0.020)	0.255*** (0.016)	0.333*** (0.019)	0.128*** (0.026)	–0.205*** [0.000]	0.38
Log(Physical stock per employee)	0.181*** (0.009)	0.153*** (0.012)	0.219*** (0.017)	0.082*** (0.007)	0.088*** (0.009)	0.062*** (0.015)	–0.026 [0.129]	0.70
Log(Employees)	0.015*** (0.005)	0.019** (0.008)	0.018** (0.008)	–0.142*** (0.014)	–0.096*** (0.017)	–0.243*** (0.024)	–0.147*** [0.000]	2.53
Constant	4.298*** (0.916)	3.914*** (0.098)	3.988*** (0.130)					
Wald time-dummies (p-value)	11.5*** (0.000)	12.2*** (0.000)	2.5*** (0.000)	23.6*** (0.000)	20.1*** (0.000)	7.7*** (0.000)		
Wald country-dummies (p-value)	24.7*** (0.000)		21.7*** (0.000)					
Wald sectoral-dummies (p-value)	100.5*** (0.000)	99.3*** (0.000)	31.0*** (0.000)					
R^2 (overall) R^2 (within)	0.39	0.41	0.37	 0.24	 0.22	 0.22		
Obs.	5,583	3,414	2,169	5,583	3,414	2,169		
N. of firms	703	441	262	703	441	262		

Notes: (Robust in POLS) standard errors in brackets; * significance at 10%, ** 5%, *** 1 %.
For time-dummies, country-dummies and sectoral-dummies, Wald tests of joint significance are reported.
^ The absolute difference between the EU and US coefficients (from the FE estimates) is reported, together with the p-value (in squared brackets) of the t-test on the significance of this difference. In the last column the ratio of the EU coefficient with respect to the US one is reported.

Table 5: Dependent variable: log(Net Sales/Employees) – MEDIUM AND LOW-TECH

	WHOLE SAMPLE	UNITED STATES	EUROPE	WHOLE SAMPLE	UNITED STATES	EUROPE	EU-US^	EU/US
	POLS	POLS	POLS	FE	FE	FE	FE	FE
Log(R&D stock per employee)	0.054*** (0.012)	0.144*** (0.021)	0.027* (0.016)	0.100*** (0.021)	0.133*** (0.041)	0.087*** (0.025)	–0.046** [0.019]	0.65
Log(Physical stock per employee)	0.331*** (0.019)	0.222*** (0.025)	0.395*** (0.026)	0.195*** (0.016)	0.162*** (0.025)	0.214*** (0.021)	0.052* [0.100]	1.32
Log(Employees)	0.013 (0.010)	0.037*** (0.012)	0.032*** (0.007)	–0.097*** (0.023)	–0.002 (0.038)	–0.173*** (0.029)	–0.171*** [0.000]	86.5
Constant	3.424*** (0.201)	3.684*** (0.361)	3.544*** (0.284)					
Wald time-dummies (p-value)	2.8*** (0.000)	1.4 (0.174)	1.7* (0.087)	7.8*** (0.000)	2.7*** (0.006)	7.0*** (0.000)		
Wald country-dummies (p-value)	6.9*** (0.000)		5.5*** (0.000)					
Wald sectoral-dummies (p-value)	20.9*** (0.000)	74.1*** (0.000)	20.4*** (0.000)					
R^2 (overall) R^2 (within)	0.42	0.38	0.49	 0.18	 0.21	 0.19		
Obs.	3,180	1,250	1,930	3,180	1,250	1,930		
N. of firms	409	167	242	409	167	242		

Notes: (Robust in POLS) standard errors in brackets; * significance at 10%, ** 5%, *** 1 %.
For time-dummies, country-dummies and sectoral-dummies, Wald tests of joint significance are reported.
^ The absolute difference between the EU and US coefficients (from the FE estimates) is reported, together with the p-value (in squared brackets) of the t-test on the significance of this difference. In the last column the ratio of the EU coefficient with respect to the US one is reported.

Table 6: Dependent variable: log(Net Sales/Employees) – 2004–2008

	WHOLE SAMPLE	UNITED STATES	EUROPE	WHOLE SAMPLE	UNITED STATES	EUROPE	EU–US^	EU/US
	POLS	**POLS**	**POLS**	**FE**	**FE**	**FE**	**FE**	**FE**
Log(R&D stock per employee)	0.143*** (0.010)	0.224*** (0.014)	0.074** (0.023)	0.243*** (0.022)	0.294*** (0.032)	0.194*** (0.030)	–0.100** [0.028]	0.66
Log(Physical stock per employee)	0.216*** (0.012)	0.161*** (0.016)	0.265*** (0.039)	0.070*** (0.011)	0.087*** (0.012)	0.034* (0.018)	–0.053** [0.021]	0.39
Log(Employees)	0.036*** (0.007)	0.046*** (0.009)	0.036*** (0.018)	–0.136*** (0.020)	–0.133*** (0.029)	–0.131*** (0.031)	0.002 [0.960]	0.98
Constant	3.565*** (0.126)	3.647*** (0.169)	3.235*** (0.238)					
Wald time-dummies (p-value)	0.6 (0.665)	2.7** (0.028)	0.5 (0.750)	1.5 (0.195)	8.8*** (0.000)	1.5 (0.195)		
Wald country-dummies (p-value)	11.2*** (0.000)		8.5*** (0.000)					
Wald sectoral-dummies (p-value)	26.5*** (0.000)	27.5*** (0.000)	17.0*** (0.000)					
R^2 (overall) R^2 (within)	0.33	0.59	0.43	 0.18	 0.22	 0.16		
Obs.	4,949	2,652	2,297	4,949	2,652	2,297		
N. of firms	1,090	588	502	1,090	588	502		

Notes: (Robust in POLS) standard errors in brackets; * significance at 10%, ** 5%, *** 1 %.
For time-dummies, country-dummies and sectoral-dummies, Wald tests of joint significance are reported.
^ The absolute difference between the EU and US coefficients (from the FE estimates) is reported, together with the p-value (in squared brackets) of the t-test on the significance of this difference. In the last column the ratio of the EU coefficient with respect to the US one is reported.

Table 7: Dependent variable: log(Net Sales/Employees) – 2009–2012

	WHOLE SAMPLE	UNITED STATES	EUROPE	WHOLE SAMPLE	UNITED STATES	EUROPE	EU–US^	EU/US
	POLS	POLS	POLS	FE	FE	FE	FE	FE
Log(R&D stock per employee)	0.164*** (0.011)	0.261*** (0.011)	0.096*** (0.018)	0.158*** (0.026)	0.199*** (0.034)	0.093** (0.041)	–0.106** [0.049]	0.46
Log(Physical stock per employee)	0.258*** (0.013)	0.191*** (0.012)	0.323*** (0.024)	0.089*** (0.010)	0.105*** (0.013)	0.058*** (0.018)	–0.047** [0.037]	0.55
Log(Employees)	0.006 (0.007)	0.002 (0.008)	0.020* (0.011)	–0.248*** (0.027)	–0.319*** (0.034)	–0.264*** (0.045)	0.055 [0.327]	0.82
Constant	2.868*** (0.095)	2.699*** (0.105)	3.605*** (0.265)					
Wald time-dummies (p-value)	5.8*** (0.665)	3.2** (0.022)	4.2*** (0.005)	57.7*** (0.000)	37.7*** (0.000)	23.7*** (0.000)		
Wald country-dummies (p-value)	11.9*** (0.000)		7.9*** (0.000)					
Wald sectoral-dummies (p-value)	19.8*** (0.000)	35.8*** (0.000)	12.0*** (0.000)					
R^2 (overall)	0.42	0.49	0.43					
R^2 (within)				0.26	0.20	0.20		
Obs.	3,814	2,012	1,802	3,814	2,012	1,802		
N. of firms	1,024	555	469	1,024	555	469		

Notes: (Robust in POLS) standard errors in brackets; * significance at 10%, ** 5%, *** 1 %.
For time-dummies, country-dummies and sectoral-dummies, Wald tests of joint significance are reported.
^ The absolute difference between the EU and US coefficients (from the FE estimates) is reported, together with the p-value (in squared brackets) of the t-test on the significance of this difference. In the last column the ratio of the EU coefficient with respect to the US one is reported.