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Ari Kokko, Patrik Gustavsson Tingvall, and Josefin Videnord

Abstract

In this paper we conduct a meta-analysis to examine the link between R&D spending and economic growth in the EU and other regions. The results suggest that the growth-enhancing effect of R&D in the EU15 countries does not differ from that in other countries in general, but it is less significant than that for other industrialized countries. A closer inspection of the data reveals that the weak results for the EU15 stem from comparisons with the US – the US has been able to generate a stronger growth response from its R&D spending. Possible explanations for the US advantage include higher private sector investment in R&D and stronger public-private sector linkages than in the EU. Hence, to reduce the "innovation gap" vis-à-vis the US, it may not be enough for the EU to raise the share of R&D expenditures in GDP: continuous improvements in the European innovation system will also be needed, with focus on areas like private sector R&D and public-private sector linkages.

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1 Introduction

The European Union's growth strategy for the period 2010–2020 (the *Europe 2020 Strategy*) identifies innovation as one of the key measures for achieving "smart, sustainable, and inclusive growth" (European Commission, 2010). Like its predecessor, the *Lisbon Strategy*, it sees research as a precondition for innovation, and stresses the need to raise the Union's R&D investments to 3% of GDP. With higher R&D investments and more innovation, it is expected that the EU will be better able to address pressing long-term challenges related to growth, competitiveness, and environmental sustainability. In addition, the Commission believes that higher R&D investments will help manage Europe's immediate short-term problems caused by the global financial crisis (European Commission, 2013).

The assumption that R&D will help reach EU's long-term objectives is largely based on economic theory (Solow, 1957; Romer, 1986, Lucas, 1988), which identifies technical change as the major source of long run economic growth. New production processes will allow firms to increase output per worker or unit of capital, or help reduce pollution, CO_2 emissions, and the consumption of fossil fuels and other non-renewable resources. New products will contribute to improving the living standard and well-being of consumers. Since the knowledge created through R&D is to some extent a public good, there may be additional benefits from positive externalities or spillovers from R&D. In fact, endogenous growth theory suggests that these externalities may be strong enough to counteract the diminishing returns to capital that restrict long-run growth in neoclassical growth models (Romer, 1990; Aghion and Howitt, 1992; Grossman and Helpman, 1991). The arguments related to short-term benefits – the belief that higher R&D investments may facilitate the recovery from the global financial crisis – are less theoretical, and instead based on the observation that the countries investing more in R&D have also been less severely affected by the crisis (European Commission, 2013).

However, at the same time as R&D and innovation are emphasized as the appropriate response to the economic, social, and environmental challenges of the 21st century, there is also a concern that Europe may suffer from an "innovation gap" in comparison with other leading economies. For example, the *Innovation Union Scoreboard 2014*, which calculates multidimensional performance indices for the EU countries and some other major economies, suggests that the EU's innovation performance has fallen short of that in the US and Japan for the past decade, and that South Korea also shows better results than the EU since 2009 (EU Commission, 2014).

One obvious explanation for the gap is that the EU invests less in R&D than its main competitors. While the EU's R&D expenditures amounted to 2.01% of GDP in 2013, Japan reached 3.34%, South Korea recorded 3.61%, and the US used 2.55% of GDP for R&D. Another reason could be that there may be differences in how efficiently countries are able to transform R&D into commercial innovations and growth. In particular, growth effects may vary depending on how total R&D expenditures are divided between the public and private sectors. Both the EU and its main competitors devote roughly one percent of GDP to publicly funded R&D, but Japan, South Korea, and the US have substantially higher rates of private sector R&D than the EU. It is possible that privately funded R&D generates stronger benefits than publicly funded R&D (OECD, 2003), that interactions between private and public R&D result in more innovations than purely public research efforts (Block and Keller, 2008), or that private R&D is necessary to create the capacity for absorption and commercial exploitation of the results of publicly funded R&D (Cohen and Levinthal, 1989; Geroski, 1995). The growth effects of R&D are also likely to vary depending on the specific features of the national innovation system, which determines how effectively knowledge is created, commercialized, and diffused (Lundvall, 1985, 1992; Freeman, 1988). The quality of higher education, the efficiency of the labor market, incentives and attitudes toward entrepreneurship, openness to trade and foreign direct investment, the availability of venture capital, the quality of market institutions, and the availability of infrastructure are only some of the determinants identified in the literature (Afonso et al., 2005; Edquist, 2005; Herrera and Pang, 2005; Jaumotte and Pain, 2005a, 2005b; Lundvall, 2007). In many of these areas – in particular those related to entrepreneurship, venture capital, and market institutions – the US is often promoted as a best-practice example, suggesting that the US position as a global technology leader has more to do with an efficient innovation system than with higher R&D expenditures (Atkinson, 2014).

This article analyzes the relationship between R&D spending and growth by conducting a meta-analysis of the relevant literature on a large number of countries at different stages of economic development.[1] The purpose is to investigate whether the EU (or more precisely, the EU15 – the 15 countries that had joined the EU before 2004) differs from other economies in terms of how it is affected by R&D. The results suggest that the growth-enhancing effects of R&D spending in the EU are somewhat weaker than those in other industrialized economies, and that the gap is largely explained by a comparison with the US. The results are related to the analysis presented by Tingvall and Ljungwall (2014), who used the same data set to perform a meta-analysis on the R&D-growth nexus for China, and found weaker growth effects for China than for other countries. Tingvall and Ljungwall (2014) also found that studies analyzing the level of income generally record a stronger relation between R&D and output than studies analyzing changes in growth rates: this finding is relevant also for the present analysis.

The remainder of the article is organized as follows. Section II provides a brief overview of the literature on the growth effects of public and private R&D, and makes some comments on the discussion about differences in national innovation systems. Section III explains the model, data and variables. Section IV presents the results and section V concludes.

2 Literature Overview

The literature on the returns to R&D presents mixed results that vary across countries, firms and over time. Considering the stochastic nature of R&D, this is not surprising, in particular when analyzing firm level R&D. As a broad generalization, findings tend to indicate that publicly funded R&D has a positive return, but that it is lower than the return on privately funded R&D. This applies both for publicly funded R&D that is performed by companies and R&D at public universities and research institutes. The relationship between publicly funded and privately funded R&D is also under debate, reflecting worries that publicly funded R&D may be a substitute for private R&D efforts. While several earlier findings

[1] Only a few papers collected for the purpose of this analysis divide total spending on R&D into public spending and private spending on R&D, and hence there are too few observations to do such estimations.

suggested that there is indeed some crowding out, more recent contributions have tended to find that publicly and privately funded R&D are complements.

A few studies have attempted to make direct comparisons between the returns on privately-funded and publicly funded R&D. Mansfield (1980), Griliches and Lichtenberg (1984), Griliches (1986), Lichtenberg and Siegel (1991), Nadiri and Mamuneas (1994), and Di Cagno et al. (2014) all find that publicly funded R&D has a lower return than privately funded R&D. Griliches (1992) draws the conclusion that there is no major difference in returns between privately funded and publicly funded R&D at the company level. Other studies have reached inconclusive results on the capacity of publicly funded R&D to promote innovative outputs and economic growth (Bilbao-Osorio and Rodriguez-Pose, 2004; Bassanini et al., 2000). In fact, a comprehensive OECD survey on the sources of economic growth in the industrialized countries during the 1980s and 1990s found that only privately funded research contributed to economic growth, while publicly funded research had no positive impact on economic growth, and might even have inhibited it by displacing private funding (OECD, 2003).

The possibility that publicly funded R&D may crowd out privately funded R&D has been noted in several studies. Goolsbee (1998) and David and Hall (2000) claim that the most important effect of public funding is that it increases the salaries of R&D personnel, at least in the short run. This cost increase may lead companies to move their resources to other investments. Although the total sum invested in R&D may increase due to public funding, the real quantity of R&D (adjusted for higher costs) may actually be lower. Another argument is that publicly funded R&D may simply replace privately funded R&D. The companies substitute their own funding with public funding and continue to conduct R&D at the same level as earlier. In such cases, the government funds R&D that would have been carried out anyway. Moreover, if the government supports an R&D project in a specific company, this may discourage other competing companies from investing in R&D. It is also possible that the government allocates resources less effectively than the market, which can create market distortions that reduce the growth effects of R&D. Summarizing their findings from a survey of over 30 studies on the relationship between public and private R&D investment, David et al. (2000) found that studies based on US data were particularly likely to find signs of crowding out.

At the same time, there are also arguments suggesting that public and private R&D may be complements, or that some types of publicly funded R&D may have distinct positive effects on research and innovation in the private sector. Some private R&D may be necessary for firms to benefit from publicly funded R&D. Hence, Cohen and Levinthal (1989) and Geroski (1995) note that private R&D competence can enhance firms´ capability to absorb outside knowledge, e.g. from public R&D – Branstetter and Sakakibara (1998) provide supporting empirical evidence, while Griffith, Redding and Van Reenen (2004) provide the theoretical foundations underlying the hypothesis of absorptive capability. Publicly funded R&D that is performed at universities and other institutes of higher learning is likely to focus on basic research that is likely to have strong positive spillover effects for commercial R&D (Adams, 1990; Mansfield, 1991, 1998). However, the time lags between basic university research and commercial applications may be so long that the links are hard to detect in quantitative studies. Moreover, fiscal incentives and public subsidies to private R&D may have stronger positive effects on private R&D than R&D that is directly performed by the public sector (Scott, 1984; Falk, 2006; Guellec and van Pottelsberghe de la Potterie, 2003).[2]

Taking the contradictory findings on the links between public and private R&D into account, Zúñiga-Vicente et al. (2014) conclude that the empirical evidence regarding the crowding-out effect is mixed. In their detailed survey on the effects of public subsidies on private R&D, they find crowding-out or no effects of public funding in about 40 percent of their 118 cases, but a positive crowding-in effect in the remaining 60 percent of cases. Becker (2014) also concludes a recent survey of the links between public and private R&D by noting that there is mixed evidence, but she goes on to argue that there has been a shift away from the earlier findings that public subsidies often crowd-out private R&D to a pattern where public subsidies typically stimulate private R&D. In particular, public R&D subsidies seem to have positive effects in smaller firms (where financial constraints may limit R&D investments in the absence of subsidies) and

[2] Some of the studies that divide publicly funded R&D into civilian and defense-related R&D suggest that defense-related R&D has a weaker effect on economic growth (Hartley, 2006; Guellec and van Pottelsberghe de la Potterie, 2003), although there are also studies that find positive effects, in particular for the US (Goel et al., 2008).

firms in low and medium-technology industries (since high-tech firms are more likely to engage in R&D even without public support).

Summing up their study of 17 OECD member countries, Guellec and van Pottelsberghe de la Potterie (2003) also conclude that publicly funded R&D has a positive net impact on private R&D. However, Guellec and van Pottelsberghe de la Potterie (2004) stress that for publicly funded R&D to have positive effects on growth, there is a need for governments to carry out a broad and coherent innovation policy approach due to the existence of strong interactions between various diffusion channels and sources of technology. This conclusion is supported by Afonso et al. (2005), Herrera and Pang (2005) and Jaumotte and Pain (2005a, 2005b) in their studies on the determinants of the efficiency of public spending. These contributions all emphasize the role played by well-functioning framework conditions, such as the level of education of the population, the competence of civil servants, the strength of the IPR systems, trade openness, transparency in public policy, civil liberty and the existence of political rights. The same framework conditions are important also for the efficiency of private R&D spending. In other words, a well-functioning national or regional innovation system that facilitates the creation, commercialization, and diffusion of knowledge and innovations is needed to translate R&D expenditures into economic growth and welfare.

At a conceptual level, there is reasonable agreement in the literature regarding the definition of a national innovation system. For example, Freeman (1995) refers to "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies", Lundvall (1992) talks about "the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge", and Nelson and Rosenberg (1993) define it as "the set of institutions whose interactions determine the innovative performance of national firms". However, there is no agreement about precisely what institutions and relationships should be included in empirical work. In fact, existing structures are likely to "reflect the complex historical interplay of social, institutional, and cultural factors in shaping current systems" (Lundvall 2010), meaning that the same institutions and relationships are not likely to be equally important in all countries. It is therefore difficult to provide accurate and concise descriptions of any specific national innovation system, let alone to compare the efficiency of different national systems.

This notwithstanding, the OECD has performed a number of innovation policy reviews of selected member countries and some emerging economies like China, Russia, and South Africa.[3] Apart from the country-specific insights provided by the individual reviews, they are based on a common analytical framework that allows some comparison across countries, and they serve to demonstrate the diversity of national experiences, the role of path-dependence, and the increasing emphasis put on innovation and R&D in national policies across the world. Unfortunately, the completed reviews cover neither the EU as a whole nor Japan nor the US, which makes it difficult analyze the European innovation system in a comparative perspective.

Despite the lack of carefully matched comparative analyses, there are observations from numerous other studies suggesting that there are major differences also between the leading economies. For example, analyzing the US innovation system, Mowery and Rosenberg (1993) stress three particular features (apart from the much larger volume of American R&D investments) that arguably set the US aside from other industrialized countries until the 1990s. First, unlike both the EU and Japan, military R&D and procurement played important roles in the US innovation system. Second, relatively new and small firms had a prominent role in the commercialization of new technologies, in contrast to the EU and Japan, where large firms were more dominant. Third, the authors emphasized fragmentation and lack of explicit innovation policy as distinct features of the US innovation system. In a more recent analysis, Atkinson (2014) largely concurs, and argues that the strength of the US national innovation system is found in the regulatory and business environments, whereas the innovation policy environment remains weaker. Some of the particular strengths of the US business environment are highlighted by the European Commission (2005a): these include for example the ability to attract science and technology talent from other countries, linkages among universities, federal laboratories, and the private sector, easily established start-ups, and well-developed financial markets.

The Japanese national innovation system is often described as being more focused on incremental rather than radical innovation, with highly developed

[3] See http://www.oecd.org/innovation/inno/oecdreviewsofinnovationpolicy.htm.

collaboration between the public sector and the large companies dominating the private sector, and a strong role for regional policy initiatives. Some drawbacks that are often recognized concern the relatively conservative business structure and weaknesses in the financial sector that may hold back entrepreneurship and renewal, although recent policy reforms have aimed to address these weaknesses (Goto, 2000; European Commission, 2005b; Ibata-Arens, 2008). The European innovation system is mainly characterized by the contrast between a policy and strategy framework defined at the EU level, e.g. in the form of the *Lisbon Strategy* and the *Europe 2020 Strategy,* and business environments and R&D structures that are still largely national in character. One of the main challenges of the European innovation and growth strategy is therefore to strengthen the coordination and integration of various national policies in order to fully benefit from the opportunities provided by the Common Market. Considering the diversity of the EU, which includes countries that are ranked among the world's innovation leaders (Denmark, Sweden, Finland, and Germany) as well as countries with much lower levels of R&D and weaker national innovation systems (Portugal, Greece, and several of the transition economies that have joined the Union since 2004) this is obviously a daunting task.

Some of the differences between the innovation systems of the European Union, Japan, and the United States can also be illustrated with a comparison of the innovation performance indicators summarized in the Innovation Union Scoreboard (European Commission, 2014). The indicators used for the international comparison include 12 measures intended to reflect innovation enablers (doctorate graduates and tertiary education, international scientific co-publications and highly cited publications, and public R&D expenditures), firm activities (private R&D expenditures, linkages between the public and private sector, and patenting) and innovative outputs (exports of high-tech products and knowledge-intensive services, and license and patent revenues from abroad). Although the EU performs relatively well in some categories, it is clear that the United States has a distinct lead in several areas. In particular, the US records notably higher scores in tertiary education, international co-publications and highly cited publications, private R&D expenditures, public-private sector linkages, and international revenues from licenses and patents. Japan scores higher than the EU in tertiary education, private R&D expenditures, and public-private sector linkages, as well as patenting. These differences suggest that the EU is not only in a relatively weak position when it comes to aggregate R&D expenditures (and in particular private R&D expenditures) but that there may also be other weaknesses in the European innovation environment that limit the growth effects of R&D.

3 Model Specification, Data and Variables

Following Tingvall and Ljungwall (2013), we perform a meta-analysis on a sample of 49 country-specific studies, yielding 538 observations that explore the link between R&D and growth.[4] Meta-analysis has been used extensively to analyze publication bias (Stanley, 2008), but we focus mainly on determining whether the relationship between R&D and growth is more or less significant in the EU15 group than in other countries or country groups.

The dependent variable is the *t*-statistic for the R&D variable reported in a large set of country specific studies investigating the relation between R&D spending and economic growth.[5] The *t*-statistic is regressed on a set of study characteristics that are meta-independent and presumed to influence the outcome of the study. Each observation is weighted by the precision (Se) of the estimated effect.[6] The standard meta-regression model is therefore specified as follows:

$$B_i / Se_i = t_i = \alpha_0 + \sum_{k=1}^{K} \alpha_k X_{ik} / Se_i + \varepsilon_i; \quad i = 1, \ldots, N \quad \varepsilon \sim iid\ N(0, \sigma) \quad (1)$$

where B is the reported coefficient on the relation between R&D and growth taken from the obtained country-specific studies, Se is the associated standard error, t is the t-value and X contains a set of meta-independent variables capturing the characteristics of the empirical studies in the sample, α are the set of coefficients to estimate, and ε is the error term.

[4] See also Tingvall and Ljungwall (2010); Tingvall and Ljungwall (2012).

[5] It is not possible to use the regression coefficient for R&D spending as the dependent variable, since study designs differ significantly. The size of the regression coefficient will obviously depend on scaling as well as on the inclusion of other explanatory variables: we are not able to control fully for these differences across studies.

[6] See Cipollina and Salvatici (2010).

A feature of our meta-data is that it often includes more than one study for each country and several observations from a single author. These observations are likely to be interdependent and we therefore project two sources of interdependency: country-specific effects and study-specific effects. A common method to improve the precision in the analysis and to handle such group effects is to estimate models that allow for either country-specific random intercepts v_j or random study effects ζ_l. To simultaneously control for these effects, we extend equation (1) to a two-level model with random intercepts by country v_j and by study ζ_l. First, we assume studies to be nested under the country level, represented by the random intercept $\zeta_{[j]l}$. Subsequently, we relax the assumption of nested data. Thus, the multi-level framework enables us to handle heterogeneity more adequately than would have been possible under a dummy variable framework.

Description

The data used consists of 538 observations drawn from 49 country specific studies on R&D and growth.[7] Compared to other economic meta-analyses, this is a large sample. In earlier studies in the field of meta-analyses in economics, Görg and Strobl (2001) used 25 observations, Meyer and Sinani (2009) worked with 121 observations, and Tingvall and Ljungwall (2013) obtained 437 observations from their data set.

Our intention is to compare the EU15 countries (countries joining the EU before 2004) with other countries in general and other industrialized countries in particular. Austria, Finland, France, Germany, Italy, the Netherlands, Spain, Sweden and the UK are the EU15 countries represented in our data set. Henceforth, these are the countries we refer to as EU15. Other EU countries in the data set are Slovenia and the Czech Republic, which joined the EU in 2004 and are counted as transition countries. Out of the 538 observations, 244 refer to EU15 countries and 95 observations originate from the US. 14 observations derive from Slovenia or the Czech Republic.

[7] See http://ratio.se/sv/medarbetare/forskare/patrik-tingvall.aspx for a listing of the included studies.

Table 1. Distribution of *t*-values, EU15, non-EU15 and the US

	Median	Share *t*-val. negative and significant	Share *t*-val. positive and significant	Share insignificant *t*-val.
***t*-val. all obs.**	2.3	4%	63%	33%
***t*-val. EU15**	2.7	1%	71%	28%
***t*-val. Non-EU15**	2.0	7%	56%	37%
***t*-val. US**	2.3	3%	64%	33%

In Table 1 the median *t*-values and the distribution of *t*-values for the EU15, the non-EU15 and the US are presented. Since there are some outliers in the data, we present median values instead of mean values. As shown in Table 1, the EU15 has a higher median than both the non-EU15 and the US. We also find that one percent of the *t*-values for EU15 are negative and significant, 71 percent are positive and significant, and 28 percent are insignificant. A comparison with the *t*-values for non-EU15 countries and the US suggests that R&D may play a more significant role in enhancing growth in EU15 than in other countries. However, the sizes of the *t*-values are affected by study design. As an example of how study design can impact descriptive statistics, we may consider how the choice between income levels and growth as the dependent variable influences results. Table 2 shows that studies on the US are more likely to focus on growth than on income levels: 83 percent of all studies on the US are designed with the growth rate as the dependent variable while the corresponding share for the EU15 is only 34 percent. Since level studies, on average, are associated with higher *t*-values, this bias inflates the results for the EU15 in comparison with the US. This highlights the importance of controlling for study characteristics when comparing cross-study results.

Table 2. *t*-values, EU15 and the US

	All studies Median	**Growth studies Median**	**Income level studies Median**
EU15	2.70	2.95 (34%)	2.45 (66%)
US	2.27	2.07 (83%)	3.53 (17%)

Note: Share of growth and income level studies respectively within parenthesis (.).

4 Results

In Table 3 we report the results of a meta-regression analysis to see whether the results for EU15 differ significantly from the average results for other countries, and if the observed differences in *t*-values can be explained by data and research design. The explanatory variables included in the meta-regressions include degrees of freedom, country type (industrialized, transition and developing country), data type used (aggregated, industry, and firm level data), period of study, control for capital, control for human capital, control for population growth, study, and whether the dependent variable is measured in levels or growth rates. We also have a EU15 dummy variable distinguishing those studies that focus on EU15 countries.

In estimations (1)–(3) we sequentially add controls for different study characteristics to the analysis. Results from column (1) suggest that unconditional *t*-values for EU15 are not significantly different from those for other countries. Adding controls for degrees of freedom, data type used, period of study, capital, human capital, population growth, and the type of dependent variable (levels or growth rates), column (2) shows that the dummy for EU15 is still not significant from other countries in general. In column (3), we find a negative and significant estimate for the EU15 dummy when we include country type as a control. Thus, when the study characteristics and country type are controlled for, *t*-values are significantly lower for EU15 countries than for other industrialized countries. This suggests that in comparison to other industrialized countries, EU15 countries have a more uncertain outcome from spending on R&D on growth.

In columns (4) and (5), we examine whether the results in column (3) could be affected by a lack of controls for interdependence. In column (4), we extend the analysis to a two-level model with mixed random intercepts at the country and study level, where we assume study effects to be nested under the country level. In column (5), we further increase the generality of the interdependence and estimate a two-way model with non-nested crossed random effects by country and study. Adding controls for these interdependencies does not alter the result that the EU15 dummy is negative and significant in comparison with other industrialized countries.

Table 3. Meta Regression Models. Dependent Variable, *t*-value, R&D and Growth Studies.

	1. OLS (a)	2. OLS (a)	3. OLS (a)	4. Mixed model (b)	5. Mixed model (c)	6. Mixed model (b)	7. Mixed model (c)
	EU15 vs. all countries	EU15 vs. all countries	EU15 vs. ind. countries	EU15 vs. ind. countries	EU15 vs. ind. countries	EU15 vs. US	EU15 vs. US
EU15	7.86e-08 (7.15e-08)	1.26e-08 (3.28e-07)	-1.30e-06 (2.91e-07)***	-1.47e-06 (6.86e-07)**	-1.48e-06 (6.86e-07)**	-1.47e-06 (6.86e-07)**	-1.48e-06 (6.86e-07)**
$\ln\sqrt{DGF}$		-5.98e-08 (1.23e-07)	2.46e-07 (1.53e-07)	2.39e-07 (3.00e-07)	2.39e-07 (3.00e-07)	2.39e-07 (3.00e-07)	2.39e-07 (3.00e-07)
Aggregated data		-3.30e-07 (1.87e-07)*	-5.24e-07 (2.18e-07)**	-5.66e-07 (7.51e-07)	-5.66e-07 (7.51e-07)	-5.66e-07 (7.51e-07)	-5.66e-07 (7.51e-07)
Industry level data		0.0147 (0.0188)	0.0145 (0.0188)	0.0313 (0.0289)	0.0314 (0.0292)	0.0312 (0.0289)	0.03126 (0.0292)
Capital		7.22e-07 (4.57e-07)	-3.53e-07 (7.72e-07)	-4.31e-07 (1.70e-06)	-4.32e-07 (1.70e-06)	-4.31e-07 (1.70e-06)	-4.32e-07 (1.70e-06)
Human capital		-9.04e-08 (2.66e-07)	-1.12e-06 (4.58e-07)**	-1.16e-06 (1.04e-06)	-1.16e-06 (1.04e-06)	-1.16e-06 (1.04e-06)	-1.16e-06 (1.04e-06)
Population growth		-1.79e-07 (1.49e-07)	-5.03e-09 (1.07e-07)	1.65e-07 (3.62e-07)	1.68e-07 (3.62e-07)	1.65e-07 (3.62e-07)	1.68e-07 (3.62e-07)
Dep.variable in growth (vs. level)		5.62e-07 (3.92e-07)	5.22e-07 (3.61e-07)	6.13e-07 (8.17e-07)	6.14e-07 (8.17e-07)	6.13e-07 (8.17e-07)	6.14e-07 (8.17e-07)
Decade dummy 60s, 70s…, 00s	No	Yes	Yes	Yes	Yes	Yes	Yes
Transition country			3.13e-07 (5.95e-07)	4.05e-07 (1.52e-06)	4.04e-07 (1.52e-06)	4.04e-07 (1.52e-06)	4.04e-07 (1.52e-06)
Developing country			-1.85e-06 (2.48e-07)***	-1.65e-06 (6.77e-07)**	-1.65e-06 (6.78e-07)**	-1.65e-06 (6.77e-07)**	-1.65e-06 (6.78e-07)**
Test: Random country effect				2.75e-06 (0.0017)	2.28e-06 (0.0038)	2.15e-06 (0.0018)	2.87e-06 (0.00007)
Test: Random study effect				1.8319 (0.2614)***	1.8748 (0.2755)***	1.8315 (0.2614)***	1.8743 (0.2763)***
LR test linear model p-value				0.000	0.000	0.000	0.000
Residual industrial country						-0.0325 (0.2189)	-0.0335 (0.22)
Obs.	538	538	538	538	538	538	538

Notes: Standard errors within parentheses (.). ***, **, * indicate significance at the 10, 5, and 1 percent level, respectively. Test i_eu15=i_us: significant at the 5 % level. (a) Robust standard errors. (b) Random intercept model with studies nested under country. (c) Non-nested (two-way) random country study-effects model.

In columns (6) and (7), we repeat the preceding estimations, but filter out non-US industrialized countries and add them as a residual group. This makes the US our new reference group. Having the US as the reference group does not change the negative significance or the magnitude of the estimate for the EU15 dummy. Since the dummy variable for the residual industrialized countries is insignificant, the negative impact of the EU15 dummy seems to be driven by the comparison with the US rather than comparison with other industrialized countries. We also note that tests for random country effects and random study effects suggest significant within-study effects, while there is less evidence of within-country interdependence. These results indicate that the negative estimate for EU15 not is driven by omitted controls for within group interdependencies but instead related to the EU-US comparison.

In Table 4 we proceed with some further robustness tests by dividing the EU15 countries into two groups with respect to their R&D-intensity, EU high R&D and EU low R&D. The EU15 countries with high R&D are the ones spending more than 2 % of their GDP on R&D, which is close to the average R&D ratio for the EU as a whole. In our data set, Austria, Finland, France, Sweden, Germany, and the Netherlands are the countries spending more than 2 % of their GDP on R&D, while Italy, Spain, and the UK spend less than 2 % of their GDP on R&D.[8]

Column (1) of Table 4 examines whether EU15 countries with high R&D intensity differ from those with lower R&D spending. The results from robust regressions are very similar for both groups of EU15 countries. When including controls for country type (column 2), the regression returns estimates that are almost identical for the high and low R&D countries. In columns (3) and (4), we estimate a two-way model with non-nested crossed random effects by country and study. Again, the estimated coefficients are negative and significant for both EU high R&D and EU low R&D countries when a control for country type is included. These results suggest that the weaker effect of R&D spending in the EU compared to the US holds for both types of EU15 countries, and is not determined by whether their R&D expenditures are above or below the EU average.

[8] http://epp.eurostat.ec.europa.eu/statistics_explained/images/5/52/Gross_domestic_expenditure_on_R%26D%2C_2002%E2%80%9312_%28%25_of_GDP%29_YB14.png

Table 4. Meta Regression Models. Dependent Variable, *t*-value, R&D and Growth Studies.

	1. OLS (a)	2. OLS (a)	3. Mixed model (c)	4. Mixed model (c)
	EU15 vs. all countries	EU15 vs. ind. Countries	EU15 vs. all countries	EU15 vs. ind. Countries
EU high R&D	2.42e-07 (2.83e-07)	-1.27e-06 (2.97e-07)***	-9.40e-08 (3.64e-07)	-1.51e-06 (7.44e-07)**
EU low R&D	-2.53e-07 (2.34e-07)	-1.32e-06 (2.91e-07)***	-4.77e-07 (3.72e-07)	-1.46e-06 (7.00e-07)**
ln$\sqrt{DGF}$	-1.21e-07 (1.13e-07)	2.45e-07 (1.53e-07)	-9.41e-08 (1.90e-07)	2.40e-07 (3.01e-07)
Aggregated data	-3.44e-07 (1.81e-07)*	-5.52e-07 (2.35e-07)**	-3.33e-07 (3.88e-07)	-5.38e-07 (7.93e-07)
Industry level data	0.0147 (0.0188)	0.0145 (0.0188)	0.0311 (0.0293)	0.0314 (0.0292)
Capital	9.25e-07 (3.96e-07)**	-3.89e-07 (7.79e-07)	7.84e-07 (5.64e-07)	-3.95e-07 (1.73e-06)
Human capital	-2.40e-08 (2.13e-07)	-1.13e-06 (4.61e-07)**	-1.24e-07 (3.49e-07)	-1.14e-06 (1.05e-06)
Population growth	-1.35e-07 (1.41e-07)	-6.20e-09 (1.06e-07)	4.52e-08 (3.59e-07)	1.69e-07 (3.62e-07)
Dep.variable in growth (vs. level)	7.27e-07 (3.45e-07)**	5.06e-07 (3.62e-07)	7.97e-07 (5.24e-07)	6.31e-07 (8.32e-07)
Transition country		3.81e-07 (6.23e-07)		3.36e-07 (1.64e-06)
Developing country		-1.82e-06 (2.53e-07)***		-1.67e-06 (7.24e-07)**
Test: Random country effect			0.00001 (0.0011)	1.67e-06 (0.0055)
Test: Random study effect			1.882924 (0.2775)***	1.87523 (0.2756)***
Linear model p-value			0.000	0.000
Decade dummies	Yes	Yes	Yes	Yes
Obs.	538	538	538	538

Notes: Standard errors within parentheses (.). ***, **, * indicate significance at the 10, 5, and 1 percent level, respectively. [(a)] Robust standard errors. [(C)] Non-nested (two-way) random country study-effects model.

Robustness

In Tables 5–6, we scrutinize the robustness of the results. Table 5 analyzes whether the results are robust with respect to outliers and clustering technique. Columns (1)–(3) exclude controls for country type. In comparison with all countries, we find a positive and significant coefficient for the EU15 dummy in column (1), where we use robust OLS. However, when controls for country type are included in column (4), the same regression model yields a negative and significant estimate for EU15, in line with previous results. In columns (3) and (6), we limit the extreme values of our dependent variable by winsorizing *t*-values higher than 12 (approximately five percent of the observations). This is an important sensitivity test, since we already know that we have some large outliers in the data set. Winsorizing the *t*-values, the coefficient for EU15 becomes non-significant in column (3), but negative and significant when country controls are included in column (6). Thus, our negative estimates for the EU15 dummy in Table 3 seem robust with respect to outliers. In column (2) and (5), we find the same patterns when performing a quantile (median) regression. The two last regressions (columns 7–8) are models where cluster effects at the country level and study level respectively are considered. Both models give negative and significant results for the EU15. To conclude, the negative results for the EU15 when compared to other industrialized countries seem robust and not driven by model specification or outliers.[9]

As a further test of robustness, Table 6 controls for the sensitivity of results with respect to publication bias. A common way of detecting publication bias is using a Funnel Asymmetry Test (FAT), which examines if the intercept in the meta-regression model is significant. As noted in columns (1) of Table 6, this is indeed the case. Publication bias appears to be present, in the sense that the published results are likely to exhibit positive and significant *t*-values. To control for this, the Precision Effect Test (PET) adds the weighting variable 1/Se of the associated *t*-values to the regression. This is done in column (2). The EU15 dummy remains negative, but it loses its significance. This gives reason to be cautious about the comparison between the EU and the US, but it is not possible to

[9] As a robustness test, we replaced EU15 with EU27. This did not alter the results. Results available on request.

Table 5. Sensitivity Analysis. Dependent Variable, *t*-value, R&D and Growth Sstudies.

	1. Robust regression	**2. Quantile regression**	**3. OLS winsorized *t*-val**	**4. Robust regression**	**5. Quantile regression**	**6. OLS winsorized *t*-val**	**7. Cluster country**	**8. Cluster study**
	EU15 vs. all countries	EU15 vs. all countries	EU15 vs. all countries	EU15 vs. ind. countries	EU15 vs. ind. countries	EU15 vs. ind. countries	EU15 vs. ind. countries	EU15 vs. ind. countries
EU15	3.16e-07 (1.65e-07)*	-8.23e-07 (1.79e-07)***	8.34e-08 (2.64e-07)	-1.13e-06 (5.79e-07)**	-9.08e-07 (3.44e-07)***	-8.51e-07 (2.84e-07)***	-1.30e-06 (4.81e-07)**	-1.30e-06 (4.65+e-07)***
ln$\sqrt{DGF}$	3.93e-07 (1.26e-07)***	1.08e-07 (1.04e-07)	5.35e-08 (1.06e-07)	1.65e-07 (1.49e-07)	1.75e-07 (1.54e-07)	2.40e-07 (1.50e-07)	2.46e-07 (2.51e-07)	2.46e-07 (2.46e-07)
Aggregated data	6.12e-07 (2.62e-07)**	-3.84e-07 (2.15e-07)	-9.27e-08 (1.49e-07)	-4.38e-07 (4.70e-07)	-4.19e-07 (3.74e-07)	-8.74e-08 (2.13e-07)	-5.24e-07 (3.15e-07)	-5.24e-07 (2.93e-07)*
Industry level data	0.0029 (0.0116)	-0.0027 (0.0133)	0.0290 (0.0204)	0.0029 (0.0114)	-0.0027 (0.0117)	0.0288 (0.0204)	0.0145 (0.0490)	0.0145 (0.0465)
Capital	-1.57e-06 (5.31e-07)***	3.40e-07 (3.02e-07)	1.81e-07 (3.65e-07)	2.02e-07 (8.42e-07)	8.80e-08 (8.66e-07)	-2.72e-07 (7.54e-07)	-3.53e-07 (1.32e-06)	-3.53e-07 (1.26e-06)
Human capital	-2.00e-08 (1.69e-07)	-6.84e-07 (1.94e-07)***	-8.07e-08 (2.23e-07)	-8.32e-07 (3.51e-07)**	-8.14e-07 (5.26e-07)	-6.61e-07 (4.47e-07)	-1.12e-06 (7.79e-07)	-1.12e-06 (7.52e-07)
Population growth	-8.13e-08 (1.72e-07)	-1.00e-07 (1.96e-07)	-1.48e-07 (1.37e-07)	-3.67e-08 (1.71e-07)	-5.39e-08 (1.76e-07)	-5.02e-09 (1.06e-07)	-5.03e-09 (5.72e-08)	-5.03e-09 (5.86e-08)
Dep. variable in growth (vs. level)	-1.72e-06 (5.22e-07)***	7.70e-07 (2.84e-07)***	2.09e-08 (3.16e-07)	8.34e-07 (1.09e-06)	6.34e-07 (4.13e-07)	1.52e-07 (3.52e-07)	5.22e-07 (6.06e-07)	5.22e-07 (5.87e-07)
Decade dummy 60s, 70s…, 00s	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Transition country				n.a	1.22e-07 (7.66e-07)	-1.30e-07 (5.83e-07)	3.13e-07 (9.61e-07)	3.13e-07 (9.13e-07)
Developing country				-1.70e-06 (6.50e-07)***	-1.47e-06 (3.37e-07)***	-1.39e-06 (2.41e-07)***	-1.85e-06 (3.63e-07)***	-1.85e-06 (3.49e-07)***
Obs.	538	538	538	538	538	538	538	538

Notes: Standard errors within parentheses (.). ***, **, * indicate significance at the 10, 5, and 1 percent level, respectively. (a) Robust standard errors. (B) Random intercept model with studies nested under country. (C) Non-nested (two-way) random country study-effects model.

Table 6. Publication bias Meta-Regression Models. Dependent Variable, *t*-value, R&D and Growth Studies. Non-Nested (two-way) Random Country Study-Effects Models.

	1. Standard meta	2. Publication bias	3. Heckman meta-regression
	EU15 vs. USA	EU15 vs. USA	EU15 vs. USA
EU15	-1.06e-06 (4.15e-07)***	-8.61e-08 (6.22e-07)	-6.22e-08 (6.30e-07)
1/Se		-2.95e-06 (1.40e-06)**	-3.03e-06 (1.42e-06)**
Se			0.0958 (0.617)
Intercept	2.8295 (0.385)***	2.8199 (0.384)***	No intercept
Full set of controls	Yes	Yes	Yes

Notes: Standard errors within parentheses (.). ***, **, * indicate significance at the 10, 5, and 1 percent level, respectively. Control variables include: Degree of freedom, type of data (firm level-, industry level-, aggregated data), human capital, physical capital, and population.

determine on the basis of the PET how the publication bias influences the relative positions of the EU and the US in our analysis. Moreover, it should be noted that there are some limitations to FAT and PET, since FAT has low power and PET sometimes suffers from inflated type-1 errors (Stanley and Doucouliagos, 2007). Column (3) takes a further step by reporting results from a Heckman meta-regression model, which can be used as a precision effect estimate to evaluate the magnitude of the publication bias (Stanley and Doucouliagos, 2007; Stanley, 2008). The results are virtually identical to those of the standard publication bias model (column 2): the coefficient estimate for the EU15 dummy is negative but not significant. Hence, there is a risk that publication bias may contribute to the apparent differences in the impact of R&D on growth in the EU15 and the US, respectively. Having said this, it is hard to imagine that there would be a systematic publication effect that generates more significant *t*-values for studies focusing on the US rather than on the EU: the typical case would instead be a bias that generates significant rather than insignificant results for all countries.

As a final robustness test, we examine if the relation between EU15 and the US is constant over time by dividing the studies with respect to period of study – before and after 1990. When data are separated this way, we find that the coefficient for EU15 appears to be positive and significant prior to the 1990s, turning to negative after 1990. Specifically, the coefficient for EU15 compared to the US goes from 0.12 in the first period to –2.04e–06 in the second period, with corresponding *t*-values of 5.35 and –6.84. With previous results in mind, we note that the drop in the latter period is strong enough to yield a negative overall estimate for the EU compared to the US. Hence, it seems that is after 1990 that the link between R&D and growth has developed in favor of the US.[10]

5 Concluding remarks

In this meta-analysis, we have investigated the link between R&D spending and economic growth using a sample of 49 studies, yielding a total of 538 observations. The results from our analysis suggest that the growth-enhancing effect of R&D in the EU15 countries does not fall behind other countries in general, but it is less significant than for other industrialized countries. A closer inspection of the data reveals that the weak results for the EU15 stem from comparisons with the US, and that the results are similar for EU15 countries with high as well as low R&D intensities. Moreover, the conclusion that R&D has less significant growth effects in the EU15 countries than in the US seems to be driven by studies focusing on the period after 1990.

One interpretation of these findings is that the US has been able to generate more systematic benefits from its R&D spending during the past decades. The present study is not able to show exactly why this is the case, although we have referred to a broad literature discussing issues such as the relative importance of public and private R&D and various characteristics of the national innovation systems in EU and the US. It is also relevant to note that the debate on the "innovation gap" in the EU tends to conclude that R&D has stronger growth

[10] The results are robust with respect to a three period division, results available on request.

effects in the US. Overall, a policy conclusion from these findings is that the EU has reason to focus on continuous improvements in the European innovation system. In particular, EU strategies for innovation and research should not only focus on raising R&D expenditures as a share of GDP, but also include policies aiming to raise private sector investment in R&D and to strengthen linkages between the public and private sectors. These are some of the areas where the US outperforms Europe – it is therefore possible that they also contribute to the stronger growth effects of R&D in the US.

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