

Bergman, Karin

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Productivity Effects of Privately and Publicly Funded R&D¹

Karin Bergman[†]

Abstract

This paper examines the productivity effects of privately and publicly funded R&D, both performed in the private sector. In doing so, it ascertains whether there are differences in the direct effects on an industry's total factor productivity growth, and whether the spillover effects of R&D performed in other industries within a country differ in terms of the two sources of funding. Using a panel of industries from 13 OECD countries, it is found that privately funded R&D has a positive productivity effect, but with diminishing returns. Publicly funded R&D shows signs of increasing returns to scale, but the total effect is negative for most industries in the sample. The results concerning spillover effects are less robust, but there is some evidence of positive spillover effects from privately funded R&D, whereas spillovers from publicly funded R&D have an insignificant or a negative effect on an industry's productivity growth.

Keywords: Privately funded R&D, publicly funded R&D, productivity

JEL classification: D24, L6, O32

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[†] Department of Economics, Lund University, P.O. Box 7082, SE-220 07 Lund, Sweden, karin.bergman@nek.lu.se

1 Introduction

The importance of research and development (R&D) for innovation, and subsequently for economic growth, has been stressed since the beginning of the 1990s following the development of endogenous growth theory (Romer 1987, 1990, Grossman and Helpman 1991, Aghion and Howitt 1992). Since the beginning of the 1980s the business enterprise sector in the OECD countries has continuously increased its expenditures on R&D and in 2008 it spent 671 billion USD in total, which is equivalent to 1.6 percent of GDP. Of these expenditures, 6.5 percent was financed by the government, a decrease from 21 percent at the beginning of the 1980s (OECD 2010c).

The objective of this paper is to examine whether there are different productivity effects from privately and publicly funded R&D performed in the business sector. Earlier studies on productivity effects from privately and publicly funded R&D have mainly used U.S. data (see e.g. Levy and Terleckyj 1983, Griliches and Lichtenberg 1984, Lichtenberg and Siegel 1991, Griliches 1995, Archibald and Pereira 2003, Bönte 2003). The study in this paper extends the previous literature by using a panel of industries from several OECD countries. It is important to note that the notion of publicly funded R&D in this paper always means publicly funded R&D performed in the business sector as opposed to publicly funded R&D performed in the public sector.

The theoretical reason for government support to R&D dates back to Arrow (1962), who argues that a free enterprise economy is expected to underinvest in R&D due to the nature of the innovation process. Because the outcome of R&D is uncertain, most R&D takes place in large firms that can spread the risks over several projects. However, the economy potentially misses out on fruitful R&D projects in small firms that are unable to diversify risks. In addition, the non-rival nature of new knowledge implies that the marginal cost of spreading the new knowledge is zero, which makes it difficult for inventive firms to fully appropriate the returns from the R&D investment, thus leading them to invest less in R&D. These features of the innovation process, which result in less investment in R&D than is socially optimal, are the rationale for public support of R&D.

Jaffe (1998) discusses how the public funder of R&D should take into account both the private and the social returns to R&D when choosing projects to finance. Even if the objective of the public funder is to maximize social returns, it may not be the best option to fund the projects with the highest perceived social returns if these projects are also the ones

with the highest perceived private returns since these projects would be undertaken anyway. Instead, the public funder should focus on the projects where there are large differences between the private and the social rate of return. However, David et al. (2000) point out that it might be the projects with the highest private returns that are funded in order to ensure the success of public funding of R&D.

If projects with lower private returns receive funding, the risk of a crowding-out effect on private R&D is smaller than for projects with higher private returns. However, it could be that a private firm that gets funding for projects with high private returns may have the opportunity to undertake more risky projects that would not have been performed otherwise.

Investment in R&D is believed to affect not only the firm's own productivity, but also other firms' productivity through spillover effects. By trading with, or just being located close to, an R&D performing firm, another firm can gain access to new technology and thus experience effects on its own productivity. If private and public funding of R&D is directed towards different kinds of projects, there could also be differences in their spillover effects. For example, if public funding of R&D is more directed towards basic research than private funding, there may be larger spillover effects from the former. Therefore, I also examine whether there are different spillover effects of publicly and privately funded R&D performed in other industries within the country.

The growth in total factor productivity (TFP) for industry i in country j is modelled not only to depend on privately and publicly funded R&D, but also on the growth in TFP in the frontier country and a lagged TFP variable. To estimate this model I use the system GMM estimator where it is possible to control for country-industry fixed effects and endogeneity of both TFP and R&D variables. The findings confirm the importance of privately funded R&D for industry productivity. However, the results also indicate that the public funder of R&D does not seem to fund projects with either high private returns or high spillover effects.

The rest of the paper is organized as follows. Section 2 reviews related literature and the empirical evidence, section 3 describes the theoretical and econometric frameworks and the data, section 4 contains the results and section 5 concludes the paper.

2 Related literature

Related to the arguments for the need of government support to R&D, Link and Siegel (2007) discuss the importance of technology infrastructure for long-term technological advancement

and economic growth. By technology infrastructure they mean an organizational form that supports knowledge creation and knowledge flows between developers and users of technology. Besides, the efficiency of these institutions in providing technology and related infrastructure services is essential to an efficiently functioning national innovation system. In line with Arrow (1962), they also suggest that there are several technological and market factors that cause private firms to appropriate lower returns from investments in technology infrastructure and to face greater risks than society does. The authors point out that there are high technical risks associated with this kind of underlying R&D, that it takes a long time to complete the R&D and commercialize the resulting technology and that the underlying R&D easily spills over to multiple markets and is not appropriable. Private firms' difficulties in appropriating the social returns can therefore make the risk unacceptably large for a private firm considering an investment. This reasoning can be interpreted as supporting the idea of Jaffe (1998) that public R&D policy should aim at projects where there are large spillover gaps and the private rate of return is low compared to the social rate of return.

The arguments of Arrow (1962) and Link and Siegel (2007) usually apply to basic research, which is associated with higher risks and longer time to completion than applied R&D. However, a higher rate of return is generally reported on basic R&D as opposed to applied or development R&D (Hall et al. 2009). Hall et al. (2009) suggest that this finding could reflect successful basic R&D projects where the higher risk factor results in higher returns. It is also the case that most studies find a higher rate of return for process as compared to product R&D. However, Hall et al. (2009) argue that it is difficult to disentangle the effects of the two, that they are complementary to a certain extent, and that these results could also depend on the difficulty of measuring the effects of product R&D because of the poor reflection of quality improvements in the price indices. In addition, new products imply adjustment costs that could lower productivity in the short run. Thus, if public support to R&D targets basic or process oriented research we might expect to see higher rates of return from this R&D than from privately funded R&D if the latter is more directed towards applied and product oriented research.

In evaluating the effects of government support to R&D, there has been a focus on the question of complementarity or substitutability between privately and publicly funded R&D. Does increased public funding of R&D increase or decrease private expenditures on R&D? Policy makers have been interested in the outcome of studies on this issue because they want to make sure that the funding they provide does not just replace investments that would have

taken place anyway. However, the results from these studies are mixed. David et al. (2000) review 33 studies on this matter, performed on different levels (line of business, firm level, industry level and aggregate level), and all their results show is that it seems to be more common to find evidence of complementarity on the macro level than on the firm level. The same conclusion is drawn by García-Quevedo (2004) who, in a meta-analysis of the econometric evidence on the complementarity or substitutability between publicly and privately funded R&D, cannot say anything about how the design of the study affects the results except that firm-level studies more often find substitution effects.

Instead of looking at only the question of complementarity or substitutability, there is a strand of literature trying to evaluate the *productivity effects* of privately and publicly funded R&D. In general, these studies have indicated a much larger rate of return for privately funded R&D than for publicly funded R&D (Hall et al. 2009). For example, in a study of the aggregate U.S. industry sector, Levy and Terleckyj (1983) found the elasticity of privately funded R&D to be 28 percent, whereas the elasticity of federally financed R&D was only 6.5 percent. Lichtenberg and Siegel (1991) and Wolff and Nadiri (1993) find that federally funded R&D has an insignificant effect on productivity, whereas privately funded R&D has a significant rate of return of 30-60 percent. In line with these results, Griliches and Lichtenberg (1984) and Griliches (1995) find a significant positive premium for company financed R&D relative to federally financed R&D. There are even findings of a negative rate of return to publicly funded R&D, e.g. Poole and Bernard (1992) find a negative effect of publicly funded defence production on total factor productivity.

How can this lack of support for positive effects of publicly funded R&D be explained? Lichtenberg and Siegel (1991) argue that one way to interpret these results is that private companies are better than the federal funder at finding R&D projects with higher returns, and Hall et al. (2009) maintain that it is likely that private firms are less efficient in their research when using the public purse. Alternatively, it could be that it is difficult to measure the benefits from government funded R&D projects in the sense that output in industries with high levels of publicly financed R&D, e.g. defence related industries, is difficult to measure (Lichtenberg and Siegel 1991). And, as Griliches (1986) points out, much of the direct output of federally funded research is sold back to the government and is thus not likely to be reflected in the firm's productivity. Moreover, Leonard (1971) reports evidence from the U.S. where the federal funds are concentrated in a few industries, such as aircraft, missiles and electrical equipment, resulting in overinvestment in R&D and lower returns.

Lichtenberg and Siegel (1991) are of the opinion that a small or insignificant effect on productivity from publicly funded R&D could be reasonable if publicly funded R&D instead has an indirect positive impact on productivity in the sense that it improves economic welfare by stimulating additional privately financed R&D, or by generating positive spillover effects of R&D that is performed outside a given firm or industry. If the public funder of R&D aims at projects with lower private returns, but high social returns, as proposed by Jaffe (1998), the results of a lower rate of return on publicly financed R&D could hence indicate a successful R&D policy (Bönte 2003). In line with this reasoning, Bönte (2003), who finds no significant differences in the effect on U.S. industry productivity of privately and publicly funded R&D, notes that, because his data is on the industry level, it may be that his estimates pick up the spillover effect between firms, which is not visible in firm-level studies. Moreover, Archibald and Pereira (2003), using a vector autoregressive model to examine the ‘total’ effect of publicly funded R&D on private sector performance in the U.S. 1956-1988, argue that publicly funded R&D not only has a direct effect on output, but also positively affects private investment in physical capital and private R&D spending. They find the total effect on private output to be much larger for publicly funded R&D than for privately funded R&D.

On the topic of spillover effects, there are also studies trying to directly investigate whether there are differences in the size of the spillover effects from privately and publicly funded R&D. However, the empirical evidence gives mixed results. Mamuneas and Nadiri (1996) and Mamuneas (1999) find positive spillover effects from publicly financed R&D when investigating the effect of publicly funded R&D on the cost behaviour of U.S. manufacturing industries. However, when examining the effects on total factor productivity, Wolff and Nadiri (1993) and Bönte (2004) reveal a significant spillover effect only from privately funded R&D, whereas publicly funded R&D has an insignificant effect. Bönte (2004), however, provides some support for positive spillovers, from both privately and publicly funded R&D in low technology sectors. He further suggests that the lack of support for spillovers from publicly funded R&D might be a result of the public funder primarily aiming at improving health care or national security and not at increasing the efficiency of private production. Moreover, the literature on behavioural additionalities of public funding of R&D points at the importance of intangible social returns such as competence building and networking (Georghiou 2004).

In sum, the empirical evidence in some sense supports Jaffe’s (1998) idea of public policy supporting projects with lower private returns, but the lack of results on productivity effects

of spillovers from publicly funded R&D does not support this idea. However, it may be that the spillover effects are not visible in the short time perspective that is often the case in these kinds of studies. The arguments for public support of R&D, as stated by Arrow (1962) and Link and Siegel (2007), generally support the idea that the public funder should fund basic research where the time horizon is longer and risks are greater. But then we would see higher rates of returns for publicly funded R&D, which we do not. Hence, public support of R&D seems to be aimed either at social welfare goals other than increasing productivity, or at product innovations where there is an adjustment cost for firms, resulting in a lower productivity in the short run. In practice, many countries seem to have a mix of R&D funding policies where some aim at more basic research whereas others aim at more applied research (see e.g. OECD 2006, Link and Siegel 2007, Bloch and Krogh Graversen 2008, Bergman et al. 2010).

3 The empirical analysis

This section first describes the theoretical framework that underlies the model to be used in the empirical analysis. It then extends the baseline model and transforms it into an econometric specification. Finally, it describes the data and discusses issues pertaining to the measurement of the variables.

3.1 Theoretical framework

Following the standard methodology, an industry i in country j produces output, value added (Y), at time t using physical capital (K) and labour (L) according to a standard neoclassical production technology,

$$Y_{ijt} = A_{ijt}F_i(K_{ijt}, L_{ijt}), \quad (1)$$

where A_{ijt} is a measure of TFP and F_i is an industry-specific production function which assumes constant returns to scale and diminishing marginal returns to each input factor. TFP is in turn a function of the stock of knowledge in the industry, generated by R&D performed in the industry itself and in other industries within the country.

To relate to the convergence literature, there also exist spillover effects in a general sense so that the growth in TFP, in any industry, is stimulated by the diffusion of new and existing technologies from the frontier country for a given industry (see e.g. Scarpetta and Tresselt 2002, Griffith et al. 2004, Cameron et al. 2005). TFP for a given industry i in country j at time t can therefore be modelled as an autoregressive distributed lag ADL(1,1) process where

the level of TFP is assumed to be cointegrated with the level of TFP of the technological frontier country, defined as the country with the highest TFP in any given industry and indexed by F :

$$\ln TFP_{ijt} = \alpha_1 \ln TFP_{ijt-1} + \alpha_2 \ln TFP_{iFt} + \alpha_3 \ln TFP_{iFt-1} + u_{ijt}. \quad (2)$$

Under the assumption of long-run homogeneity ($1 - \alpha_1 = \alpha_2 + \alpha_3$), equation (2) has the following equilibrium correction model representation.

$$\Delta \ln TFP_{ijt} = \alpha_2 \Delta \ln TFP_{iFt} + (1 - \alpha_1) TGAP_{ijt-1} + u_{ijt}, \quad (3)$$

where $TGAP_{ijt-1} = \ln TFP_{iFt-1} - \ln TFP_{ijt-1}$ is the technological gap between the frontier country F and country j in a given industry. The further industry i in country j lies behind the technological frontier, the larger the gap term and the greater the potential for productivity growth through technological transfer.

The residual in equation (3), u_{ijt} , includes the main variables of interest, privately and publicly funded R&D expenditures in the industry ($R^{P,G}$) and spillovers from privately and publicly funded R&D expenditures in other industries within the country ($S^{P,G}$):

$$u_{ijt} = \gamma_1 \left(\frac{R^P}{Y} \right)_{ijt-1} + \gamma_2 \left(\frac{R^G}{Y} \right)_{ijt-1} + \gamma_3 \left(\frac{S^P}{Y} \right)_{ijt-1} + \gamma_4 \left(\frac{S^G}{Y} \right)_{ijt-1} + \rho' X_{ijt-1} + \eta_{ijt}, \quad (4)$$

where the superscripts P and G denote privately and publicly funded R&D, respectively. The variable X is a vector of control variables and η is a stochastic error. Equations (3) and (4) together give the basis for the econometric specification:

$$\begin{aligned} \Delta \ln TFP_{ijt} = & \alpha_2 \Delta \ln TFP_{iFt} + (1 - \alpha_1) TGAP_{ijt-1} + \gamma_1 \left(\frac{R^P}{Y} \right)_{ijt-1} + \gamma_2 \left(\frac{R^G}{Y} \right)_{ijt-1} \\ & + \gamma_3 \left(\frac{S^P}{Y} \right)_{ijt-1} + \gamma_4 \left(\frac{S^G}{Y} \right)_{ijt-1} + \rho' X_{ijt-1} + \eta_{ijt}. \end{aligned} \quad (5)$$

We will see support for the reasoning of Jaffe (1998), that the public funder of R&D supports the projects with lower private returns but higher spillover effects, if $\gamma_2 < \gamma_1$ and $\gamma_4 > \gamma_3$, whereas the reasoning of David et al. (2000) will be supported if $\gamma_2 > \gamma_1$ or if they are equal. Even if $\gamma_4 < \gamma_3$ or there is no difference between them, Jaffe could be right since it may be that we do not see the effect of spillovers just one time period later. Moreover, if the public funder mainly funds basic research and privately funded R&D is more directed towards applied research then we would expect $\gamma_2 > \gamma_1$, based on the existing empirical evidence. We would also expect spillovers from this kind of research to be larger, i.e. $\gamma_4 > \gamma_3$.

3.2 Empirical framework

This section describes how total factor productivity is measured and gives a more detailed description of the econometric specification to be estimated.

3.2.1 Calculating total factor productivity

To calculate total factor productivity the superlative index approach of Caves et al. (1982) is used. Assuming a translog production function, the growth rate in TFP can be measured as follows:

$$\Delta \ln TFP_{ijt} = \ln \left(\frac{Y_{ijt}}{Y_{ijt-1}} \right) - \frac{1}{2} (s_{ijt} + s_{ijt-1}) \ln \left(\frac{L_{ijt}}{L_{ijt-1}} \right) - \left(1 - \frac{1}{2} (s_{ijt} + s_{ijt-1}) \right) \ln \left(\frac{K_{ijt}}{K_{ijt-1}} \right), \quad (6)$$

where s_{ijt} is the share of labour costs in value added. This share is in reality quite volatile over time, which indicates the presence of measurement errors. I therefore use the properties of the translog production function and smooths the observed labour shares using an estimation procedure from Harrigan (1997). This smoothing procedure is based on regressing s_{ijt} on a country-industry constant and on the capital-labour ratio, using a fixed effects estimator where the coefficient of the capital-labour ratio is allowed to vary across industries. The fitted values from this regression are then used in the calculation of the growth rate of TFP in equation (6).²

To be able to calculate the variable for the distance to the frontier, $TGAP$, we also need a measure for the *level* of TFP in industry i in country j . To have a measure of TFP that makes it possible to compare the TFP levels between countries at the same time as allowing for industry-specific technology, a common reference point is chosen for each industry – the geometric mean of value added, labour and capital in that industry over all countries (Van Biesebroeck 2007):

$$\ln TFP_{ijt} = \ln \left(\frac{Y_{ijt}}{\bar{Y}_{it}} \right) - \tilde{s}_{ijt} \ln \left(\frac{L_{ijt}}{\bar{L}_{it}} \right) - (1 - \tilde{s}_{ijt}) \ln \left(\frac{K_{ijt}}{\bar{K}_{it}} \right), \quad (7)$$

where a bar above a variable denotes the geometric mean of that variable in industry i at time t . The variable $\tilde{s}_{ijt} = \frac{1}{2} (s_{ijt} + \bar{s}_{it})$ is the average of the labour share in industry i in country j and the geometric mean of the labour shares in industry i , and again the smoothed labour shares are used. The assumptions of perfect competition in output and input markets,

² When using a translog production function and standard market-clearing conditions are assumed to hold, the share of labour costs in value added is given by $s_{ijt} = \theta_{ij} + \phi_i \ln (K_{ijt}/L_{ijt})$. If actual labour shares deviate from this equation by an i.i.d. measurement error term, its parameters can be estimated using a fixed effects estimator (Harrigan 1997). This procedure is also used e.g. in Griffith et al. (2004).

optimizing behaviour by firms, and absence of measurement errors need to hold to calculate this measure of TFP (Van Biesebroeck 2007). Here, constant returns to scale are also assumed, but it is not a necessary assumption for this measure of TFP. However, without information on the level of scale economies, it is difficult to control for them and I follow the general practice of assuming constant returns to scale.

3.2.2 The econometric specification

Equation (5) is modified in a few ways in order to end up with the econometric specification to estimate. First, following Lokshin et al. (2008) equation (5) is extended to include quadratic terms of the R&D variables. There is empirical evidence of decreasing returns to R&D even though the quadratic terms have often been excluded in empirical studies due to the problem of estimating the linear and quadratic term simultaneously. This problem might still be prevalent in this study, but as Lokshin et al. (2008) point out, the availability of panel data reduces it.

Second, the vector of control variables is specified to include a variable for the level of human capital (H) in country j , measured as the share of the population of those more than 15 years old and with completed tertiary education.³ To capture the business cycle effect, the variable ΔU_{jt} , measured as the difference in one minus the unemployment rate, is included following Guellec and van Pottelsberghe de la Potterie (2004).

Third, the measure of domestic inter-industry spillovers from R&D is calculated following Wolff and Nadiri (1993), where spillovers are assumed to occur through trade in the sense that spillovers from R&D in industry k in country j is proportional to the trade intensity of industry i in country j . Denoting this trade intensity M_{kij}/Q_{ij} where M_{kij} is the total amount of intermediate goods sold by industry k to industry i and Q_{ij} is total output in industry i , the domestic spillovers, $S^{P,G}_{ijt}$, can be written as:

$$S^{P,G}_{ijt} = \sum_{k \neq i} \left(\frac{M_{kij}}{Q_{ij}} \right) R^{P,G}_{kjt}.$$

Fourth, the error term, η , is divided to include a country-industry specific effect, μ_{ij} , a time effect, λ_t , and an idiosyncratic error, ε_{ijt} . The econometric specification to estimate then becomes:

³ The results are not sensitive to other common human capital variables like the average years of schooling or the share of the population that has completed secondary education.

$$\begin{aligned}\Delta \ln TFP_{ijt} = & \beta_1 \Delta \ln TFP_{iFt} + \beta_2 TGAP_{ijt-1} + \beta_3 \frac{R_{ijt-1}^P}{Y_{ijt-1}} + \beta_4 \left(\frac{R_{ijt-1}^P}{Y_{ijt-1}} \right)^2 + \beta_5 \frac{R_{ijt-1}^G}{Y_{ijt-1}} + \beta_6 \left(\frac{R_{ijt-1}^G}{Y_{ijt-1}} \right)^2 \\ & + \beta_7 \frac{S_{ijt-1}^P}{Y_{ijt-1}} + \beta_8 \frac{S_{ijt-1}^G}{Y_{ijt-1}} + \beta_9 H_{jt-1} + \beta_{10} \Delta U_{jt} + \mu_{ij} + \lambda_t + \varepsilon_{ijt}.\end{aligned}\quad (8)$$

Equation (8) is hence equation (5) with the extensions outlined above. The estimates on β_4 and β_6 will show if investments in R&D are characterized by decreasing returns to scale, as often stated in the theoretical literature. A positive estimate on β_1 will show that there is technological transfer in the sense that when the frontier country is advancing, some of this new technology will spread to the other countries. And the estimate on β_2 will show if there is convergence in the sense that the countries that are further behind the frontier can enjoy more spillover effects of technology transfer from the frontier country.

3.3 Data

The study in this paper uses data for 18 manufacturing industries from 13 OECD countries in the period 1987 to 2007. The countries are Austria, Canada, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Norway, Spain, Sweden and the U.S. The countries are chosen based on data availability, and most industries are on the two digit level, but some are grouped together due to data limitations.

Data on value added, capital formation, labour, trade intensities and deflators comes from the OECD STAN data base (OECD 2010d, OECD 2010e), data on R&D expenditures and their source of funds comes from the OECD Science, Technology and R&D Statistics (OECD 2010a), data on education levels comes from the Barro and Lee dataset (2010) and data on unemployment rates is from the OECD Labour Force Statistics (OECD 2010b). Value added and R&D expenditures are deflated using country-industry specific value added deflators and capital is deflated using country-industry specific capital deflators (base year 2005).^{4,5} All variables are converted to USD using economy-wide PPPs. The literature on productivity effects highlights the importance of industry-specific PPP exchange rates, but empirical findings using industry-specific PPPs compared to those using aggregate PPPs generally do not differ much (see e.g. Scarpetta and Tresselt 2002, Griffith et al. 2004, Unel 2008).

⁴ Most deflators are on the two digit level but for some countries and some industries a more aggregated deflator is used due to data constraints.

⁵ It is not clear which is the most appropriate deflator for R&D. However, the results presented in this paper are not sensitive to a deflator that is an average of the industry-specific value added deflator and the more aggregated manufacturing value added deflator in the country.

3.3.1 Measurement of variables

Labour is measured as the number of employees in a given industry i times the average annual hours worked in country j . Capital stocks (K) are calculated using the perpetual inventory method as follows:

$$K_{ijt} = (1 - \delta)K_{ijt-1} + I_{ijt},$$

where I are real investments in physical capital in time t , δ is the depreciation rate of capital and, following the literature, assumed to be 8 percent (see e.g. Machin and van Reenen 1998, Brandt 2007, Madsen 2008, Unel 2008). To calculate initial capital stocks a presample growth rate of 5 percent is assumed. It should be noted that the results are not sensitive to different assumptions about the depreciation rate or the presample growth rate. Neither labour nor capital is corrected for double counting of R&D expenditures in the sense that some of the employees and some of the physical capital are used in R&D. In this way, the estimated rate of returns to R&D will be excess returns.

R&D statistics are not always collected on an annual basis. For almost half of the countries the data is biennial, for two countries the data is sometimes annual and sometimes biennial and for one country the data is at first only available every fourth year, and then the data is biennial. Missing values in the R&D variables have been linearly interpolated when data exists both the year before and the year after.⁶ In total almost 20 percent of the observations on R&D expenditures has been interpolated. Another problem concerning the R&D variables is distinguishing between privately and publicly funded R&D projects. In reality, it is often the case that a specific R&D project is financed by both the private firm and the public sector, but that distinction is not possible to make with this data.

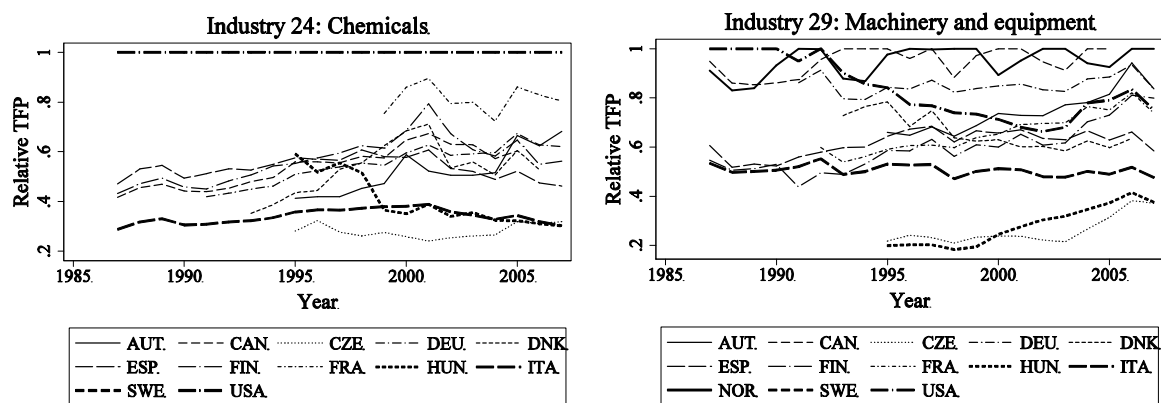
The trade intensity, M_{kij}/Q_{ij} , is derived from Input-Output tables and these are only available for three periods, the mid-1990s, the early 2000s and, the mid-2000s. Therefore, the first trade intensity is used for the period up to 1997, the second is used for the period from 1998 to 2002, and the third for the period from 2003 to 2007. The trade intensity variable is then multiplied with R&D expenditures in industry k at time t to give the variable for possible spillovers in industry i of country j , $S_{ijt}^{P,G}$.

⁶ Linear interpolation is not unproblematic. However, in this study the interpolation does not seem to affect the results in terms of the size of the estimates or the significance level.

3.3.2 Descriptive statistics

From the calculation of total factor productivity, it can be seen that the U.S. is the frontier country in 38 percent of the industry years. In some industries it is the same frontier country over the whole period, whereas the frontier country changes a lot in other industries. Figure 1 shows TFP relative to the frontier (TFP_{ijt}/TFP_{iFt}) for two industries, Chemicals and Machinery and equipment. In Chemicals, the U.S. is the frontier country over the whole period, whereas in Machinery and equipment, the frontier shifts between the U.S., Norway and Canada.

Figure 1. Relative TFP (TFP_{ijt}/TFP_{iFt})



The final sample of industries includes 205 industries and a total of 2176 observations. Table 1 displays some descriptive statistics and shows that the overall means of the two R&D intensity variables differ quite a lot.

TABLE 1

Descriptive statistics

Variable	Obs.	Mean	Sd.	Min	Max
$\Delta \ln TFP$	2176	0.02	0.15	-2.19	1.79
$\Delta \ln TFP_F$	2176	0.01	0.10	-1.37	0.41
TGAP	2176	0.57	0.52	0.00	4.03
R^P/Y	2176	0.05	0.08	0.00	0.79
R^G/Y	2176	0.01	0.03	0.00	0.37
S^P/Y	2176	0.02	0.12	0.00	2.94
S^G/Y	2176	0.00	0.01	0.00	0.30
H	2176	0.09	0.04	0.03	0.26
ΔU	2176	0.00	0.01	-0.05	0.03

To show that R&D intensities also differ a lot between industries and between countries, Table 2 contains mean R&D intensities by industry for the sample as a whole and for two sample countries, France and the Czech Republic. France is one of the countries with higher R&D intensities and the Czech Republic is one of the lower R&D intensity countries. In

general, industries with high privately funded R&D intensities also have a lot of publicly funded R&D, but there are exceptions. The chemicals industry, which includes pharmaceuticals, has a lot of privately funded R&D but not so much R&D funded by the public sector. The sector for ‘other transport equipment’, which includes the building and repairing of ships and boats, and aircraft and spacecraft manufacturing, has very high publicly funded R&D intensities because there are a lot of defence outlays in this sector.

TABLE 2

Mean R&D intensities (in percent) for all countries, France and the Czech Republic

Industry (ISIC Rev 3)	Total		France		Czech Rep.	
	R ^P /Y	R ^G /Y	R ^P /Y	R ^G /Y	R ^P /Y	R ^G /Y
15-16: Food, beverages and tobacco	0.94	0.04	1.11	0.05	0.11	0.01
17-19: Textiles, clothing and leather	0.97	0.06	0.96	0.05	0.49	0.04
20: Wood	0.41	0.05	0.32	0.04	0.02	0.00
21-22: Paper and publishing	0.64	0.03	0.35	0.01	0.06	0.02
23: Coke, refined petroleum products	2.82	0.05	4.51	0.17	0.34	0.00
24: Chemicals	10.07	0.25	17.44	0.77	3.80	0.21
25: Rubber and plastics products	2.27	0.10	6.03	0.04	1.55	0.02
26: Non-metallic mineral products	1.24	0.06	1.96	0.04	0.73	0.05
27: Basic metals	2.30	0.13	3.41	0.06	1.00	0.13
28: Metal products	1.02	0.10	0.79	0.03	0.51	0.08
29: Machinery and equipment	4.13	0.70	3.84	1.34	2.22	0.37
30: Office, accounting and computing machinery	14.69	1.43	22.77	1.89	0.44	0.00
31: Electrical machinery	4.56	0.23	8.61	0.23	1.33	0.09
32: Radio, television and communication eq.	24.57	2.08	33.41	5.68	4.06	0.61
33: Medical, precision and optical instruments	10.42	1.93	9.63	4.44	2.12	0.33
34: Motor vehicles, trailers	8.87	0.52	19.75	0.08	9.94	0.02
35: Other transport eq.	7.33	5.16	13.69	11.18	12.44	1.38
36-37: Other manufacturing; Recycling	1.03	0.04	2.37	0.05	0.58	0.03

3.4 Estimation strategy

There are several possible problems to consider in the estimation of equation (8). There are country-industry fixed effects which may be correlated with the explanatory variables. Hence, a fixed effects estimator is needed. However, equation (8) also includes an implicit lagged dependent variable in the $TGAP$ term, and using a fixed effects estimator in this situation will bias the estimate on $TGAP$ if the time dimension, T , is small (Nickell 1981). In this sample the average time span is only about ten years, which may induce quite a large bias. Moreover, there could be some problems of endogeneity. There may be common shocks, not captured by the other variables, to an industry across countries, and hence the $\Delta \ln TFP_{iFt}$ variable would be endogenous. R&D expenditures are usually assumed to be weakly exogenous in the sense that current shocks can influence future levels of R&D, but not past levels, i.e. $E((R/Y)_{ijt-1}, \varepsilon_{ijt}) = 0$. With a short time dimension, this variable will be

biased in a within groups setting. However, for publicly funded R&D expenditures, the story might differ. Because the process of getting funding can be quite lengthy and the budget for this part of the R&D expenditures is not decided upon by the industry, it could be argued that this variable is strictly exogenous.

To deal with these issues, I will use the system Generalized Method of Moments (GMM) estimator, proposed by Arellano and Bover (1995) and further developed by Blundell and Bond (1998). The system GMM uses a system of equations where lagged levels of the explanatory variables are used as instruments for an equation in first differences, and lagged first differences are used as instruments for an equation in levels. In the estimations for this paper, the variables for TFP growth in the frontier country, the technological gap and privately funded R&D are instrumented. In the first difference equation, the first lags of TFP growth in the frontier and of R&D intensities are used as instruments, whereas the first, second and third lags are used for the technological gap term. The first lag of the first differences of the variables is used for all endogenous variables in the levels equation. In all specifications, a collapsed instrument set is used to keep the instrument count down.⁷ When using the system GMM, it is also possible to test the validity of the instruments and the assumed exogenous variables with the Hansen test of overidentifying restrictions. Here, a separate test is used for each instrument subset, and the results indicate that the used instruments are all valid and that publicly funded R&D can be treated as an exogenous variable. Due to the use of lagged variables as instruments, the sample of observations is reduced to 1971 observations on 205 industries.

4 Results

Table 3 shows the estimation results for five different specifications, where the first four are simpler versions of equation (8) with different R&D variables excluded in each of them. The fifth specification includes all the variables in equation (8), and is the most preferred specification.

Starting with the main variables of interest, neither privately nor publicly funded R&D is significant in the first two specifications, but when the squared R&D terms are included, the variables become significant. Privately funded R&D expenditures show clear signs of positive but decreasing returns, whereas publicly funded R&D expenditures seem to be

⁷ See Roodman (2009) for a discussion on the importance of limiting the instrument count.

characterized by increasing returns to scale. However, the linear term is negative for publicly funded R&D, indicating that low levels reduce productivity growth.

TABLE 3
Estimation results

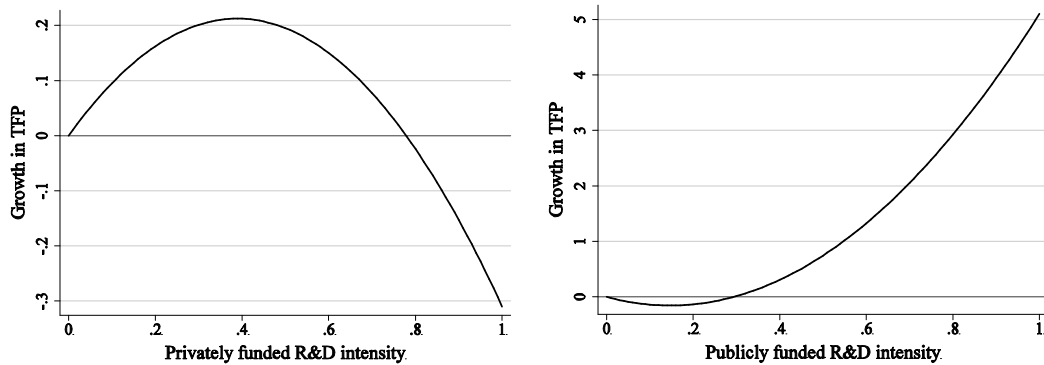
Dependent variable: Growth rate in total factor productivity					
	(1)	(2)	(3)	(4)	(5)
$\Delta \ln TFP_{iFt}$	0.10 (0.074)	0.09 (0.084)	0.10 (0.074)	0.12 (0.073)	0.12 (0.084)
$TGAP_{ijt-1}$	0.14** (0.066)	0.13* (0.077)	0.13* (0.067)	0.15** (0.066)	0.15* (0.078)
$(R^P/Y)_{ijt-1}$	0.54 (0.497)	0.42 (0.636)		1.09*** (0.386)	0.82** (0.380)
$(R^P/Y)_{ijt-1}^2$				-1.40*** (0.458)	-1.13*** (0.430)
$(R^G/Y)_{ijt-1}$	-0.36 (0.575)	-0.24 (0.660)		-2.12** (0.901)	-1.50* (0.854)
$(R^G/Y)_{ijt-1}^2$				7.22** (3.133)	5.18* (3.068)
$(S^P/Y)_{ijt-1}$		0.38 (0.250)	0.43* (0.226)		0.31 (0.213)
$(S^G/Y)_{ijt-1}$		-2.12 (1.477)	-1.67 (1.679)		-1.66 (1.591)
H_{jt-1}	0.36 (0.251)	0.33 (0.266)	0.39* (0.222)	0.36 (0.221)	0.36 (0.250)
ΔU_{jt}	0.58** (0.284)	0.51 (0.327)	0.53* (0.305)	0.62* (0.316)	0.56* (0.327)
Observations	1971	1971	1971	1971	1971
Number of industries	205	205	205	205	205
AR(1)	0.012	0.012	0.012	0.016	0.014
AR(2)	0.262	0.275	0.296	0.284	0.287
Hansen	0.630	0.681	0.656	0.657	0.840
Diff. Hansen	0.661	0.689	0.664	0.656	0.896
No. of instruments	31	33	30	34	36

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order, respectively. Hansen is the Hansen test of overidentifying restrictions. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time dummies included in all models. Instruments are discussed in the text.

The growth rate of TFP as a function of the R&D variables, following the fifth specification, is displayed in Figure 2. For privately funded R&D the effect on productivity increases up to an R&D intensity of 0.39, and then it declines and becomes negative at an R&D intensity of 0.78. About 99 percent of the industries have privately financed R&D intensities that are lower than 0.39, and could hence increase their productivity by increasing their R&D expenditures. For those levels of privately funded R&D, the rate of return ranges from 82

percent for those with no R&D to 0 percent for those with R&D intensities of 0.39. For the median industry, in terms of privately funded R&D, the results imply a rate of return of 78 percent.

Figure 2. Growth in TFP as a function of privately and publicly funded R&D



For publicly funded R&D the total effect on productivity growth is negative until the R&D intensity is above 0.29, something that is only true for about 0.1 percent of the industries in the sample. Hence, for most industries in the sample there is a negative effect on productivity from publicly funded R&D. These results are in line with the reasoning of earlier findings regarding a low or insignificant effect even though publicly funded R&D has a negative effect here. It could be that Hall et al. (2009) and Lichtenberg and Siegel (1991) are right in their interpretation that private firms are more efficient in choosing projects, but it could also be that publicly funded R&D is directed mainly towards product development, which induces a negative effect in the short run. Poole and Bernard (1992) argue that their finding of a negative rate of return (from publicly funded defence production) depends on the Canadian defence production being more closely linked to the way the market is politically managed than to the intrinsic characteristics of defence production. This reasoning is in line with that of Bönnte (2004) or Georghiou (2004) in that there could be welfare goals for public R&D other than increasing firm productivity. The negative effect may also depend on the difficulties of measuring the benefits from publicly funded R&D, as pointed out by Lichtenberg and Siegel (1991).

For the spillover variables, only the estimate for spillovers from privately funded R&D is significant, and only when the other R&D variables are excluded. Yet, it is a positive estimate of around 0.3-0.4 in all specifications. The variable for spillovers from publicly funded R&D is insignificant in all specifications. Hence, it is not possible to explain the negative effect from publicly funded R&D with the arguments of Jaffe (1998) about a higher spillover effect.

However, it may be argued that it takes much more than one period to get an effect on productivity growth from the spillover variables. For example, Bönte (2004) and Unel (2008) both use spillover variables lagged three periods. But allowing longer lags in the estimation does not change either the sign or the significance level of these variables. It may also be that the trade intensities from three points in time, taken from the input-output tables, are too static to be a good approximation of the true trade intensities.

TFP growth in the frontier country is not significant in any of the specifications. However, this variable suffers from a discontinuity problem because every time the frontier country changes, the growth rate is set to zero.⁸ Nevertheless, the rest of the results are robust both to dropping this variable and to excluding the frontier country. The technological gap variable is positive and significant in all specifications with a value of 0.13-0.15 indicating that within each industry the countries that are further behind the frontier experience higher productivity growth. This convergence rate is perhaps somewhat higher than is found in most similar empirical studies, but not disturbingly high. In a study investigating Polish manufacturing industries, Kolasa (2008) finds a convergence rate of 0.10-0.20, whereas others (see e.g. Scarpetta and Tressel 2002, Griffith et al. 2004, Cameron et al. 2005, Economidou and Murshid Antu 2008) have found everything between 0.02 and 0.11. The estimate on the technological gap variable is also a test for the system GMM estimator, because the estimate of this implicit lagged dependent variable should lie between those of the OLS and fixed effects estimators, which it does.⁹

Both the human capital variable and the business cycle variable have the expected positive signs, but the human capital variable is only significant in one of the specifications, and only on the 10 percent level, whereas the business cycle variable is significant at least on the 10 percent level in all but one of the specifications.

4.1 Effects in different subgroups of the sample

To see if the results differ among subgroups of the sample, the sample is divided based on (i) the distance to the frontier and (ii) the intensity of privately funded R&D. The first division is based on the argument that there is greater potential for R&D to increase TFP growth the further behind the technological frontier an industry is situated (Griffith et al. 2004). The second division is based on the findings that the returns to R&D differ between sectors (see

⁸ This procedure is also used by Griffith et al. (2004).

⁹ OLS gives estimates of TGAP of 0.07-0.08, and the fixed effects estimator gives estimates of TGAP of 0.20-0.22.

e.g. Bönnte 2004, Hall et al. 2009). In the first case, an industry is classified in the group that is further away from (closer to) the frontier, ‘large gap’ (‘small gap’), if the mean value of TGAP in this industry is above (below) the median over all industries. A similar procedure is used to divide the sample into high and low private R&D intensities. Table 4 shows the results from the estimations on these subgroups for the specification including all variables of interest.

TABLE 4

Large vs. small technological gaps and high vs. low R&D intensities

Dependent variable: Growth rate in total factor productivity				
	(1)	(2)	(3)	(4)
	Large gap	Small gap	High R&D	Low R&D
$\Delta \ln TFP_{iFt}$	0.02 (0.118)	0.28*** (0.085)	0.01 (0.073)	-0.07 (0.398)
$TGAP_{ijt-1}$	0.13 (0.113)	0.22*** (0.067)	0.05 (0.074)	0.01 (0.104)
$(R^P/Y)_{ijt-1}$	1.25*** (0.464)	0.44* (0.245)	1.19** (0.581)	0.61 (0.566)
$(R^P/Y)_{ijt-1}^2$	-1.43** (0.611)	-1.78*** (0.442)	0.22 (1.677)	-2.63*** (0.906)
$(R^G/Y)_{ijt-1}$	-3.04 (2.535)	-0.69* (0.382)	-2.44* (1.273)	6.71 (7.338)
$(R^G/Y)_{ijt-1}^2$	10.73 (20.436)	2.32 (1.401)	8.55* (4.682)	128.39 (555.686)
$(S^P/Y)_{ijt-1}$	0.34 (0.220)	0.53 (0.357)	0.31** (0.148)	2.77* (1.556)
$(S^G/Y)_{ijt-1}$	-1.80 (1.971)	6.63 (5.431)	-1.11 (1.063)	55.83** (26.024)
H_{jt-1}	-0.25 (0.323)	0.14** (0.069)	0.02 (0.217)	-0.17 (0.427)
ΔU_{jt}	0.74 (0.817)	0.69** (0.323)	0.34 (0.384)	0.32 (0.341)
Observations	988	983	978	993
Number of industries	105	100	107	98
AR(1)	0.043	0.009	0.012	0.111
AR(2)	0.269	0.810	0.315	0.464
Hansen	0.764	0.770	0.927	0.445
Diff. Hansen	0.724	0.535	0.762	0.397
No. of instruments	36	36	36	36

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order, respectively. Hansen is the Hansen test of overidentifying restrictions. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time dummies included in all models. Instruments are discussed in the text.

The first two columns show the results from the subgroups based on the distance to the frontier. Concerning the R&D variables, the linear and squared terms of privately funded R&D are significant in both columns, but with a higher rate of return for those industries that are further from the frontier, a result that corroborates the findings of Griffith et al. (2004). The estimate on the linear term for publicly funded R&D is again negative but only significant for those industries that are closer to the frontier, and the quadratic term is insignificant. The major differences between the two columns concern the growth in the frontier and the technological gap variable. These two variables are only significant for those industries that are closer to the frontier suggesting that an industry needs to be relatively close to the frontier to enjoy spillovers from the frontier industry and to experience convergence. Moreover, the estimate on the technological gap variable for the industries closer to the frontier is much higher than those in Table 3 when all industries are included, indicating that within this group there is faster convergence towards the frontier. This finding means that even though there is larger potential for technology transfer for industries far behind the frontier, it seems that an industry needs to be quite close to the frontier to enjoy spillovers and convergence. This reasoning is in keeping with that of absorptive capacity, as described by Cohen and Levinthal (1989, 1990); i.e. that firms or industries need to have certain capabilities to enjoy spillovers. Griffith et al. (2004) test and confirm the role of R&D for technology transfer in a similar setting to this study. However, a direct test of this hypothesis lies outside the scope of this study. Another interesting finding in this division of the sample is that the education variable is only significant for the industries closer to the frontier.

The two last columns in Table 4 show the results from the subgroups based on the intensity of privately funded R&D. For the high R&D intensity group, the linear terms for both privately and publicly funded R&D are significant with the same signs as before, as well as the quadratic term for publicly funded R&D. The quadratic term for privately funded R&D is only significant in the low R&D intensity group, and it is the only one of the industry's own R&D variables that is significant. Spillovers from privately funded R&D now seem to have a positive effect in both subgroups, and spillovers from publicly funded R&D also have a positive effect in the low R&D intensity group. This latter result corroborates the findings of Bönte (2004). Industries that do not perform much R&D themselves gain more from other industries' R&D than those industries with much R&D of their own. Another interesting result in this division of the sample is that the technological gap term is not significant for any of these subgroups. Hence, it does not appear that the R&D intensity affects the

possibilities for technology transfer, which is in contrast to the findings of Griffith et al. (2004). However, as pointed out before, their hypothesis is not directly tested in this study.

4.2 Robustness of results

To check the validity of the results several procedures have been undertaken. First, to see if certain industries or countries drive the results I separately drop one industry and one country at a time. Second, a few outliers in the dependent variable have been excluded. Third, to increase the within variation in the data, the industries with only a few observations are dropped, and fourth, I use average productivity growth as the dependent variable. These procedures are further discussed in the following paragraphs, and the results are summarized in Table 5. The general conclusion is that the significance of the technological gap term and that of the quadratic terms of R&D intensities are not very robust, whereas the rest of the results are quite robust.

Dropping one industry at a time from the sample shows that the significance of the variables for publicly funded R&D is not quite as robust as for privately funded R&D, but the size of the estimates is very similar throughout. Dropping one country at a time instead, gives similar conclusions to dropping one industry at a time. Significance for publicly funded R&D disappears in some estimations, but is always close to the 10 percent level. Significance for the technological gap variable also disappears in some cases. This variable is originally only significant on the 5 or 10 percent level and this exercise, together with the results shown in Table 4, suggests that this variable is somewhat sensitive to the chosen sample.

Concerning outliers, there are a few possible outliers in the dependent variable. Excluding these observations again makes the technological gap variable insignificant, as can be seen in columns (1)-(3) in Table 5. The variable for spillovers from privately funded R&D is now significant with a similar estimate to those presented earlier. The rest of the variables are in general unaffected by this procedure, except that both privately and publicly funded R&D are significant in the first specification.

In the analysis the average time span of data on an industry is about ten years, but the shortest time span is only three years, which makes it difficult to capture the within variation over time. Gradually excluding the industries with the shortest time spans does not affect the results much. The quadratic R&D terms lose their significance after a while, but the estimates are similar and the linear terms are significant with the same signs as previously displayed; privately funded R&D is now also significant in the first two specifications. Again, the

estimate on the technological gap variable becomes insignificant after a while. Moreover, the estimate for TFP growth in the frontier turns up significant in some of the estimations. Columns (4)-(6) in Table 5 show the estimates when there are at least eight observations for each industry.

TABLE 5
Results from robustness checks

Dependent variable: Growth rate in total factor productivity									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Outliers removed			At least eight observations			Averages		
$\Delta \ln TFP_{ift}$	0.10 (0.066)	0.03 (0.081)	0.04 (0.069)	0.13* (0.065)	0.10 (0.072)	0.12* (0.064)	0.19** (0.082)	0.15* (0.080)	0.18* (0.095)
$TGAP_{ijt-1}$	0.09 (0.068)	-0.01 (0.114)	-0.00 (0.075)	0.12* (0.074)	0.10 (0.080)	0.10 (0.074)	0.03 (0.027)	0.00 (0.031)	0.02 (0.027)
$(R^P/Y)_{ijt-1}$	1.20*** (0.370)	0.59 (0.633)	1.10*** (0.418)	0.86* (0.492)	0.92** (0.427)	0.97** (0.485)	0.55*** (0.143)	0.52*** (0.157)	0.37 (0.274)
$(R^P/Y)_{ijt-1}^2$			-1.05** (0.488)			-0.22 (1.484)			-0.11 (0.641)
$(R^G/Y)_{ijt-1}$	-0.94* (0.495)	-0.33 (0.593)	-1.93** (0.977)	-0.88 (1.117)	-0.98 (1.021)	-3.99** (1.600)	-2.10** (0.894)	-2.25** (0.946)	-4.01* (2.198)
$(R^G/Y)_{ijt-1}^2$			6.39* (3.438)			18.89** (7.466)			35.10 (25.134)
$(S^P/Y)_{ijt-1}$		0.56 (0.438)	0.51** (0.225)		0.20 (0.506)	0.24 (0.466)		0.19 (0.130)	0.37*** (0.133)
$(S^G/Y)_{ijt-1}$		-1.33 (1.654)	-0.95 (1.294)		-0.84 (3.877)	-1.01 (3.580)		-0.52 (1.241)	-2.53** (1.077)
H_{jt-1}	0.07 (0.249)	-0.12 (0.302)	-0.13 (0.228)	0.43 (0.311)	0.34 (0.333)	0.35 (0.320)	-0.01 (0.120)	-0.13 (0.141)	-0.08 (0.090)
ΔU_{jt}	0.49* (0.275)	0.05 (0.511)	0.07 (0.307)	0.44 (0.353)	0.37 (0.353)	0.40 (0.361)			
Observations	1960	1960	1960	1563	1563	1563	238	238	238
No. of industries	205	205	205	129	129	129	79	79	79
AR(1)	0.000	0.000	0.005	0.026	0.029	0.031	0.097	0.087	0.083
AR(2)	0.263	0.294	0.295	0.307	0.315	0.328	0.493	0.470	0.291
Hansen	0.503	0.295	0.490	0.613	0.624	0.704	0.536	0.445	0.254
Diff. Hansen	0.796	0.319	0.560	0.964	0.977	0.980	0.894	0.736	0.430
No. of instruments	33	33	36	31	33	36	36	38	45

Robust standard errors in parentheses. The finite-sample correction to the two-step covariance matrix, derived by Windmeijer (2005), is used. ***, **, * Coefficients are significant on the 1, 5 and 10 % levels respectively. AR(1) and AR(2) are tests for autocorrelation of first and second order, respectively. Hansen is the Hansen test of overidentifying restrictions. Diff. Hansen is the difference in Hansen test for the validity of the GMM type instruments. P-values are reported for these tests. Time dummies included in all models. Instruments are discussed in the text except for column (1), which also uses the second lag of privately funded R&D in the first difference equation, and for columns (7)-(9) where the instrument set is not collapsed due to the short time span.

Instead of using R&D variables lagged more than one period, another way to approach the question of the time it takes for R&D to affect productivity is to use R&D against average productivity growth over several years. Therefore, the dependent variable and contemporaneous TFP growth in the frontier are averaged over one 5-year period and four 4-

year periods, and for the other variables the values for the first year in the period are used. This procedure heavily reduces the sample to only 79 industries and 238 observations. Columns (7)-(9) in Table 5 display the results from this estimation. The R&D variables have the same signs as before, and again both privately and publicly funded R&D are significant in the first two specifications. In column (9), however, only the linear term for publicly funded R&D is significant. But both estimates for the spillover variables are now significant with a positive sign for privately funded R&D and a negative sign for publicly funded R&D. The technological gap term is again insignificant whereas the estimate on TFP growth in the frontier is significant on the 10 percent level with a value of 0.15-0.19. The results concerning both the spillover variables and TFP growth in the frontier indicate that it takes some time for both R&D and technology from the frontier to spill over to the other industries.

In sum, the first results, presented in Table 3, are in general robust in several aspects. However, both the technological gap term and the squared R&D terms are sensitive to the chosen sample. In addition, this analysis has given some support for the existence of positive spillovers from privately funded R&D.

5 Conclusions

This paper has examined the productivity effects from privately and publicly funded R&D in a panel of manufacturing industries in 13 OECD countries, at the same time as controlling for endogeneity of the variables. The importance of privately funded R&D for industry performance is confirmed. For most of the industries in this sample, privately funded R&D is found to have a private rate of return between 0 and 82 percent whereas publicly funded R&D has a negative private rate of return, but the significance of this variable is somewhat sensitive to which countries or industries are included. The results concerning publicly funded R&D are also in line with previous research, which in general has found a low, insignificant or negative effect.

Looking at the spillover effects of R&D from these two sources of funds, there is some evidence that there is a positive, and quite large, effect from privately funded R&D whereas the estimate on the spillover variable from publicly funded R&D is almost always insignificant, or even negative. Thus, it does not seem that the public funder of R&D manages to find the projects with the highest private rates of returns, disproving the David et al. (2000) contention that it might do in order to ensure the success of the public funding program. Neither does it seem to find the projects with the largest spillover gap, in contrast to

the claim by Jaffe (1998). However, it may still be that Jaffe is right, but that we do not see the positive spillover effects on this time horizon.

As previously discussed, it may be that the government primarily has goals other than increasing productivity when funding business R&D. This reasoning would explain a lower or an insignificant effect, but not a negative one. The negative effect of publicly funded R&D may hence be a result of private firms being less efficient in spending the public funds or mainly using them for product development.

As mentioned in the introduction, the OECD countries have diminished their share of publicly funded R&D by quite a lot during the time period of this study. A reason for this reduction might be the lack of results of positive effects and the fear of substituting private R&D expenditures.

This study only deals with publicly funded R&D that is performed in the business sector. The effects of publicly funded R&D that is also performed in the public sector is another question where other results might emerge.

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