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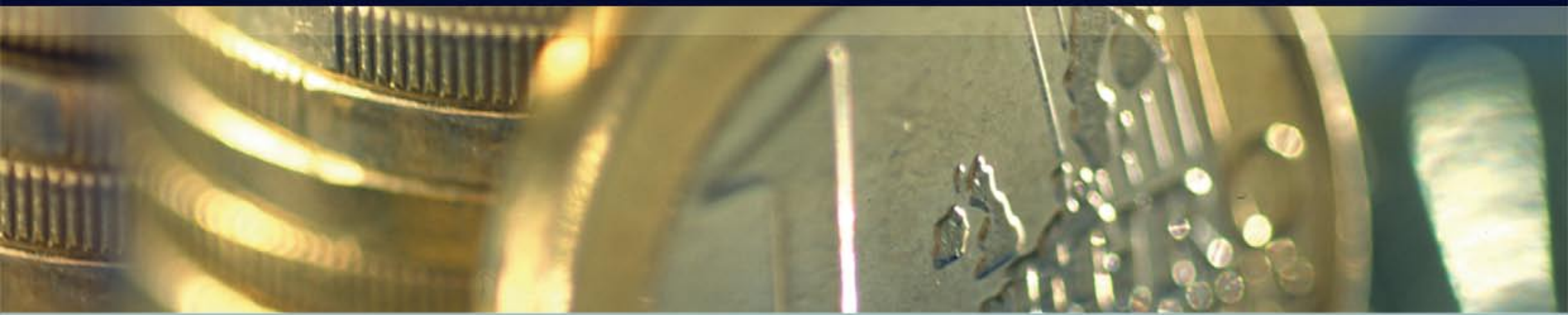

Efficiency of public spending in support of R&D activities

Michele Cincera, Dirk Czarnitzki and Susanne Thorwarth

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Efficiency of public spending in support of R&D activities[1]

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Abstract

This study aims at assessing the level of efficiency of public R&D spending and public R&D support for private R&D and to compare efficiency scores among OECD countries, in particular EU Member states over the past two decades. The analysis rests on the concept of efficiency which is based on the relationship between public R&D spending and the additional R&D in the business sector induced by such measures. The differences observed in efficiency performance across countries is then explained in relation to control variables, e.g. exogenous framework conditions.

Given the different specifications considered and the two methods implemented, i.e. Stochastic Frontier and non-parametric Data Envelopment Analysis, results inevitably diverge and in some cases to a large extent. Some results are nevertheless robust and consistent through the different methods and model specifications.

For the efficiency scores, three groups of countries emerge. The first group refers to the most efficient countries in terms of R&D public support, namely Australia, Canada, Finland, Germany, Japan, Netherlands, New Zealand, Singapore, Switzerland, and the USA. The second group is composed by France, Hungary, Italy, Korea, Norway, Sweden, Spain and the United Kingdom. The third group of the less efficient countries in terms of R&D public spending includes China, Croatia, Czech Republic, Israel, Latvia, Poland, Romania, Russia, and the Slovak Republic.

In terms of the determinants explaining these performances, conditional efficiency scores are found to be higher in the most industrialized countries worldwide. In terms of GDP per capita, countries in an intermediate position are characterized by lower efficiency scores of their public R&D support funding. Unsurprisingly countries with the best performance in terms of innovative activities are also the ones that exhibit the highest efficiencies of their public R&D support, while higher government expenditures in percentage of total consumption are associated with lower performance in terms of efficiency. In terms of industrial structure, economies with a higher share of high-tech manufacturing sectors in the total manufacturing value added benefit from higher efficiency performance of their public R&D supporting policy instruments while economic growth does not seem to affect efficiency scores.

In terms of regulatory and macroeconomic conditions, a positive and significant impact is observed on the efficiency scores of a more favourable tax regime to international trade, of more deregulation in the labour and business markets as well as of the strength of the Intellectual Property Right System. On the other hand, access to sound money does not appear to positively affect public R&D efficiency. The share of the general government consumption in percentage of total consumption negatively affects the efficiency scores and as expected countries with high inflation rates appear to be less efficient.

Finally, there seems to be no unique public strategy that determines high efficiency levels and more general conclusions about “optimal” policy mixes with respect to public R&D would require to go beyond the pure macroeconomic level.

Keywords

Public, private R&D, (determinants of) efficiency, framework conditions, SFA, DEA.

JEL-codes: E22, O31, O57

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Executive Summary

The objective of the study is to explore the possibility of using quantitative methods to assess efficiency of public R&D with respect to stimulating private R&D at the macroeconomic level. The study sought to make use of readily available indicators and statistics to measure the level of efficiency of public R&D spending and public R&D support for private R&D and to compare efficiency indices among OECD countries, in particular the EU member states. In order to do so, the study makes use of macroeconomic data from the recent two decades. The analysis rests on the concept of efficiency which is based on the relationship between public R&D spending (inputs) and the additional R&D in the business sector induced by such measures (output). As such the study can be considered as a first step of the analysis of the effects of R&D on the outcomes of such activities, e.g. output or TFP growth.

The differences observed in efficiency performance across countries can then be explained in relation to control variables. Among those are exogenous framework conditions, e.g. the nature of competition, the quality of the business environment, the IPR regime, the access to market and to external financing conditions, etc. Based on the results obtained, it is assessed whether quantitative efficiency analysis at the country level is suitable to draw conclusions on recommendations for reinforcement or retargeting innovation policy to meet the national goals of the revised Lisbon agenda.

This study uses two main methods that have been widely used in the literature, namely a parametric regression approach, the Stochastic Frontier Analysis (SFA), and a non-parametric method called Data Envelopment Analysis (DEA). Both methods relate the output, i.e. private R&D spending (BERD) and alternatively the R&D personnel employed in the business sector, to inputs. The study considers public R&D funding in the business sector including other direct payments towards R&D from government to industry (BERDBYGOV), expenditures on higher education research and development (HERD) and R&D conducted in public labs (GOVERD) as relevant input measures. Both methods estimate an efficiency term, that is, the extent of slack in government expenditures. In other words they allow the estimation of efficiency frontiers and efficiency losses.

The obtained technical efficiency scores of public R&D spending across countries can then be explained by exogenous factors or framework conditions varying across countries in a second stage. While the SFA allows to simultaneously estimate the R&D equation and the efficiency terms, Tobit models are used after unconditional efficiency scores are calculated with DEA. By applying the DEA and the SFA method, this study uses two approaches which represent the most commonly used in the literature to assess the efficiency of public spending at the macroeconomic level.

The Stochastic Frontier Analysis is conducted by estimating cross-sectional estimations, i.e. using only one-time period, as well as panel models, i.e. using all time periods at once. It turned out that the variables BERDBYGOV and HERD always have a positive impact on private R&D (BERD) and R&D personnel employed in the business sector, and that the

estimated coefficients have a reasonable and meaningful magnitude. However, the sample of countries is too small to detect statistically significant inefficiencies in a single time period. In other words the small sample size of the cross-section does not allow to estimate inefficiencies with enough precision, so that we only find insignificant estimates of the efficiency index. Even in the panel data models, the SFA does not detect significant unconditional inefficiencies, that is, if the efficiency term is not related to certain country characteristics, the SFA does not report statistically significant inefficiencies. In a final step we apply panel regressions in which we assume that the conditional mean of the inefficiency term depends on covariates. Contrary to the former results we now find interesting differences across countries' efficiencies based on the choice of the dependent variable (BERD or R&D personnel). Results indicate that the inefficiency is highest in EU15 countries when it comes to R&D employment in the business sector as reaction to public R&D spending either as subsidies or R&D performed in the public sector.

The results improve further if we apply more structural variables rather than ad-hoc country groupings. It turns out that index variables, such as the access to sound money and the legal structure and security of property rights, point in the same direction for both dependent variables, BERD and R&D employment: the better the index, the higher is the efficiency in a country's R&D investment in the business sector as response to public R&D.

The DEA analysis which is conducted by using an one-output three-input framework leads to the result that - averaged over five time periods - 3 countries out of 21, namely Japan, Switzerland and the United States are ranked in the first position and lie on the production possibility frontier. The other countries are inefficient in the sense that given their combination of inputs they achieve a lower amount of output as compared to the efficient countries which use similar combination of inputs. Regarding the evolution of efficiency scores over time it turns out that Japan, Switzerland and the United States are the three countries which are efficient for each of the five sub-periods. This is also the case for Ireland and Iceland, except for the last sub period. For the other countries, efficiency scores appear to decline over time. This drop is more pronounced for countries like Austria, Italy, Spain and Norway. On the contrary, France, Germany and Sweden are characterized by a relative small decline of their efficiency scores. Finally, Canada and Denmark are the only two countries which improve the efficiency of their public R&D over time.

Applying the DEA over the more recent time period substantially increases the number of countries in the sample. Japan, Switzerland and the United States are still among the top efficient countries and some new Member States are listed among the most efficient countries (Cyprus, Estonia, Lithuania, Malta) and other among the less efficient ones (The Slovak Republic, Latvia and Poland). The unique situation of some of these transition economies, the crowding in effect through the wages of the R&D personnel may explain their lower efficiency performance while the small size of some of these countries tends to overestimate their efficiency.

In terms of the impact of different determinants to explain differences in DEA efficiency scores across countries, conditioning the scores on different country groupings partly confirm the crownding out/in effects. Conditional efficiency scores are also found to be higher for the most industrialized countries worldwide. In terms of GDP per capita, countries in an intermediate position are characterized by lower efficiency scores of their public R&D support funding. Unsurprisingly countries with the best performance in terms of innovative activities are also the ones that exhibit the highest efficiencies of their public R&D support, while higher government expenditures in percentage of total consumption are associated with lower performance in terms of efficiency.

In terms of regulatory and macroeconomic conditions, we observe a positive and significant impact of a more favourable tax regime to international trade as well as more deregulation in the labour and business markets on the efficiency scores. Access to sound money does not appear to positively affect public R&D efficiency. The share of the general government consumption in percentage of total consumption negatively affects the efficiency scores and conversely for the legal structure and security of property rights. Then as expected countries with high inflation rates appear to be less efficient while economic growth does not seem to affect efficiency scores.

In terms of administrative, institutional and business conditions that enhance R&D activities in the private sector and affect the efficiency of public R&D policies, results as regards the former were inconclusive. In terms of industrial structure, economies with a higher share of high-tech manufacturing sectors in the total manufacturing value added benefit from higher efficiency performance of their public R&D supporting policy instruments. The importance of public procurement advertised in the Official Journal as a percentage of GDP and as a percentage of total public procurements as well as the strength of the IPR system negatively affect the efficiency performance. Yet, as regards IPR, this result must be mitigated as a positive impact is found for the EU15 Member states and the most advanced countries in the world.

To sum up, given all these different specifications it appears that the results inevitably diverge and in some cases to a large extent. Some results are nevertheless robust and consistent through the different methods and model specifications. For the efficiency scores it has been shown that three groups of countries emerge. The first group refers to the most efficient countries in terms of R&D public support. The countries that belong to this group are Australia, Canada, Finland, Germany, Japan, Netherlands, New Zealand, Singapore, Switzerland, and the USA. The second group is composed by France, Hungary, Italy, Korea, Norway, Sweden, Spain and the United Kingdom. The third group of the less efficient countries in terms of R&D public spending includes China, Croatia, Czech Republic, Israel, Latvia, Poland, Romania, Russia, Slovak Republic. On the one hand, one can attempt to explain the differences in efficiency performance by the possible presence of crowding-in or crowding-out effects of the public R&D support depending on certain country characteristics. For example, countries with low BERD may turn out to be inefficient when the efficiency of *public spending is considered. However, a low level of wages of R&D personnel and the relatively abundant stock of researchers and scientists in these countries may result in a relatively large employment effect compared to e.g. EU15 member states (where wages are higher and unemployment among scientists may be relatively low) when public spending is extended. On the other hand, it is questionable if the results are suitable enough to draw these conclusions as, first, the DEA and SFA results are not always comparable due to different assumptions underlying the estimations (which cannot be tested), second, macroeconomic country data may not necessarily be sufficient to judge about inefficiencies without a detailed case-by-case study of the underlying policy mix, that is, a careful review of the different policy schemes at work and countries' industry composition, the composition of the public science sector in terms of weaknesses and strengths of the research disciplines in comparison to other countries, and finally the match or mismatch between foci of business and public R&D in a country.*

1. Introduction

As a matter of fact, the scarcity of public expenditures is strengthened by the increased needs stemming from the ageing of the population and by a growing tax competition among industrialized countries. Moreover, the Stability and Growth Pact prevents EU Member States to run into 'excessive' deficits. Since public funds are scarce, available resources should be used as efficient as possible. Therefore, governments are drawing an increased attention on how to use public resources in the most efficient and effective ways and on analyzing the main factors affecting efficiency and effectiveness of public expenditures. Then, the role of Research and Development (R&D), and more generally of technological and innovative activities on economic growth, has been examined extensively in the economic literature for several decades. The ability to understand, exploit and adapt to a rapidly changing technological environment is seen to be a key factor to improve the standards of living and the prosperity of a nation. New and better products produced by firms allow them to gain market shares, while process R&D allows firms to make cheaper products, reduce their production costs and increase the overall performance of their total factor productivity (TFP).

The objective of the study is to develop an analytical framework empirically implementable to assess the efficiency of public R&D instruments, i.e. direct subsidies, public procurement, tax incentives and R&D performed in the public sector, to support firms' R&D and innovation related activities. The study, which can be defined within the broader context of the analysis of the efficiency of both public and private R&D spending in terms of stimulating productivity and growth, seeks to collect readily available indicators and statistics to measure the level of efficiency of these instruments and compare them in the EU-27 Member States, Japan, China and the US and over the last two decades. The study rests on the concept of efficiency which is based on the relationship between policy instruments to increase firms' R&D activities (inputs) and the additional R&D induced by such measures (output). As such the study can be considered as a first step of the analysis of the effects of R&D on the outcomes of such activities, e.g. output or TFP growth.

The differences observed in the levels (and changes) of efficiency performance across countries can then be explained in relation to control variables among which exogenous framework conditions, e.g. the nature of competition, the quality of the business environment, the IPR regime, the access to market and to external financing conditions, etc. Based on the results obtained, conclusions and recommendations are formulated to increase the efficiency of public spending for the Member states in the context of their national targets for R&D activities following the revised Lisbon strategy of 2005.

The plan of the study is as follows. Section 2 proposes a survey of the literature assessing the performance and efficiency of public expenditure in general and R&D in particular. Section 3 defines some concepts relating to inputs, output and outcomes and discusses some issues regarding the assessment of their efficiency. Section 4 discusses the empirical framework to assess the efficiency of public spending on R&D. Section 5 describes the data sources and indicators used in the study and presents some descriptive statistics. Section 6 presents the empirical findings based on the Stochastic Frontier Analysis (SFA) and the Data Envelope Analysis (DEA) as regards the efficiency of public expenditures to support R&D activities in the private sector as well as the results as regards the impact of the framework determinants and business conditions affecting the efficiency of the public R&D policies.

2. Survey of the empirical literature[3]

Several approaches for measuring the efficiency of governmental expenditures have been proposed in the literature. Studies dealing with efficiency of government spending use three main categories of methods, namely composite indicators, non-parametric methods and stochastic methods[4].

2.1. Studies assessing the efficiency of public spending

Non-parametric production frontier techniques, more precisely Free Disposable Hull (FDH) analysis and/or DEA methods estimate the extent of slack in government expenditures, in other words they allow the estimation of efficiency frontiers and efficiency losses. Both methods are linear programming based techniques that are able to convert multiple input and output measures into a single comprehensive measure of productive efficiency or productivity for the particular decision making units (DMUs), e.g. firms, non-profit or public organisations. In the FDH framework, it is possible to rank the efficiency of producers by comparing each individual performance with a production possibility frontier. Along this possibility frontier it is possible to observe the highest possible level of output for a given level of input and conversely it is also possible to determine the lowest level of input necessary to attain a given level of output. Likewise, the DEA method can be conducted for calculation of technical efficiency measures. Contrary to FDH, the DEA analysis assumes a convex production function which makes DEA more stringent than FDH. Thus, a country that is efficient under FDH is not always efficient under DEA whereas a country which is efficient under DEA will be always efficient under FDH[5].

Afonso et al. (2006) mention different studies that investigated the performance and efficiency of the public sector and its functions using non parametric methods. These studies find significant inefficiencies in many countries[6]. Most of them deal with the efficiency of

[3] See Appendix 1 for a summary of the main findings of the studies presented in this section.
[4] See Section 4 for further details.
[5] Further details on these methods are provided in Section 4.1.
[6] Studies include Gupta and Verhoeven (2001) for education and health in Africa, Clements (2002) for education in Europe, St. Aubyn (2002) for education spending in the OECD, Afonso et al. (2006) for public sector performance expenditure in the OECD, Afonso and St. Aubyn (2005a, b) for efficiency in providing health and education in OECD countries. De Borger et al. (1994), De Borger and Kerstens (1996), and Afonso and Fernandes (2006) find evidence of spending inefficiencies for the local government sector. Afonso and St.

public spending on education and health. For example, the FDH analysis to assess the efficiency of government expenditure on education and health is used by Gupta and Verhoven (2001), St. Aubyn (2002) and Clements (2002) where the latter one only deals with the efficiency of education spending. Clements (2002) discusses the efficiency of education spending in the European Union and compares their performance with a larger set of OECD countries. His dataset consists of data from 1996 onwards for 20 countries from the OECD where 12 are from the European Union. Using two input indicators (spending per student as a share of per capita GDP and the share of educational expenditure to GDP adjusted for cross-country differences in the school age population) and two output indicators (percentage of people that completes secondary education at a normal graduation age and test scores on international examinations at the eight grade) shows that about 25 percent of education spending of countries belonging to the European Union are wasteful compared to the "best practices" observed in the OECD countries.

The FDH method is also used by Afonso et al. (2003) who examine the performance and the efficiency of the public sectors of 23 industrialised OECD countries for 1990 and 2000. Since the measurement of public sector performance (PSP) and public sector efficiency (PSE), however, is still very limited, they provide a proxy for measuring PSP and PSE. The public sector performance (PSP) indicator consists of seven sub-indicators whereas the first four look at administrative, education, health and public infrastructure outcomes and the three other sub-indicators reflect the "Musgravian"[7] tasks for government, namely distribution, stability and allocation (See Appendix 2). The PSP indicator is then compiled by giving equal weight to each sub-indicator and in order to facilitate the compilation the values are normalised and the average for all indices is set equal to 1. Public sector efficiency (PSE) is calculated by weighting public sector performance by the amount of relevant public expenditure[8]. Unlike the PSP indicators which show only moderate differences across industrialised countries, there are important differences across countries in the PSE indicators suggesting diminishing marginal products of higher public spending. The results indicate that the most efficient countries are the US, Japan and Luxembourg. Furthermore, small governments tend to show better results. To be more precise and regarding the 15 EU countries the average input efficiency is 0.73 which means that these countries are able to attain the same output level using only 73 percent of their currently used input. The output efficiency score is 0.82 which indicates that with given public expenditure, public sector performance is only 82 percent of what it could be if the EU was on the production possibility frontier.

Aubyn (2005b) applied a two-step DEA/Tobit analysis to examine the efficiency of secondary education across countries.

[7] The 'Musgrave Three-Function Framework' which was developed by Richard Musgrave in his work 'The Theory of Public Finance' (1959) suggests that government activity should be separated into three functions macroeconomic stabilization, income redistribution, and resource allocation.

[8] Additionally to total public spending, the average spending on goods and services, transfers, functional spending on education and health and public investment were also taken into account. In order to compute efficiency indicators, public spending was also normalised across countries with the average taking the value of one for each of the six categories.

Both methods, FDH as well as the DEA approach are used in studies conducted by Afonso and St. Aubyn (2005b) as well as Herrera and Pang (2005). Both studies deal with the efficiency in the education and health sector. Afonso and St. Aubyn (2005b) finally arrive at the conclusion that results using DEA were broadly comparable to results using FDH. Herrera and Pang (2005) additionally use a censored Tobit regression model to analyse the relationships between the efficiency scores and environmental variables. As the dependent variable, the input efficiency score already calculated with the DEA method is used. Several variables, such as the size of government expenditure, urbanization, income distribution inequality etc. are included as independent variables. This second stage analysis of the paper verifies statistical associations between the environmental variables and the efficiency scores. Afonso et al. (2006) also extend their analysis about public sector efficiency in the new EU member states. The computed DEA output efficiency scores are used to evaluate the importance of non-discretionary inputs via a Tobit regression where output efficiency scores are regressed on several non-discretionary factors. The results confirm the authors' hypothesis that environmental factors, such as the security of property rights, per capita GDP, the competence of civil servants and the education level of people positively affect expenditure efficiency.

Evans et al. (2000) as well as St. Aubyn (2002) also use parametric methods to examine efficiency on health and education. Evans et al. (2000) argue that since neither the maximum (frontier) nor the minimum levels of health are observable they have to be estimated. Thus, first of all a corrected ordinary least squares (COLS) procedure is then applied to estimate the minimum health level for 1997. Applying COLS a production function is first estimated using OLS and then shift up the OLS intercept parameter by the value of the largest positive residual to give the equation for the frontier. This ensures that all data points lie below the estimation frontier. In a next step a full translog model is estimated by using fixed effects. The fixed-effects model is a variable intercept model which means that there is a different intercept for each country. The country with the maximum intercept is taken as the reference country (frontier) and technical efficiency can be measured by the distance from this maximum. The results indicate that efficiency is positively related to health expenditure per capita, especially at low expenditure.

2.2. Efficiency of R&D policies

David et al. (2000) provide an extensive review of econometric studies over the 1965-2000 period on the effects of publicly-financed R&D expenditure in the private sector at different levels of aggregation. Studies at the meso- and macro levels tend towards complementarity instead of substitution (crowding out) between publicly- and privately-financed R&D-expenditure. Yet, these studies tend to overestimate the complementarity effect since they concentrate on R&D expenditures which include the upward effect (higher wages) due to the crowding out effect. Results based on studies at the micro or plant level are more mitigated. Studies focusing on US data find evidence of a substitution effect while for non US countries, a complementarity effect seems to predominate.

The cross-country study by Guellec and van Pottelsberghe (2003) suggests a complementarity between public funds to support R&D in the private sector. Furthermore, R&D expenditure performed in the public sector, in particular in the defence sector, appears to crowd out private R&D. Building up on this model, Falk and Leo (2006) investigate the effects of different public support channels on the R&D spending in the business sector of 15 Western European countries, putting a focus on the case of Austria. Contrary to Guellec and van Pottelsberghe (2003), they use four-year averages instead of annual data and estimate their approach by using the fixed effects method and the generalized method of moments (GMM) estimator. They conclude that although direct government subsidies to R&D performing firms unfold great leverage effects, the dynamics of output growth as well as the R&D prone high tech structure seem to be more important drivers of the R&D intensity in the business sector.

To the best of our knowledge, studies based on non parametric methods and examining the efficiency of R&D policies at the macro level in particular have not been performed yet. Though the studies of Lee and Park (2005) as well as those by Wang and Huang (2007) and Zabala-Iturriagagoitia et al. (2007) are not directly concerned with the assessment of public R&D efficiency, it is worth surveying them since they are three of the few studies at the macro level measuring R&D productivity at the national level by using the DEA method[9]. Lee and Park (2005) investigate a two inputs (R&D expenditure, average number of researchers) and three outputs (technology balance of receipts, number of scientific and technical journal articles published and number of triadic patent families) framework and cover 27 countries whereas the focus lies on analysing the performance of the Asian states for the period 1994-1998 with their analysis. Lee and Park (2005) state that the objective of R&D lies in increasing outputs rather than decreasing inputs and therefore only apply the output-oriented models. Furthermore, in a second phase the 27 countries are grouped into four clusters by output-specialized efficiency, namely inventors, merchandisers, academicians and duds. The results indicate a very low R&D efficiency level of China, Korea and Taiwan and a high efficiency of Singapore which seems to be due to the high technology balance of receipts –oriented efficiency. The authors also state that Japan will be able to obtain much more outputs even with a slight improvement in R&D efficiency since it possesses a large R&D scale.

Wang and Huang (2007) address the relative efficiency of R&D activities across 30 countries (23 OECD members, 7 are non-OECD economies). They treat R&D capital stocks and manpower as inputs and use patents and academic publication as output measures. Like Herrera and Pang (2005) as well as Afonso et al. (2006) they use Tobit regressions to control for the external environment. The Tobit regressions include the enrolment rate of tertiary education, the PC density and the index of English proficiency as regressors to control for the effects of higher education, PC popularity etc. on R&D efficiency. The estimation results show that an increase in the enrolment rate of tertiary education as well as better English

[9] While our study is concerned with the assessment of the efficiency of R&D policies on R&D activities carried out in the private sector, the papers of Lee and Park (2005) and Wang and Huang (2007) investigate the relationship between firms' R&D activities and their technological and economic outcomes, while Zabala-Iturriagagoitia et al. (2007) assess the performance of regional innovation systems.

skills of a country's R&D personnel improve the efficiency of R&D. However, the PC density variable shows no significant result which implies that the popularity of PCs in a country does not contribute substantially to reducing R&D slack directly. Using the DEA approach leads Wang and Huang (2007) to the conclusion that less than one-half of the countries are fully efficient in R&D activities. Zabala-Iturriagagoitia et al. (2007) use the DEA analysis to evaluate the regional innovation performance based on information provided by the European Innovation Scoreboard (EIS) for the years 2002 and 2003. They use several input indicators, namely higher education, lifelong learning, medium/high-tech employment in manufacturing, public R&D expenditure, business R&D expenditure and high-tech patent applications to the European Patent Office (EPO) and as an output measure regional GDP per capita. The results show that the higher the technological level of a region, the greater is the need for system coordination. They are compared with those obtained by using the Revealed Regional Summary Innovation Index (RRSII) index which is recommended by EIS to measure the progress of the EU in innovation activities. The authors show that the use of these two different approaches yield to different results, however, they conclude that different approaches should be seen as complementarities for policy makers to obtain a comprehensive picture of regional innovation systems and to enrich the knowledge base for future policy decision-making.

2.3. Determinants of the efficiency of R&D activities and policies

Jaumotte and Pain (2005a) use panel regressions for 20 OECD countries over the period 1982 – 2001 to assess the effects of innovation policies and framework factors on business R&D intensity and patenting. Intuitively, the performance of the aggregate economy, the level of the real interest rates, the development of the financial markets, the degree of regulation and competition as well as the international openness of an economy (see Table 1 for an overview of the variables used in their regressions) will influence the attempt and desire of a firm to invest in new ideas and technologies.

First of all, macroeconomic factors seem to be clearly important for the understanding of the evolution of business R&D expenditure. R&D activities are sensitive to cyclical conditions as well as to a robust output growth and a low and stable inflation which have a positive influence on the growth rate of the R&D expenditure. To sum it up, investment in R&D is fostered by a stability oriented macroeconomic framework. Jaumotte and Pain (2005b) also highlight the potential sensitivity of R&D expenditures to the availability of external as well as internal finance. Many studies suggest that capital imperfections affect investment in R&D[10]. Several studies also deal with the sensitivity of R&D expenditure to cash flow in the United States, Japan, the United Kingdom, and a number of countries in the European Union (Hall and van Reenen 2000). However, the results are mixed. To be more precise, R&D appears to be more sensitive to cash-flow in the United States, the United Kingdom and Ireland than in other economies.

[10] see Hall and van Reenen (2000) for an overview.

Jaumotte and Pain (2005a) also include product and labour market regulations as well as restrictions on inward foreign direct investment in their regressions. They argue that enhanced product market competition can provide incentives to innovate and escape competition. However, this is only possible up to a certain point, after which the prospective rents from innovation begin to reduce. Labour market regulations could constrain the firms' ability to undertake innovation-driven workplace re-organizations, but could also foster incremental process innovations since there is specialist knowledge in the workforce which has considerable company and occupation-specific experience. According to Jaumotte and Pain (2005c) many cross-country studies of economic growth emphasize the importance of the diffusion of both codified and tacit knowledge across national borders. Nevertheless, the effect of restrictions on inward foreign direct investments is also ambiguous. On the one hand they may slow the rate at which foreign knowledge is brought into national economies and on the other hand they can provide a more favourable environment for future innovators amongst national firms, especially in large economies.

Table 1 Framework conditions on Business R&D

GDP Growth
Consumer price inflation
Real interest rate
B-index
High level of financial development
Ratio of bank credit plus stock market capitalization to GDP
Corporate profits or Profit share of GDP
Indicator of product market regulation
Indicator of employment protection legislation
Indicator of strength of FDI restrictions
Trade openness adjusted for population size
Real exchange rate
Ratio of import to weighted domestic final expenditure
Ratio of (trade-weighted) foreign R&D stock to GDP
Share of hi-tech industries in GDP
Share of scientists and engineers in total employment
Index of strength of intellectual property rights
R&D expenditures in the non-business sector (flows)
Government funding of business sector R&D
Business funding of non business R&D
Public procurement as % of GDP
Fundamental research as % of total R&D expenditures
Defence R&D in % of total R&D expenditures

Another set of important determinants which may influence business R&D are variables dealing with the influence of specific science policies and institutions, e.g. R&D in the non-business sector, direct government subsidies for private sector R&D, support for intellectual property rights, industrial structure, human resources available for science and technology etc. Jaumotte and Pain (2005a) emphasize that there might be some important trade-offs between these factors, which means that some policies lead to the crowding out of the real resources available for R&D in the business sector. The authors also conclude in another paper (2005c) that fiscal incentives can be effective, especially when firms face financial constraints, but their overall impact on innovation appears comparatively small. On average, tax relieves for private R&D are found to provide a stronger stimulus than direct government subsidies.

The strength of intellectual property rights is also an additional factor which could influence R&D and innovation. Jaumotte and Pain (2005b) have already argued that the relationship between the intellectual property rights system, patenting and innovative activity is a complex one. Firms can be encouraged to innovate by stronger intellectual property rights, but equally they can also hinder companies in accessing knowledge and thus deter cumulative innovation processes.

The share of high-tech manufacturing industries (in GDP) as well as the share of scientists and engineers in total employment can also be expected to be positively related to the level of R&D. According to Jaumotte and Pain (2005a, 2005b), differences in the number of scientists may be an important explanation for cross-country differences in R&D. Furthermore, absorptive capacity of an economy could be also affected by the number of scientists.

To briefly review, framework conditions as well as specific science policies and institutions help to support innovation independently and in interaction with each other. Furthermore, Jaumotte and Pain (2005a) conclude that there seems to be a clear evidence of policy trade-offs, in other words policies that stimulate the demand for scientists and engineers will also lead to raising costs for R&D resources, especially in the period where labour supply can adjust.

Afonso and St. Aubyn (2005b), Afonso et al. (2006) and Jaumotte and Pain (2005b) also identify several framework conditions (or environmental variables) for explaining the efficiency of public spending. Among these factors, we can mention the level of education of the population, the competence of the civil servants, the per capita GDP, the strength of the IPR systems, trade openness, and transparency in public policy, civil liberty or political rights.

Another approach departs from comparing the estimated efficiency scores between countries relying on performance budgeting techniques and those ones not relying on such techniques. The former may experience better budgetary results (lower debt, deficit, better composition of government expenditures) compared to the other ones. With that respect, Joumard et al. (2004) based on a detailed survey for over two-thirds of OECD countries identify three main areas for action to enhance the effectiveness of public spending: budget process, management practices and the use of market mechanisms in the delivery of public services.

Curristine et al. (2007) investigate the institutional drivers of efficiency in the public sector. By reviewing the literature they figure out that there is indeed evidence that some institutional variables help improving efficiency. Hence, efficiency gains can be obtained by increasing the scale of operations (evidence on this was collected mainly in the education and health sector). Furthermore, functional and political decentralization (i.e. spending responsibility) to sub national governments and human resource practices (e.g. soft aspects of human resource management like employee satisfaction and morale) seem to be beneficial for efficiency. Regarding the impact of ownership, competition and agencification findings were quite inconclusive. Curristine et al. (2007) conclude as well that e-government practices may reduce time demands which, however, come along with more technical requirements of staff members. Contradictory findings are also found for the impact of workforce diversity and representativeness on efficiency. Assessment of the role of unions in public sector efficiency is also really scarce. Although there is some empirical evidence from the United States which suggests that high levels of unionization constrain flexibility and productivity and that collective bargaining in local governments led to increased municipal expenditures, the impact of unions on efficiency and effectiveness remains unclear. Furthermore, studies conducted in Europe do not find either a positive or negative relationship (Curristine et al. 2007). In terms of attractiveness the authors also point out that the image of the public sector plays an important role as well. To sum it up, except for the first three variables which were clearly identified as key institutional drivers that improve efficiency, there is a lack of empirical evidence of the impact of institutional factors on the aspect of efficiency.

2.4. Conclusion of the literature section

Several of the studies reviewed above used the FDH approach to assess efficiency, e.g. Afonso et al. (2003), Gupta and Verhoven (2001), Clements (2003) as well as Herrera and Pang (2005). However, as Afonso et al. (2003) emphasize this approach is likely to overestimate efficiencies since countries which lie on the production possibility frontier are efficient by definition. Furthermore, public sector policies may be also effected by economies of scale being able to deliver better outcomes. These constraints could be overcome by applying another non-parametric approach, namely DEA, e.g. Afonso et al (2006), Lee and Park (2005), Wang and Huang (2007). However, studies where both methods were conducted, e.g. Afonso and St. Aubyn (2005b) have also shown that results of the two analysis were broadly comparable.

A drawback of using non-parametric approaches is that they do not statistically assess differences across countries. Non-parametric methods show a high sensitivity of the results to sampling variability, to the quality of the data and to the presence of outliers (Afonso et al. 2003). Additionally, the dynamic structure is treated inadequately given the lag between input consumption (public expenditure) and output production, e.g. health and education outcomes or referring to our study business R&D expenditures (Herrera and Pang, 2005). Nevertheless, Data Envelopment Analysis is the preferred estimator for productivity levels if development is likely to vary across countries and scale economies are not constant (van Biesebroeck, 2007). Afonso et al.(2006) as well as Herrera and Pang (2005) conduct Tobit analysis to control for non-discretionary inputs since this is not taken into account by the FDH and DEA method. This seems quite appropriate since such factors may play a relevant role in determining heterogeneity across countries and influence performance and efficiency.

The strengths and the weaknesses of the different methods, namely composite performance indicators, data envelopment analysis and stochastic frontier analysis are shown in Figure 1. In a nutshell, methods based on composite indicators are not well suited to assess the efficiency of particular policies such as public R&D spending. The FDH method does not appear to be the most appropriate technique neither as this method tends to overestimate efficiencies of countries. The non parametric DEA must be complemented by a Tobit regression analysis to allow for heterogeneity across countries and for examining the role played by environmental non discretionary factors to explain differences in efficiency scores across and within countries. Given the dependency of DEA towards sample composition, outliers or data quality, a sensitiveness analysis should always be carried out in order to assess the robustness of results. SFA allows for hypothesis testing and to explain inefficiencies. Yet this method is quite data demanding since the convergence of the maximum likelihood iterative procedure to perform the efficiency terms requires a quite large number of observations which is not always likely when we use macro economic data over relative short time periods. Finally and more generally, whatever the strengths and weaknesses of these different approaches, any analysis aimed at examining the efficiency of public policies should consider different methods and compare the results obtained.

Figure 1 Strengths and weaknesses of alternative methods for assessing the (in)efficiency of public spending on R&D

Method	Strengths	Weaknesses
1. Composite performance indicators		
	• Evaluation of public spending in its entirety	• Not suited to assess the efficiency of particular policies e.g. health, education, R&D policies
2. Data Envelopment Analysis (DEA)		
	• Allow one to directly compare the efficiency of countries (ranking) • No need to define the relative importance of the various inputs employed and output produced (due to the absence of weights or prices attached to each outcome) • No need to specify a functional relationship between inputs and outputs • Not subject to simultaneous bias and/or specification errors • Allow to deal with the simultaneous occurrence of multiple inputs and outputs	• Heavy reliance on the accuracy of the data • Difficult to distinguish between output and outcomes • Efficiency scores attributed to inputs while other factors may also contribute • Frontier depends from the set of countries considered (Inefficiencies can be underestimated)
3. Stochastic Frontier Analysis (SFA)		
	• Error term with 2 components: conventional error term + term representing deviation from frontier (relative inefficiency) • Allow for hypothesis testing, confidence interval • Allow to explain inefficiency	• Assume functional form for the production function • Assume distributional form of the technical efficiency term • Single output dimension • Frontier depends from the set of countries considered (Inefficiencies can be underestimated)

3. Efficiency and R&D: Some concepts and issues

The assessment of the efficiency and effectiveness of government expenditures is inherently difficult. The studies in the economic literature dealing with these questions are limited and conceptual and measurement issues are important. To begin with, it seems useful to clearly define the concepts of economic efficiency and effectiveness. Conceptual issues in assessing efficiency in general and efficiency of public R&D in particular are then discussed.

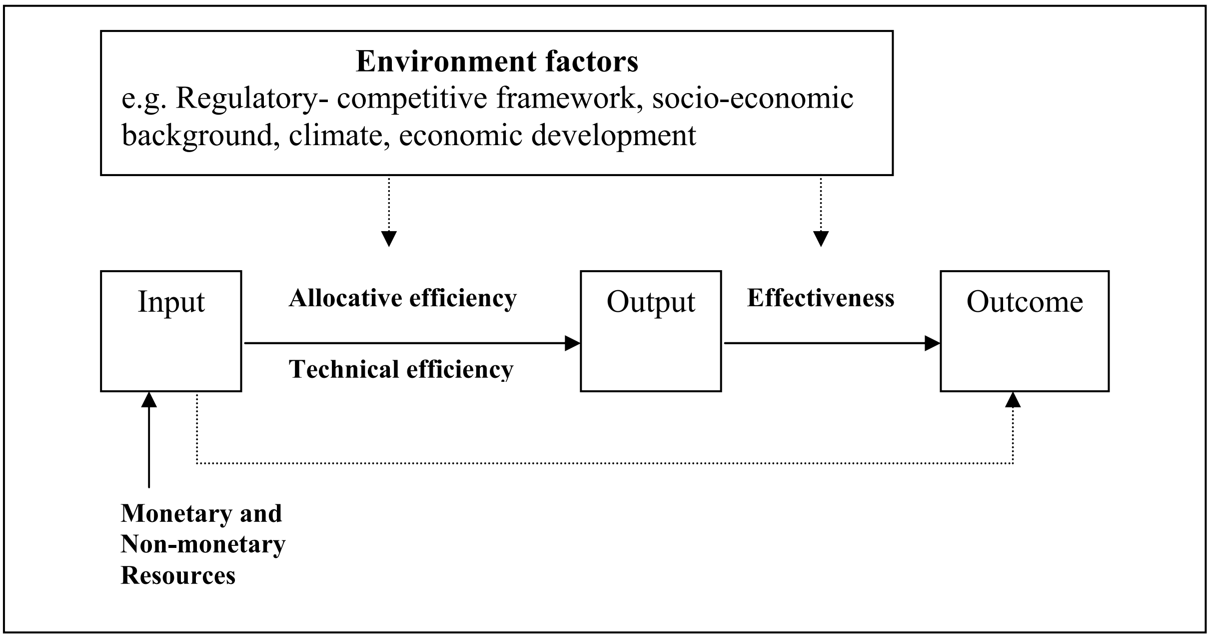
3.1. Input, output, outcome, efficiency and effectiveness

Since the seminal work of Farrell (1957), the term ‘efficiency’ has been extensively used in economics and refers to the optimal use of resources in production, i.e. producing the maximum quantity of output from a given quantity of input (output-oriented measure), or alternatively producing a given output with minimum quantities of inputs (input-oriented measure).

The concept of efficiency can be extended to the case where several inputs are used to generate multiple outputs. In this case, ‘technical efficiency’ is attained when the maximum amount of output is produced from a given amount of inputs or conversely a given amount of output (services) can be produced (delivered) from minimum quantities of inputs. In this case the entity producing the output is said to be technically efficient and operates on its production frontier. The optimal mix of inputs, given input prices, is obtained when the costs to produce a given amount of output are minimized. This situation refers to ‘allocative efficiency’. It is also common to use the term ‘overall efficiency’ which encompasses both technical and allocative efficiencies.

Besides efficiency, it is also common in economics to assess the effectiveness of the production or provision of public services (See Figure 2). The difference between these two terms is not always clear and many authors use them in an interchangeable way. According to Hatry (1978: p. 28), “efficiency indicates the extent to which the government produces a given output with the least possible use of resources. Effectiveness indicates the amount of end product, the real service to the public that the government is providing. Effectiveness encompasses the concept of quality and level of service provided.” Note that as illustrated in Figure 1, both efficiency and effectiveness are affected by environment factors or framework conditions. In order to better grasp the differences between these concepts, it is helpful to introduce the concept of input, output and outcomes. Referring to the example of Afonso et al. (2006: p. 15), “the output of educational spending may be school enrolments, or number of students completing a grade. The outputs of health expenditure may be the number of operations performed or days spent in a hospital bed. However, the outcomes should be based on how much students learned and how many patients got well enough to return to a productive life”.

Figure 2 Concepts of efficiency and effectiveness



Source: Mandl and Ilzkovitz (2007).

In the case of R&D activities, the inputs refer to the main policy instruments governments generally implement to stimulate investment in R&D in activities in both the public and private sectors. While there have been many attempts to classify the different policy instruments that affect R&D and innovation-related activities[11], governments in general rely heavily on a small group of instruments which can be classified into direct policy measures and indirect support to R&D activities[12]. As regards the former, it is common to operate a distinction between three main categories of instruments, namely grants, subsidies and loans, public procurements as well as public funding of research performed in higher education institutions, in particular universities, and public research and technology organizations[13]. Indirect fiscal measures to provide incentives to firms to invest more in R&D activities mainly consist in R&D tax credit. A main difference between tax incentives and direct subsidies is that the former reduces the marginal cost of R&D while the latter increases its private marginal rate of return (David et al., 2000). Another difference rests in the fact that R&D tax credits does not affect the choice of research projects by firms which is not the case

[11] "The range of policy instruments that affect R&D activities is vast and policy design is complicated by their number, diversity and potential to interact both positively and negatively. Instruments range from highly targeted mechanisms that provide direct financial support to individual organizations to perform R&D, to broad changes in the legislative and regulatory environments of firms which can and do affect a multitude of business activities, including those related to R&D. Lying in between these R&D specific mechanisms and broader measures that affect the general business milieu are instruments that differ along many other dimensions. Some measures involve the direct transfer of funds from the public purse to private organizations, while measures such as R&D tax incentives are more indirect in that they involve the state forsaking income rather than increasing direct expenditure on R&D. Other measures are aimed at innovation-related activities other than R&D, though many seek to enhance the commercialization of R&D via improved links between R&D performing units and productive units, e.g. between universities and industry" (European Commission, 2003d: p. 31).

[12] See Appendix 3 for a more detailed picture.

[13] In practice, the distinction between direct subsidies and public procurement of R&D services is not easy to operate since it is difficult if not impossible to distinguish between the channels through which subsidies are transferred.

for direct subsidies or grants since these funds are distributed by the government for specific projects in certain research areas.

The new knowledge generated in the public sector, typically the research output of universities and or public research facilities, is also considered to affect R&D activities of firms in the private sector. Indeed the output of this kind of research of a more fundamental nature and which is basically publicly funded are at the source of important and positive spillover effects for the R&D activities carried out in the private sector. Indeed, the outcomes of publicly funded R&D performed in public research institutes or higher education institutions may in turn be used by private agents in their own applied research.

In a nutshell, these different inputs affect R&D activities either by lowering the costs of doing R&D or by increasing the opportunity to engage in new research projects. Therefore, it is common to consider as the direct output of the policy intervention and the public funding of R&D in the public sector, the additional R&D activities induced by these inputs and performed by private companies. In terms of outcomes, the ultimate goal of R&D policy instruments is to help firms to improve profits and grow by creating new high value-added products, processes and services. In the literature of the economics of innovation and technology change, these outcomes are usually measured by different variables such as the number of patents, the number of innovations (product or process innovation), the share of sales due to innovations, the job creation, the growth of export or of output, changes in total factor productivity or profit increases (Cincera 1998).

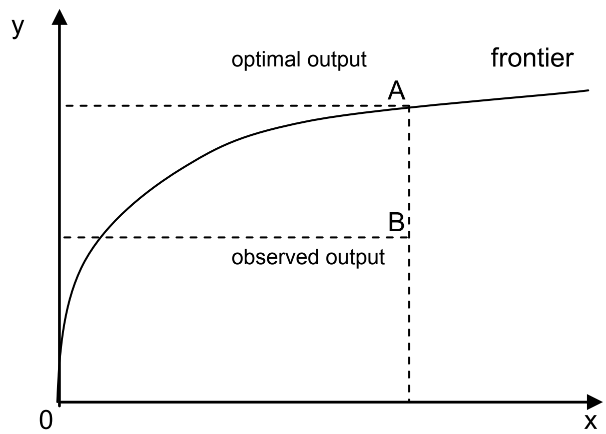
As regard the determinants affecting the efficiency (and effectiveness) of public R&D measures, as the review of the literature of the previous section indicates, various indicators can be considered among which framework conditions or environmental factors affecting the business milieu and the R&D conducted as well as institutional determinants including indicators of budgetary practices reflecting the quality of internal governance, public administration, e.g. composite indicators capturing corruption, red tape and shadow economy). To this end, a distinction can be made between two components of the overall efficiency. First, the business sector efficiency, i.e. the efficiency with which the private sector uses R&D public support and, second, the administrative or institutional efficiency, i.e. the efficient management practices in the public sector. In addition, public procurement can also be considered as an environment factor affecting the efficiency of public spending.

Finally, it should be noted that in this study, the stress is put on a better understanding of the relations between R&D inputs and outputs (efficiency). Therefore the study has to be viewed as a first step of the analysis of the effects (or the impact) of R&D activities on firms economic performance, e.g. output or TFP growth (effectiveness).

3.2. Assessing efficiency

As said before, economists are concerned about the efficient use of scarce resources, in particular those regarding the spending and taxing activities of governments. Following the idea that, at a given input, the greater the output, the more efficient an activity is, the efficiency of public expenditures to support R&D can be measured by comparing the amount spent (input or cost) with the benefits (output or outcomes) of the public expenditure or supporting scheme. Note that in this study, we will stick to the generally used concepts of input, output and efficiency.

Figure 3 Efficiency frontier

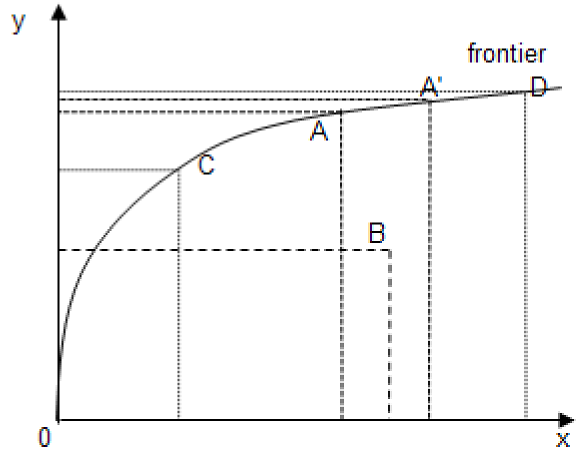


The difference between the output, i.e. the level of (additional) private R&D induced from public R&D, and the costs, i.e. the amount spent on the supporting measure (tax and subsidy measures for instance), can then be compared across countries. For instance if two countries A and B experience the same level of public expenditures, but for one country, A for instance, the gap between these expenses and the benefits is higher, than this country can be defined as more efficient than the other one (see Figure 3). This concept allows one to assess the level of efficiency (and changes in these levels) of the different Member States with regards to their R&D policy instruments and subsequent innovation performance.

As emphasized by Wadhwa et al. (2005), one advantage of using DEA as compared to other methods is that it identifies peers for inefficient units. A peer is a Decision Making Unit (DMU), a country in our case, which lies on the efficiency frontier and with similar combination of inputs as that of an inefficient country[14]. Hence the identification of country peer groups allows to better compare countries' performances and to formulate more specific country recommendations on how to improve the efficiency. Countries A and A' in the example illustrated in Figure 4 lie on the efficiency frontier and represent the peer group for country B as they are closest to it in terms of the combination of inputs.

[14] Quoting the authors, "Where two or more of these units act as peers for an efficient unit, they provide a peer group for the inefficient unit. The peer group is also known as the reference set of an inefficient unit. The characteristics of the units in the reference set provide the targets for the inefficient units to work towards".

Figure 4 Peer group and efficiency frontier



3.3. Issues in assessing the efficiency of public policies in general and R&D in particular

Note that the framework discussed in the previous section for measuring the efficiency of public spending raises a certain number of measurement issues. These issues can be general to the assessment of any public expenditure or specific to policies aimed at supporting R&D activities.

As stressed by Afonso et al. (2006), higher public spending requires higher tax revenues which can be obtained only at progressively higher marginal costs given dead weight, administrative, compliance, opportunity and fixed costs of running a government. Then, opportunity costs[15] and fixed costs associated with the government taxing activities tend to underestimate the costs of public spending activities.

Afonso et al. (2006) identify two other sources of inefficiencies of public expenditure. The first one, which they call 'efficiency with wrong goals' refers to the case where a government delivers efficiently in a technical sense certain services, e.g. public defence, but in a proportion which compared to other services, e.g. education, may be not efficient from a social point of view. The second source of inefficiency refers to a situation where public funds are used again in an efficient way but the budget is distorted towards the specific benefits of special pressure groups, higher wages which are not accompanied by higher productivity performance or corruption and X-inefficiency factors.

Other measurement issues still need to be mentioned. The efficiency and outcomes of public spending also depend on different environmental factors or framework conditions shaped by the economy or other public policies. It is therefore important to control for such external factors in the assessment exercise. Different methods can be implemented to address this question. These methods are discussed in the Section 4.

[15] For instance the rental value of government-owned assets such as buildings, land and forest (Afonso et al., 2006).

Some issues are specific to R&D public spending. As emphasized by Guellec and van Pottelsberghe (2003), the effectiveness of public expenditures aimed at encouraging private R&D activities can be challenged on three main grounds: crowding out effect, substitution effect and allocative distortions. Indeed, public funds allocated to R&D projects increase the demand for researchers and depending on the elasticity of the supply of such a skilled workforce, the wages of researchers, and hence the price of R&D, will increase (Goolsbee, 1998; David and Hall, 2000)[16]. This 'crowding-out' effect between publicly financed R&D and privately financed R&D arises when firms, coping with higher R&D costs, reallocate their funds to other investment projects. Thus, in real terms, the total amount of R&D expenditures corrected for the higher wages of the researchers will be lower even if the total amount of R&D expenditure is higher due to the public funding.

One way to address this issue is to take the approach proposed by Reinthaler and Wolff (2004) which consists in considering as the output variable R&D personnel in the private sector besides total private R&D expenditures. Comparing the results, i.e. the inefficiencies scores, between the two variables allows one to assess the degree of crowding-out effects through wages increases.

Another issue concerns the 'additionality' of R&D policy. How much additional private R&D is stimulated by government support? Publicly-funded R&D may provide knowledge that is useful to firms and will invigorate private R&D. In this case, public R&D is complement to private R&D. However, if public funding supports research projects that would have been performed anyway, there is no additionality coming from public R&D. In this case, firms merely substitute public support for their own, while undertaking the same amount of R&D as initially intended. This question is in general investigated at the micro level by means of counterfactual analysis where a group of government-funded R&D firms is compared to a control sample of R&D firms receiving no support (Klette et al., 2000).

Then, distortions in the allocation of resources between R&D projects may occur. This happens when governments allocate resources less efficiently than market forces due for instance to asymmetrical flows of information. Competition may also been distorted when (less efficient) firms get R&D funds at the expense of others.

[16] On average, about two-thirds of R&D expenditures consist of the wages of the R&D personnel (Cincera, 2005).

4. Empirical framework

This section presents the methodological framework implemented to assess the efficiency of public R&D spending as well as its determinants.

While several studies have used different methods for assessing efficiency of public expenditures, as emphasized before, studies specifically measuring the efficiency of public measures aimed at supporting R&D activities are relatively scarce[17]. The measurement of efficiency at the macro level can be achieved through the use of three main categories of methods: composite indicators, non parametric methods and stochastic methods[18].

The composite indicators based method consists in relating the level (or changes in the level) of total public spending to a composite public sector performance indicator based on various socio-economic indicators assumed to reflect the benefits from the public spending[19]. The main drawback of this method rests in the difficulty to precisely identify the benefits, i.e. the effects of public spending on outcomes and separate them from other influences.

Relative efficiency of public expenditures across countries can be achieved by means of non parametric methods, e.g. Free Disposal Hull (FDH) analysis[20], Data Envelopment Analysis (DEA)[21] and parametric ones, e.g. Stochastic Frontier Analysis (SFA), Thick Frontier Analysis (TFA)[22]. Figure 1 in section 2.4 summarizes the strengths and weaknesses of these different methods. To sum it up and as emphasized by Coelli et al. (2005), SFA is better than DEA as it accounts of measurement errors and other statistical noise and it allows for hypothesis testing and confidence interval. On the other hand it requires to assume a distributional form of the inefficiency term and a functional form for the frontier function. In what follows, we describe these two methods, i.e. DEA and SFA, which also represent the most commonly used in the literature to assess the efficiency of public spending to R&D at the macro level[23]. Note that one objective of the study is to compare the results obtained through these two methods.

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[17] Afonso et al. (2006) distinguish between macro and micro assessment according to whether total public spending or particular categories of spending are considered. More generally, among the methods for the ex-post evaluation of RTD programmes and policies, Rojo and Polt (2002) distinguish between statistical data analysis, modelling methodologies and qualitative and semi-quantitative methodologies (see Appendix 4).

[18] We do not discuss the methodologies specific to micro level data such as for instance the counterfactual method. See David et al. (2000) for a review of these methods.

[19] See Appendix 2.

[20] See Tulkens (1993) for a discussion.

[21] See Sengupta (2000) for a number of applications.

[22] See Berger and Humphrey (1991).

[23] The direct impact of R&D public support on R&D and innovation activities can also be estimated through more traditional econometric models based on R&D investment functions. See Guellec and van Pottelsberghe (2003) for an application.

4.1. Non parametric methods to measure efficiency

Data Envelopment Analysis (DEA) uses linear programming methods to construct a (non parametric) empirical based production frontier (or envelope) over the data[24]. (In)efficiencies can then be calculated relatively to the frontier. Formally, the imputation of efficiencies can be obtained by solving the following linear program:

$$\begin{aligned} &\max\text{imise}_{u,v}\left(\frac{u'y_i}{v'x_i}\right) \\ &\text{subject to } \frac{u'y_i}{v'x_i} \le 1, j=1,...,N, \qquad (1) \\ &\text{and} \qquad u, v \ge 0. \end{aligned}$$

Where x_i are inputs, y_i are outputs and u and v are scalar values chosen for each Decision Making Unit (DMU), countries in our case, such that the efficiencies of each DMU are maximised and no efficiencies are greater than one.

When the DMU operates at an optimal scale, it is appropriate to assume Constant Return to Scale (CRS). Banker et al. (1984) propose a Variable Returns to Scale (VRS) model which introduces a Scale Efficiency (SE) measure for each DMU. SE is calculated as the ratio of CRS Technical efficiency (TE) to VRS TE. Scale efficiency can then be interpreted as follows: if SE=1, then a country is scale efficient that means its combination of inputs and outputs is efficient under both CRS as well as VRS. If SE>1 (resp. <1) in the output- (resp. input) oriented case, then the combination of inputs and outputs is not scale efficient. Scale efficiency can be measured in terms of production by referring to the concept of returns to scale. In the output oriented case for instance, increasing returns are observed when a proportional increase in inputs causes output to increase by a greater proportion, whereas decreasing returns refers to the case where an increase in inputs causes output to increase by a smaller proportion. The smaller this proportion, the higher the SE score is (and conversely for the input oriented case). The VRS TE scores can then be decomposed between two terms, one referring to scale efficiency and the second to pure technical efficiency (PE).

As discussed in Section 3, technical efficiency can be achieved by producing a given output with minimum quantities of inputs (input-oriented measure) or by producing the maximum quantity of output from a given quantity of input (output-oriented measure)[25]. In this study, we will focus on output-oriented measures of technical efficiency. In a revenue maximizing perspective, a reasonable justification to use the output oriented measure rests in the fact that the main objective of R&D policies is to maximize private R&D activities (output) and not to minimize the funds (inputs) used to achieve this goal.

[24] As an alternative to DEA, the Free Disposal Hull (FDH) method is another non parametric approach. This methods performs a piecewise linear function (the frontier or envelope) such that all observed data points lie either on this frontier or below it.

[25] It should be noted that when CRS exist, the input and output-oriented measures are equivalent measures of technical efficiencies (Färe and Lovell, 1978).

Once the technical efficiency scores of public R&D spending across countries have been calculated with the DEA method, the differences observed in the level (changes of levels) of efficiency scores can be explained by exogenous factors or framework conditions in a second stage. We shall come back to the discussion of these determinants in the next section. Following Afonso and St. Aubyn (2005a), the impact of framework conditions on efficiency scores across countries can be estimated through a Tobit econometric model with the following specification:

$$TE_{it} = \delta z_{it} + \varepsilon_{it} \quad (2)$$

Where TE_{it} is the technical efficiency score calculated from the DEA of country *i* at time *t*, z_{it} is a vector of framework conditions or exogenous environmental variables and ε_{it} is the error term.

As noted by Coelli et al. (2005, p. 194), a drawback of this two-stage method is that "if the variables used in the first stage are highly correlated with the second-stage variables then the results are likely to be biases".[26] In practice, it is possible to determine the importance of this issue by examining the correlation matrix of variables. It should also be noted that the use of such a model is justified when the left hand-side variable (efficiency scores) is censored, i.e., it cannot take values below or above a certain threshold value (McDonald and Moffitt, 1980)[27].

4.2. Parametric methods to measure efficiency

Following the framework developed by Battese and Coelli (1995), technical efficiency can be measured by estimating a stochastic frontier model that includes two equations[28].

The first equation specifies the production frontier, in general of the Cobb-Douglas type:

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[26] Some authors (Wang and Schmidt, 2002) favour single-stage procedures where the inefficiency term and the impact of environmental variables on the efficiency scores are estimated simultaneously.

[27] Furthermore the estimated values of the Tobit regression can be used to separate the environmental variables from the net technical efficiency in R&D public instruments (see Wang and Huang, 2007 for a discussion and an application of this multi-stage approach for analyzing efficiency). Another potential issue is that the results may be biased due to the small size properties of the sample. This however is less likely to be the case in our study since we consider countries over a relatively long time period. According to Simar and Wilson (2004), ε_{it} may be serially correlated and/or correlated with some right hand-side variables. In the latter case, correlation occurs when the non discretionary variables and the outputs used to calculate the efficiency scores are correlated. As pointed out by Afonso and St. Aubyn (2005a) both sources of correlation are likely to disappear asymptotically but in small samples, inference is usually not valid. In order to address this issue, Simar and Wilson (2005) propose a semi-parametric approach based on bootstrap methods. In addition, when the number of bootstrap estimates is large, hypotheses testing and confidence intervals for the estimated coefficients becomes possible.

[28] Alternatively to the stochastic approach, a parametric deterministic approach is sometimes used. The Corrected Ordinary Last Square (COLS) is an example of such a method. It consists in estimating first a production function through OLS and than shifting up the intercept parameter by the value of the largest positive residuals which gives the equation for the frontier. Note that this approach is refereed as being deterministic (rather than stochastic) to the extent that it is not possible to separate true inefficiency from random shocks. In such a model, all deviations from the frontier are assumed to be the result of technical inefficiency.

$$\ln(y_{it}) = \alpha + \beta \ln(x'_{it}) + \lambda t + v_{it} - u_{it} \qquad (3)$$

Where *i* indexes countries and *t* years of observations. *y* and *x* are respectively the output and a vector of inputs. The variable *t* accounts for the drift of the common production function over time. v_{it} is a random term accounting for measurement errors and other random shocks in the economy. It is assumed to be normally distributed with zero mean and variance σ^2_v. u_{it} is assumed to reflect technical inefficiencies. It is a one-sided component with variance σ^2_u. As is common in the literature, we assume a half-normal distribution for the inefficiency term[29]. The second equation specifies the inefficiency terms as:

$$u_{it} = \delta Z_{it} + w_{it} \qquad (4)$$

Where u_{it} is the inefficiency term, z_{it} is again a vector of exogenous environmental variables and w_{it} is the disturbance term with mean zero and variance $\sigma^2 = \sigma_u^2 + \sigma_v^2$.

The two-equations stochastic frontier model given by (3) and (4) can be estimated by maximum likelihood. It should be noted that the Stochastic Frontier Analysis can be extended in a panel data framework when both cross-sections of countries over time periods are available.

5. Data

5.1. Data sources

The study covers the EU Member States as well as other OECD countries. Our main data sources are statistics on Science and Technology issued by EUROSTAT and the OECD database on "Main Science and Technology Indicators (MSTI)" which contains time series information on most EU27 and OECD countries since 1981. We investigate the impact on performance at the country level. We choose to analyze 5 different time periods in order to compare the evolution of efficiency parameters over time, i.e. we carry out analyzes with all country data available for the time periods 1981-1984, 1985-1989, 1990-1994, 1995-1999 and 2000-2004. The five years in each period are averaged in order to smooth out short term volatility in the indicators that are used in the empirical analysis.

The composite indicators available from the Fraser Institute[30] based both on survey data and on data provided by different national and international sources refer to business regulations, ease of starting a new business and irregular payments connected with, among others, import/export permits, with business licences or with exchange controls. These indicators are designed to identify the extent to which regulatory restraints and bureaucratic procedures limit competition and the operation of markets. We will use them as well as indicators for

[29] Note that more general distributional forms like the truncated normal and the two-parameter gamma can be used for the u_{it}.
[30] See Gwartney and Lawson (2004).

administrative, institutional and business R&D enhancing factors which are provided by the OECD Main Science and Technology database, EUROSTAT, European Innovation Scoreboard and by Park (2001) and Park and Wagh (2002) in a later step of the project to investigate possible reasons for inefficiencies occurring in some countries after our initial estimations[31].

5.2. Descriptive statistics

The dependent variable throughout this study is the Business Expenditure on R&D (BERD), to be more precise BERD is scaled by GDP to ensure better comparability between the different countries. This also accounts for the other variables, namely BERDBYGOV, HERD and GOVERD which will be also specified later in this chapter. Since scaling by GDP leads to rather small numbers of these variables we show them as intensities, which means as their percentage value of GDP. Our goal is to analyze how the most relevant determinants that influence R&D and, even more important in this study, what efficiency value each country achieves in combining its resources. As main determinants, we consider the amount of subsidies within BERD, that is, BERDBYGOV which reflects direct payments from governments to industry. Furthermore, R&D conducted in public research institutions may trigger private expenditure on R&D if industry makes use of publicly provided results in, e.g. fundamental research for privately conducted applied research which in turn may lead to new product inventions or the implementation of new processes in production. The two main indicators are R&D activities carried out in universities and other institution of higher education, and those activities conducted in other public research institutions. Both efforts are measured through the expenses, HERD and GOVERD.

Table 2 shows the intensity of the dependent variable BERD (measured as the percentage of GDP) and the subsidies granted (BERDBYGOV; here in % of BERD) for all available countries in the database for three sub periods, 1980-1984, 1990-1994 and 2000-2004[32]. The countries are sorted by size of BERD intensity in the period 2000-2004. Calculations are made on the basis of monetary numbers expressed as million US$ in constant prices of the year 1995. Note that BERD as we use it in this study measures the business R&D expenditure financed by the private sector. Thus, the data represent BERD net of subsidies. Furthermore, BERD refers to all R&D activities performed by businesses within a particular sector and territory, regardless of the location of the business's headquarters, and regardless of the sources of finance.

Japan, Sweden and Switzerland exhibit the highest intensity of R&D spending in the business sector in the first two sub periods (1980-1984 and 1990-1994). Sweden and Japan are also

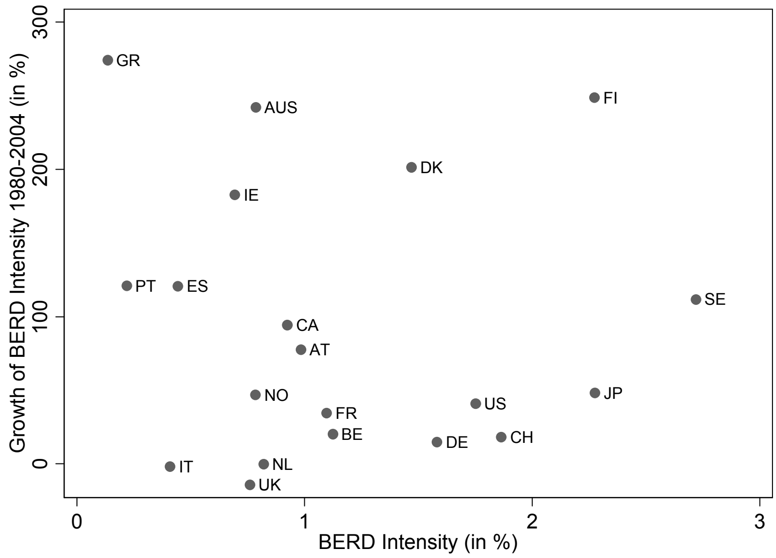
[31] We also experimented with the B-index proposed by Warda (1996). Due to missing values, however, and since values do not change over time, this variable was finally omitted in the subsequently presented analysis. When i twas included in specifications of the models using only the sub sample where the B-index is available it always turned out to be insignificant.

[32] Data does not change much over time. For this reason only these three sub periods are shown in the descriptive statistics section.

listed within the top three performs in the third sub period (2000-2004) with a BERD intensity of clearly over two percent, while Switzerland slightly increased from 1.72% during the 1990ies to 1.84% in the early 2000s. The highest intensity of BERD in the third sub period is shown by Israel which almost tripled its R&D spending in the business sector measured as a percentage of GDP from 1.05% in the second to 2.99% in the third sub period. However, as one can see in the growth rates in the right column of the table, Finland which is the well-known European example for the smaller economies was only in the middle field regarding BERD intensity at the beginning of the 1980ies. However, it was able to catch up and place itself into the field of the top five performs in the third sub period with one of the highest growth rates of 249%. Nevertheless, the highest growth rate of BERD/GDP is clearly shown by Iceland with outstanding 1815%. During the first sub period Iceland was almost bottom of the table with 0.06% and is now ranked within the middle field with 1.19% BERD intensity. High growth rates of BERD intensity were also realised by Greece which, however, still lies in the bottom third in 2000-2004.

Figure 5 illustrates the intensity of BERD and the growth rates for BERD intensity for a subsample of countries for which both variables are available. Sweden, Japan and Finland clearly show the highest BERD intensity in 2000-2004, however Japan's growth rate of BERD intensity is rather low compared to the rest of the sample countries. The lowest growth rates are shown by the Netherlands, Italy and the United Kingdom where the latter two even have a decreasing evolution in their BERD intensity. These countries also have a BERD intensity in 2000-2004 below 1%. Furthermore, Figure 5 illustrates that more than half of the sample countries, to be more precise 11 out of 20 countries exhibit a BERD intensity of smaller than 1%, however, three of them, namely Greece, Australia and Ireland exhibit among the highest growth rates from BERD intensity between 1980-2004 in the sample.

Figure 5 Scatterplot of BERD Intensity (2000-2004) vs. growth rates of BERD Intensity (both in %)



Note: For better illustration Iceland was excluded from the picture. Country codes follow the international standard ISO 3166.

Among the top ten countries, the share of subsidies within BERD (BERDBYGOV) has been reduced since the 1980s. While share of subsidies amounted 43% in the United States in the period 1980-1984, on average, it reduced to 10% in the early 2000s. A reduction of the governmental share in BERD took place for most of the countries over the last decades (if data is observed for the early 1980s). Exceptions are Spain, Austria, Portugal and Switzerland where an increase has occurred. A high share of public budget in BERD is prevalent in the Eastern European countries such as Romania, Poland, the Slovak Republic, Latvia and the Czech Republic. The Russian Federation can almost be considered as an "outlier" as the public share in private R&D reaches more than 125% in the early 2000s. Among the top ten countries, Italy, the United Kingdom and France exhibit the highest share of public support in BERD. It remains to be investigated whether the higher shares of subsidies in the business sector relate to relative inefficiency in combining R&D-resources in such countries.

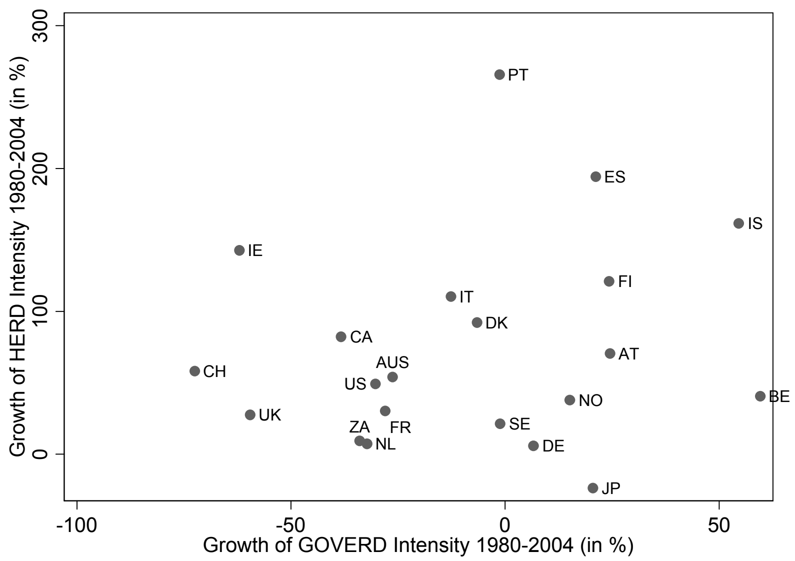
Table 3 shows the intensity of expenditures in higher education (HERD) and other public research institutions (GOVERD) as well as their growth rates. The data is sorted in descending order by HERD intensity in 2000-2004. In addition, the B-Index and the R&D personnel (BER) divided by GDP (see Table 4) are shown. Unfortunately the B-Index is only available for a subsample of countries. The countries are sorted in descending order by R&D personnel/GDP in 2000-2004.

The only country which is ranked among the top five countries in both HERD and GOVERD intensity is Finland. Regarding the intensity of HERD the top five performers in 2000-2004 are Sweden, Israel, Finland, Switzerland and Canada. For the intensity of GOVERD this accounts for Iceland, France, New Zealand, Finland and Germany. Furthermore the data shows that most countries have increased not only the private efforts for R&D in terms of GDP as expressed through BERD intensity over time, but also the intensity of expenditures in higher education as can be seen by the growth rates of HERD intensity. Interestingly, another component of public efforts on R&D, namely GOVERD intensity mostly shows a negative evolution from 1980s to the first half of 2000s. Figure 6 illustrates that 13 out of 21 countries show a negative development of GOVERD/GDP while they exhibit a positive evolution of their HERD intensity from 1980-1984 until 2000-2004. The highest growth rate of HERD intensity is clearly shown by Greece with almost 700%. Regarding GOVERD intensity the biggest increase from the early 1980ies until the beginning of the 2000s was conducted by Belgium and Iceland.

We employ the public efforts devoted to R&D as further determinants of private R&D as scholars hypothesize that the government provides some amount of basic research findings through university research and other research. Results of such are typically be assumed to be in the public domain as they are usually disseminated through journal articles, where the public including industry has easy access. It is believed that public research results will constitute a basis for more applied research and development in the business sector, and thus one should control for different levels of public spending when the evaluation of a country's efficiency is the goal (Salter and Martin 2001).

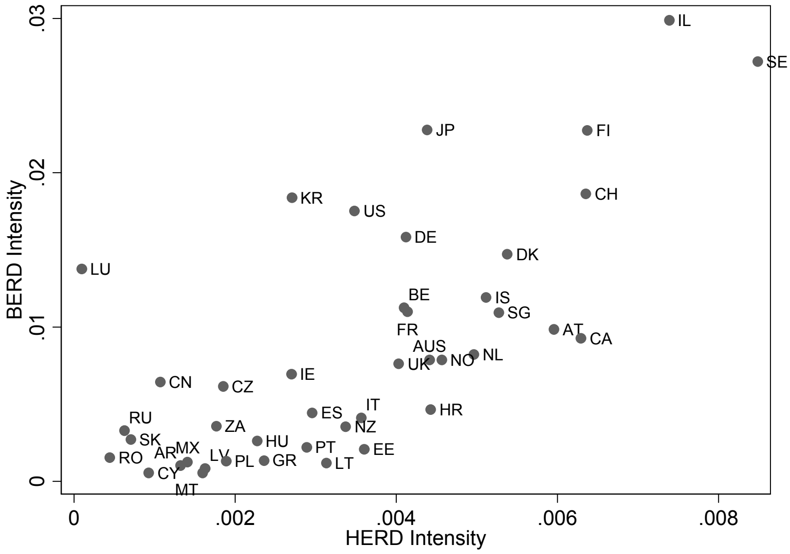
Comparing HERD intensity with BERD intensity in 2000-2004 leads to the conclusion that countries, such as Israel and Sweden which clearly show the highest BERD intensity in this period also take the leading positions regarding the intensity of expenditures in higher education on R&D. The same accounts for the lower performing countries, e.g. Romania, Slovakia and Russia which have low intensities of HERD as well as of BERD. Luxembourg takes an outlying position in this case since it exhibits quite a high BERD intensity, but the lowest HERD intensity in the sample for the 2000-2004 period (see Figure 7).

Figure 6 Scatterplot of growth rates of HERD Intensity vs. GOVERD Intensity (both in %)



Note: Country codes follow the international standard ISO 3166

Figure 7 BERD intensity vs. HERD intensity for 2000-2004



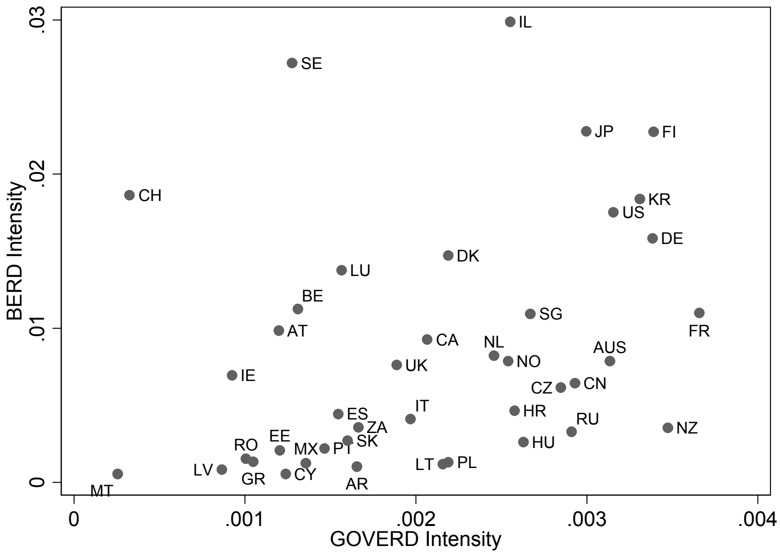
Note: Country codes follow the international standard ISO 3166.

Figure 8 shows the relationship of BERD intensity and GOVERD intensity where Iceland is not included in the picture due to its high intensity of GOVERD which was almost twice as high as the one of the country with the second highest GOVERD intensity (France in this case) in 2000-2004. It can be seen that Israel ands Sweden (the countries with the highest BERD intensity in 2000-2004) are only positioned in the middle field regarding GOVERD intensity. Furthermore, Switzerland which has among the highest BERD intensities in the sample shows the second lowest intensity of GOVERD in 2000-2004. This finding is only beaten by Malta which clearly offers the lowest intensities of both variables.

Finally, Figure 9 illustrates BERD intensity vs. BERDBYGOV intensity in 2000-2004. This time Russia is excluded from the figure due to its high intensity of BERDBYGOV. Israel which exhibits the highest intensity of BERD also shows the (second) highest intensity of BERDBYGOV. Nevertheless, most of the countries lie within the third quadrant of Figure 9[33].

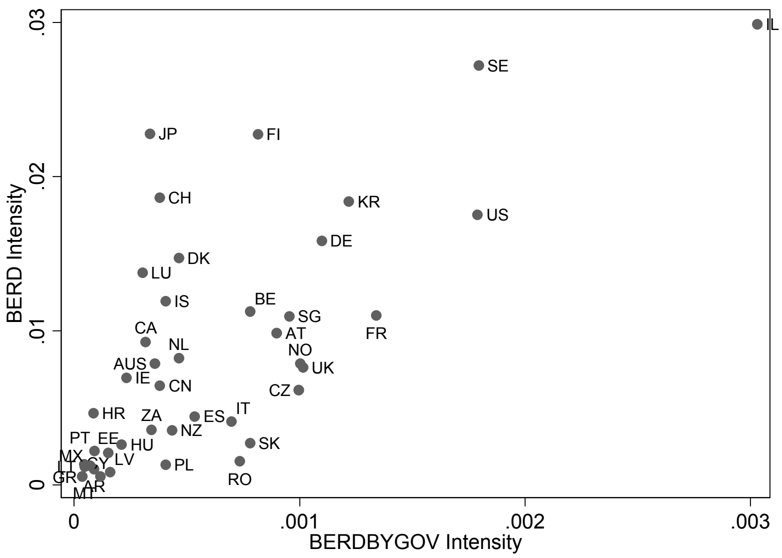
[33] A correlation table with significance level for the discussed variables is provided in the appendix (see Table A 2)

Figure 8 BERD Intensity vs. GOVERD Intensity in 2000-2004



Note: For better illustration Iceland was excluded from the picture. Country codes follow the international standard ISO 3166.

Figure 9 BERD Intensity vs. BERDBYGOV Intensity in 2000-2004



Note: For better illustration Russia was excluded from the picture. Country codes follow the international standard ISO 3166.

Regarding the R&D personnel/GDP Table 4 shows that Russia exhibit the highest value for 2000-2004. Others countries which show quite high values in the same period as well are Romania and Bulgaria. However, one has to be aware of the fact that actually the number of R&D employees has decreased since the beginning of the 1990ies in all three countries (see Table A 1). Japan, the United States, Germany and the United Kingdom remain quite stable over all three sub period.

The determinants on the quality of the regulatory framework are listed in Table 5. These indicators are classified into five categories: ease of starting a new business, trade tariffs and barriers, state involvement in the economy, and importance of administrative burdens and regulatory quality. These indicators are similar to the ones used by Cincera and Galgau (2005) and come from the Fraser Institute, which reports them on a five-year interval basis and annually from 2000 onwards. The latest period currently available is 2004.

Table 6 shows that the highest value for the first indicator and the freedom to trade internationally indicator are clearly shown by Singapore in all three sub periods. Regarding the legal structure and security of property rights Denmark, Finland and the Netherlands are the leading countries in 1990-1994 and 2000-2004 as well as the United States and Switzerland which show the highest values for this component at the beginning of the early 1980ies. Israel clearly underwent the biggest change for the access to sound money from 1.54 in 1980-1984 to 9.08 in 2000-2004. It can also be seen that the United States exhibit the highest value for the regulation of credit, labour and business in all three sub periods.

Finally descriptive statistics for the indicators dealing with the business conditions enhancing R&D activities of firms are provided in Table 7 and Table 8, again for the three periods, 1980-1984, 1990-1994 and 2000-2004. Most of the indicators come from the OECD Main Science and Technology Indicators database as well as from EUROSTAT. Data for the PPP exchange rates and the GDP deflator came from the World Economic Outlook Database 2007 of the International Monetary Fund and the World Development Indicators 2006. The source for the Strength of the IPR system is Park (2001) and Park and Wagh (2002). Data for this variable was linearly intrapolated. For the indicator "share of firms that received public funds for R&D" data from the European Innovation Scoreboard database was used as well as for the composite indicator "summary innovation index", which, however, only was available for the year 2005. The indicator shows highest values for Finland, Sweden as well as Switzerland and is lowest for Romania and Turkey.

It can be seen from Table 7 and Table 8 that data for most of the other indicators was not available in the first sub period (1980 - 1984). Although this has slightly improved for the second sub period (1990 – 1994), information is still only available for about half of the investigated countries. Table 8 (sub period 2000 – 2004) shows that regarding the share of basic R&D performed in the private sector in percent of total business R&D is highest in the Slovak Republic and Switzerland. Numbers on the industry university links indicate that about two third of the countries for which data is available are ranked over 90 percent. A notable improvement was made by Hungary which caught up by gaining 30 percent points from 56.84% in the second up to 85.94% in the third sub period. The share of public credit appropriation in the defence sector is clearly highest in the United States, Russia, the United Kingdom, Spain, France and Sweden. Table 8 (sub period 2000 – 2004) also demonstrates that the intellectual property rights (IPR) system has its biggest strength in the United States, Austria and Germany. However, the discussion of these indicators seems rather insufficient due to the huge data gaps, especially the unavailability of numbers for key countries like the United States, Germany etc.

Table 2 Average BERD Intensity and subsidies by government (BERDBYGOV) in 1980-1984, 1990-1994 and 2000-2004

	1980 – 1984		*1990 – 1994*		*2000 – 2004*		
Country[#]	*BERD Intensity*	*Subsidies in % (BERDBYGOV)*	*BERD Intensity*	*Subsidies in % (BERDBYGOV)*	*BERD Intensity*	*Subsidies in % (BERDBYGOV)*	*Growth of BERD Intensity (1980/2004) in %*
Israel			1,05%	31,88%	2,99%	10,13%	
Sweden	1,28%	13,84%	1,72%	12,18%	2,72%	6,60%	111,75%
Japan	1,54%	1,78%	1,96%	1,30%	2,28%	1,48%	48,12%
Finland	0,65%	4,02%	1,09%	6,21%	2,28%	3,58%	248,70%
Switzerland	1,58%	1,37%	1,72%	1,78%	1,86%	2,04%	18,23%
Korea					1,84%	6,63%	
United States	1,25%	*42,39%*	1,45%	*24,89%*	1,75%	*10,22%*	40,72%
Germany	1,38%	20,58%	1,42%	11,97%	1,58%	6,94%	14,88%
Denmark	0,49%	13,93%	0,79%	8,75%	1,47%	3,16%	201,40%
Luxembourg					1,38%	2,21%	
Iceland	0,06%	35,17%	0,26%	14,60%	1,19%	3,41%	1815,30%
Belgium	0,94%	10,13%	1,02%	6,32%	1,13%	6,95%	20,03%
France	0,82%	33,12%	1,03%	24,25%	1,10%	12,20%	34,64%
Singapore			0,76%	2,45%	1,09%	8,74%	
Austria	0,55%	8,19%	0,69%	11,40%	0,98%	9,14%	77,59%
Canada	0,48%	16,30%	0,61%	12,89%	0,93%	3,44%	94,32%
Netherlands	0,82%	11,40%	0,84%	10,15%	0,82%	5,66%	-0,06%
Australia	0,23%	11,09%	0,59%	2,89%	0,79%	4,57%	242,12%
Norway	0,53%	28,86%	0,68%	20,80%	0,79%	12,78%	46,96%
United Kingdom	0,89%	48,45%	0,98%	18,47%	0,76%	13,36%	-14,17%
Ireland	0,25%	15,34%	0,61%	6,06%	0,69%	3,36%	182,54%
China					0,64%	5,93%	
Czech Republic					0,61%	16,24%	
Croatia					0,46%	1,85%	
Spain	0,20%	5,25%	0,34%	14,04%	0,44%	12,07%	120,76%
Italy	0,42%	17,26%	0,50%	17,93%	0,41%	17,05%	-2,01%
South Africa					0,36%	9,64%	
New Zealand			0,24%	7,88%	0,35%	12,32%	
Russia					0,33%	124,49%	
Slovak Republic			0,39%	16,27%	0,27%	28,71%	
Hungary					0,26%	8,09%	
Portugal	0,10%	2,00%	0,10%	9,98%	0,22%	4,12%	120,79%
Estonia					0,21%	7,30%	
Romania					0,15%	48,46%	
Greece	0,04%	4,82%	0,06%	7,11%	0,14%	3,38%	273,94%
Poland					0,13%	31,10%	
Mexico			0,05%	1,62%	0,12%	5,77%	
Lithuania					0,12%	3,95%	
Argentina					0,10%	8,84%	
Latvia					0,08%	19,32%	
Cyprus					0,05%	6,89%	
Malta					0,05%	22,22%	

Note: BERD Intensity refers to BERD as the percentage of GDP. Calculations were made on the basis of monetary figures expressed in millions of 1995 US $ (PPPs exchange rate and GDP deflator).
BERD refers to privately financed R&D in the business sector, i.e. it excludes the business R&D subsidized by the government.
Due to very high inflation rates it was not possible to characterize the economies of Bulgaria, Slovenia and Turkey. Therefore, they were excluded from the analysis.
Source: Eurostat 2007, OECD Main Science and Technology Indicators 2007.

Table 3 R&D expenditure in Higher Education (HERD) and other governmental institutions (GOVERD)

Country	1980 – 1984 HERD Intensity	1980 – 1984 GOVERD Intensity	1990 – 1994 HERD Intensity	1990 – 1994 GOVERD Intensity	2000 – 2004 HERD Intensity	2000 – 2004 GOVERD Intensity	Growth of HERD Intensity (1980/2004)	Growth of GOVERD Intensity (1980/2004)
Sweden	0.70 %	0.13 %	0.76 %	0.12 %	0.85 %	0.13 %	21.25%	-1.13%
Israel			0.61 %	0.26 %	0.74 %	0.26 %		
Finland	0.29 %	0.27 %	0.42 %	0.41 %	0.64 %	0.34 %	120.87%	24.35%
Switzerland	0.40 %	0.12 %	0.64 %	0.09 %	0.64 %	0.03 %	58.22%	-72.51%
Canada	0.35 %	0.34 %	0.48 %	0.28 %	0.63 %	0.21 %	82.19%	-38.28%
Austria	0.35 %	0.10 %	0.51 %	0.13 %	0.60 %	0.12 %	70.49%	24.53%
Denmark	0.28 %	0.23 %	0.37 %	0.29 %	0.54 %	0.22 %	92.20%	-6.54%
Singapore			0.33 %	0.16 %	0.53 %	0.27 %		
Iceland	0.20 %	0.43 %	0.33 %	0.53 %	0.51 %	0.67 %	161.58%	54.62%
Netherlands	0.46 %	0.36 %	0.57 %	0.35 %	0.50 %	0.25 %	7.12%	-32.24%
Norway	0.33 %	0.22 %	0.44 %	0.31 %	0.46 %	0.25 %	37.96%	15.18%
Croatia					0.44 %	0.26 %		
Australia	0.29 %	0.43 %	0.37 %	0.42 %	0.44 %	0.31 %	54.05%	-26.22%
Japan	0.57 %	0.25 %	0.55 %	0.24 %	0.44 %	0.30 %	-23.68%	20.57%
France	0.32 %	0.51 %	0.36 %	0.51 %	0.41 %	0.37 %	30.43%	-27.92%
Germany	0.39 %	0.32 %	0.40 %	0.34 %	0.41 %	0.34 %	5.93%	6.67%
Belgium	0.29 %	0.08 %	0.38 %	0.09 %	0.41 %	0.13 %	40.45%	59.60%
United Kingdom	0.32 %	0.47 %	0.35 %	0.30 %	0.40 %	0.19 %	27.47%	-59.52%
Estonia					0.36 %	0.12 %		
Italy	0.17 %	0.23 %	0.26 %	0.25 %	0.36 %	0.20 %	110.34%	-12.66%
United States	0.23 %	0.45 %	0.31 %	0.39 %	0.35 %	0.32 %	49.20%	-30.33%
New Zealand	0.00 %		0.28 %	0.42 %	0.34 %	0.35 %		
Lithuania					0.31 %	0.22 %		
Spain	0.10 %	0.13 %	0.22 %	0.17 %	0.30 %	0.15 %	194.33%	21.21%
Portugal	0.08 %	0.15 %	0.22 %	0.13 %	0.29 %	0.15 %	265.69%	-1.27%
Korea					0.27 %	0.33 %		
Ireland	0.11 %	0.24 %	0.23 %	0.12 %	0.27 %	0.09 %	142.58%	-62.10%
Greece	0.03 %	0.11 %	0.12 %	0.11 %	0.24 %	0.10 %	695.56%	-2.00%
Hungary					0.23 %	0.26 %		
Poland					0.19 %	0.22 %		
Czech Republic					0.19 %	0.28 %		
South Africa	0.16 %	0.25 %	0.16 %	0.21 %	0.18 %	0.17 %	9.15%	-33.91%
Latvia					0.16 %	0.09 %		
Malta					0.16 %	0.03 %		
Mexico			0.12 %	0.11 %	0.14 %	0.14 %		
Argentina					0.13 %	0.17 %		
China			0.07 %	0.33 %	0.11 %	0.29 %		
Cyprus					0.09 %	0.12 %		
Slovak Republic			0.04 %	0.37 %	0.07 %	0.16 %		
Russia					0.06 %	0.29 %		
Romania					0.04 %	0.10 %		
Luxembourg					0.01 %	0.16 %		

Note: HERD/GOVERD Intensity refers to HERD/GOVERD as the percentage of GDP. Calculations were made on the basis of monetary figures expressed in millions of 1995 US $ (PPPs exchange rate and GDP deflator).
Source: Eurostat 2007, OECD Main Science and Technology Indicators 2007.

Table 4 R&D personnel/GDP

Country	1980 - 1984	1990 - 1994	2000 – 2004
Russia		0.0090	1.4087
Romania		0.0098	1.2885
Bulgaria		0.0093	0.6979
Turkey		0.0007	0.2132
Finland	0.0300	0.0539	0.1621
Korea			0.1410
Sweden	0.0489	0.0804	0.1209
Iceland	0.0018	0.0336	0.1191
Japan	0.1305	0.1338	0.1171
United States	0.1102	0.1136	0.1131
Denmark	0.0258	0.0463	0.0962
Singapore		0.0780	0.0902
Norway	0.0421	0.0661	0.0888
Canada	0.0358	0.0592	0.0828
China		0.0489	0.0785
Slovenia		0.0676	0.0727
Germany	0.0612	0.0778	0.0725
Austria	0.0218	0.0389	0.0689
Switzerland	0.0406	0.0545	0.0637
United Kingdom	0.0673	0.0671	0.0635
France	0.0369	0.0535	0.0617
Hungary		0.0236	0.0616
Luxembourg			0.0607
Belgium	0.0303	0.0450	0.0602
Ireland	0.0146	0.0390	0.0570
Netherlands	0.0406	0.0372	0.0510
Estonia			0.0509
Czech Republic			0.0508
Slovak Republic		0.0521	0.0441
New Zealand		0.0258	0.0425
Latvia		0.0269	0.0422
Australia	0.0150	0.0410	0.0409
Spain	0.0046	0.0167	0.0317
Poland		0.0212	0.0316
Croatia			0.0304
Mexico		0.0013	0.0237
Greece		0.0058	0.0234
Italy	0.0133	0.0227	0.0206
Portugal	0.0026	0.0061	0.0192
Malta			0.0157
Lithuania			0.0145
Argentina			0.0083
Cyprus			0.0068

Source: OECD Main Science and Technology Indicators 2007.

Table 5 The Areas and Components of the Fraser Institute composite indicators

Area 1:	Size of Government: Expenditures, Taxes, and Enterprises
A	General government consumption spending as a percentage of total consumption
B	Transfers and subsidies as a percentage of GDP
C	Government enterprises and investment
D	Top marginal tax rate
Area 2:	Legal Structure and Security of Property Rights
A	Judicial independence
B	Impartial courts
C	Protection of property rights
D	Military interference in rule of law and the political process
E	Integrity of the legal system
F	Legal enforcement of contracts
G	Regulatory restrictions on the sale of real property
Area 3:	Access to Sound Money
A	Money growth
B	Standard deviation of inflation
C	Inflation: most recent year
D	Freedom to own foreign currency bank accounts
Area 4:	Freedom to Trade Internationally
A	Taxes on international trade
B	Regulatory trade barriers
C	Size of the trade sector relative to expected
D	Black-market exchange rates
E	International capital market controls
Area 5:	Regulation of Credit, Labour, and Business
A	Credit market regulations
B	Labour market regulations
C	Business regulations

Source: Fraser Institute, Economic Freedom of the World 2007.

Table 6 Descriptive Statistics for the five area indicators of the Fraser Institute

Country	*1980-1984*					*1990-1994*					*2000-2004*				
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*
Argentina	5.74	4.36	2.50	3.80	4.50	7.10	5.80	4.14	5.38	5.22	7.88	3.86	7.90	6.40	5.52
Australia	5.02	7.54	9.06	6.84	6.54	5.52	8.34	9.16	7.50	6.88	6.16	9.12	9.30	7.52	7.38
Austria	3.06	7.96	8.40	6.94	5.44	2.98	8.50	9.56	7.62	5.66	4.66	8.86	9.60	8.40	6.40
Belgium	3.60	7.84	9.54	8.88	5.46	4.12	7.98	9.64	8.62	5.74	4.26	7.86	9.66	8.74	6.32
Bulgaria	4.50					3.10	6.68	3.44	5.34	3.52	4.42	4.84	7.08	7.14	5.76
Canada	4.82	7.48	9.12	7.76	6.76	5.30	8.54	9.60	7.42	7.10	6.46	8.74	9.50	8.02	7.46
China	3.12		6.12	4.72	3.00	3.76	5.68	6.22	5.50	3.70	3.78	5.08	8.22	7.38	4.58
Croatia								2.86			3.84	5.46	7.90	6.50	6.14
Cyprus	5.92		6.10	5.90	5.36	5.72	6.54	7.12	5.48	5.22	6.54	6.98	8.04	6.18	5.74
Czech Republic							6.92			4.08	4.32	6.60	8.84	8.28	5.96
Denmark	3.10	7.48	6.58	7.18	5.66	2.98	8.62	9.56	7.30	6.60	3.96	9.34	9.68	8.08	6.98
Estonia								3.62		3.98	6.32	6.58	9.28	8.66	6.94
Finland	4.58	7.24	7.80	6.76	5.74	4.00	8.70	9.42	6.94	6.32	4.52	9.24	9.60	8.08	6.94
France	3.46	6.96	6.42	6.64	5.70	3.38	7.62	9.68	7.22	5.82	3.14	7.58	9.60	7.94	6.44
Germany	4.48	7.62	9.48	8.16	5.20	4.70	8.62	9.42	8.20	5.62	4.62	8.84	9.60	8.50	5.72
Greece	4.66	5.60	6.86	5.88	4.40	5.16	6.76	6.94	6.30	4.84	6.08	5.78	9.54	7.48	5.42
Hungary	3.44		6.62	4.38	3.64	3.62	7.36	5.84	5.78	5.16	5.18	6.68	8.76	8.22	6.78
Iceland	5.18	7.24	2.24	5.60	5.50	5.88	8.30	7.84	6.14	6.28	5.86	9.00	9.18	6.68	7.86
Ireland	4.54	6.94	6.12	7.50	6.12	5.68	8.26	7.92	7.88	6.90	6.10	8.48	9.58	8.84	6.80
Israel	2.18	5.18	1.54	6.66	3.42	3.10	5.44	4.76	6.54	4.58	3.60	7.30	9.08	7.94	5.66
Italy	3.36	6.14	5.66	7.46	4.84	3.46	7.22	9.36	7.34	5.10	5.02	6.78	9.58	7.86	5.48
Japan	5.88	7.62	8.32	6.86	6.50	5.66	7.86	9.70	6.56	6.38	5.94	7.56	9.56	6.68	6.46
Korea	6.20	5.58	5.56	6.24	5.34	6.28	5.48	7.10	7.04	5.16	6.56	6.26	9.14	7.18	5.38
Latvia								5.04			5.82	5.88	9.04	7.44	6.22
Lithuania								5.22		3.30	5.80	5.32	8.58	7.60	5.82
Luxembourg	7.04	8.00	9.14	8.68	6.90	4.58	8.62	9.46	8.46	6.68	4.52	8.64	9.64	8.86	7.12
Malta	4.28		6.62	6.00	5.66	4.98	5.74	7.22	6.50	5.18	5.80	7.08	7.36	6.64	6.52
Mexico	5.70	5.94	5.76	3.86	4.72	7.20	6.20	4.36	7.50	5.50	7.84	4.08	7.44	7.34	5.38
Netherlands	3.80	7.82	9.44	8.38	5.48	4.86	8.62	9.64	8.30	6.06	4.62	9.18	9.54	8.64	6.98
New Zealand	3.68	7.96	6.18	7.32	5.74	6.30	8.66	8.26	7.98	7.48	6.72	8.96	9.50	8.24	7.72
Norway	3.02	7.44	6.42	7.18	5.32	3.22	8.66	9.02	7.94	6.06	4.42	8.66	8.96	7.28	6.48
Poland	3.86		6.20		3.10	2.24	6.44	3.90	5.82	3.90	5.38	5.84	8.10	6.78	5.60
Portugal	3.72	7.24	5.50	6.78	4.66	4.90	7.82	7.10	7.48	5.10	5.60	7.56	9.52	7.86	6.16
Romania	5.48		6.72		2.56	3.76	6.02	4.54	4.92	2.86	4.44	4.94	5.24	6.70	5.46
Russia	1.20		6.02		2.50	2.64		4.12		3.44	5.48	4.32	4.36	6.82	4.66
Singapore	7.04	7.74	7.20	9.36	6.20	8.28	7.64	9.46	9.60	6.94	8.04	8.38	9.56	9.32	7.18
Slovak Republic								7.96			4.00	5.88	8.06	8.26	6.06
Slovenia											2.60	6.56	8.46	7.20	5.62
South Africa	4.78	5.52	5.30	7.00	5.54	5.68	4.18	6.04	6.42	6.14	5.52	6.66	7.96	7.18	6.56
Spain	4.50	6.34	6.14	6.98	5.28	4.50	7.32	7.50	7.56	5.66	4.98	6.64	9.54	8.06	6.54
Sweden	2.30	6.92	7.76	7.06	5.44	2.48	8.54	8.48	8.38	5.92	3.40	8.78	9.72	8.14	6.56
Switzerland	7.06	8.18	9.58	8.40	5.52	6.80	8.62	9.66	7.94	6.38	7.32	8.78	9.68	8.16	7.36
Turkey	4.60	5.68	1.22	4.46	4.72	6.24	4.62	3.26	5.88	5.50	7.02	4.90	4.24	7.02	5.20
United Kingdom	3.80	6.88	7.04	8.50	6.24	5.52	8.14	8.70	8.20	7.40	6.44	9.12	9.42	8.22	7.64
United States	5.52	8.30	9.24	7.98	6.80	6.78	8.50	9.68	7.84	7.36	7.64	8.36	9.76	7.78	7.86

Note: (1) Size of Government: Expenditures, Taxes and Enterprises, (2) Legal Structure and Security of Property Rights, (3) Access to Sound Money, (4) Freedom of Trade Internationally, (5) Regulation of Credit, Labour and Business

Table 7 Descriptive Statistics for Business R&D enhancing factors (1980 -1984 and 1990-1994)

	1980 – 1984									1990 – 1994								
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*
Argentina																		
Australia																		
Austria			98.30							0.19	1.02	98.06	4.40					
Belgium			97.31				1.18			0.84	5.70	94.69				0.24		
Bulgaria												76.68						
Canada																		
China																		
Croatia																		
Cyprus																		
Czech Republic													1.19					
Denmark			98.63				0.47			2.16	14.60	97.96		0.38	48.72	0.60		
Estonia																		
Finland			94.92				1.80			0.48	2.81	94.85				1.95		
France			98.65	2.98			35.78			0.77	4.28	96.01	4.31	0.30	41.56	29.50		
Germany			98.59				12.85			0.65	3.59	97.23				9.14		
Greece							2.23			4.35	34.15	89.41		0.04	36.36	1.62		
Hungary												56.84						
Iceland			89.51	0.39			0.00					77.06				0.00		
Ireland			91.75	3.38						1.49	10.39	93.65	4.04					
Israel																		
Italy			98.10				7.04			0.95	7.22	96.92				7.42		
Japan			95.41				6.00					95.51				5.07		
Korea																		
Latvia																		
Lithuania																		
Luxembourg										0.86	5.74							
Malta																		
Mexico																		
Netherlands			95.14				2.98			0.89	4.22	92.49		0.24	35.29	3.04		
New Zealand																		
Norway			96.13				10.72					93.40				5.72		
Poland												67.94	5.24					
Portugal			93.36							1.60	11.26	85.58		0.03	42.86	1.16		
Romania												97.49	4.82			4.10		
Russia																		
Singapore																		
Slovak Republic												83.72	5.07					
Slovenia												93.69						
South Africa																		
Spain			98.79				6.45			1.03		93.48		0.09	38.21	11.78		
Sweden			97.79				24.44			0.99	4.35	97.50		0.39	42.86	21.10		
Switzerland			96.03				11.25					99.18				4.73		
Turkey												71.97						
United Kingdom			91.51				46.70			2.60	12.34	94.04				41.82		
United States			98.53	3.46			57.15					98.03	4.27			53.65		

Note: (1) Public procurement advertised in the Official Journal as a % of GDP; (2) Public procurement advertised in the Official Journal as a % of total public procurements; (3) Industry university links (business funded R&D performed in other sector than the business one); (4) Basic R&D performed in the private sector in % of total business R&D; (5) Share in % of researchers, scientists & engineers in the private sector as a % of total active population; (6) Share in % of researchers, scientists & engineers in the total business R&D personnel; (7) Share of Public Credit Appropriation in the defence sector; (8) Strength of the intellectual property rights (IPR) system; (9) Value added in hi-tech manufacturing sector as % of total manufacturing value added.

Table 8 Descriptive Statistics for administrative, institutional and business R&D enhancing factors (2000 -2004)*

Countries	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*
Argentina								3.33						
Australia								4.19						
Austria	2.60	16.31	96.55		0.51	54.94		4.71	10.57	0.48		0.51	54.94	10.57
Belgium	2.49	16.76	94.62	7.16	0.45	51.64	0.30	4.05	13.27	0.49	7.16	0.45	51.63	13.27
Bulgaria			75.97	0.08	0.04	52.86		3.24	7.65	0.21	0.08	0.04	52.86	7.65
Canada								3.90						
China								2.48						
Croatia			89.71	1.34	0.06	42.45				0.26	1.34	0.06	42.45	
Cyprus			95.92	5.59	0.08	50.33	0.00		3.93	0.30	5.59	0.08	50.33	3.93
Czech Republic			95.71	3.35	0.20	43.40	3.00	3.52	6.94	0.33	3.35	0.20	43.40	6.94
Denmark	2.86	16.03	98.20	5.24	0.64	49.25	0.93	4.19	15.16	0.63	5.24	0.64	49.24	15.16
Estonia			84.99	1.27	0.12	60.67	1.25			0.34	1.27	0.12	60.67	
Finland	2.39	14.90	96.29		1.05	66.88	2.34		24.02	0.68		1.05	66.88	24.02
France	2.93	17.71	96.51	4.33	0.38	50.61	23.30	4.05	16.97	0.48	4.33	0.38	50.61	16.97
Germany	1.23	7.41	96.41		0.45	52.07	6.15	4.52	11.17	0.60		0.45	52.07	11.17
Greece	4.68	34.10	87.80	4.89	0.09	34.20	0.70	3.19		0.22	4.89	0.09	34.20	
Hungary			85.94	6.26	0.13	58.42		3.71	16.59	0.25	6.26	0.13	58.42	16.59
Iceland			91.79		0.79	57.66	0.00			0.50		0.79	57.66	
Ireland	2.63	20.68	97.87	5.58	0.36	55.42		4.00	22.57	0.48	5.58	0.36	55.42	22.57
Israel								4.05						
Italy	2.24	18.05		4.97	0.13	37.91	3.70	4.33	9.48	0.34	4.97	0.13	37.91	9.48
Japan			97.96	5.74			4.53	4.19		0.62	5.74			
Korea								4.19						
Latvia			65.95	2.53	0.08	55.43	0.80			0.22	2.53	0.08	55.43	
Lithuania			68.26	0.02	0.03	58.67	0.27		8.05	0.24	0.02	0.03	58.67	8.05
Luxembourg	2.04	13.59	99.20		0.83	45.60				0.53		0.83	45.60	
Malta					0.07	59.51	0.00			0.29		0.07	59.51	
Mexico								2.86						
Netherlands	1.97	9.35	90.79		0.33	44.03	1.74	4.38		0.49		0.33	44.03	
New Zealand								4.00						
Norway			94.12	4.07	0.64	67.69	6.94	3.90		0.38	4.07	0.64	67.69	
Poland			81.43	4.81	0.06	52.45	5.00	3.24	5.76	0.21	4.81	0.06	52.45	5.76
Portugal	2.32	17.62	93.98	2.85	0.10	65.92	1.48		6.17	0.23	2.85	0.10	65.92	6.17
Romania			86.52	8.87	0.10	56.46	1.36	2.71	4.85	0.18	8.87	0.10	56.46	4.85
Russia			85.98	3.00			44.65	3.52			3.00			
Singapore								4.05						
Slovak Republic			92.89	9.56	0.10	46.47	7.17		4.84	0.22	9.56	0.10	46.50	4.84
Slovenia			92.37	2.33	.18	36.18	0.80		14.11	0.34	2.33	0.18	36.18	14.11
South Africa								4.05						
Spain	3.06	24.72	93.06		0.17	41.84	26.68	4.05	6.12	0.31		0.17	41.84	6.12
Sweden	3.81	19.81	98.18		0.67	58.77	16.12	4.38	16.38	0.73		0.67	58.77	16.38
Switzerland			96.94	11.10			0.45	4.05		0.69	11.10			
Turkey			69.90		0.02	46.67		2.86		0.08		0.02	46.67	
United Kingdom	4.69	26.27	94.03	6.46			32.70	4.19	16.91	0.54	6.46			16.91
United States			98.21				54.90	5.00		0.55				

*Administrative and institutional R&D enhancing factors were only available for the last sub period, namely 2000 – 2004, data for the Summary innovation index was only available for 2005.

Note: Business R&D enhancing factors: (1) Public procurement advertised in the Official Journal as a % of GDP (2) Public procurement advertised in the Official Journal as a % of total public procurements; (3) Industry university links (business funded R&D performed in other sector than the business one); (4) Basic R&D performed in the private sector in % of total business R&D; (5) Share in % of researchers, scientists & engineers in the private sector as a % of total active population; (6) Share in % of researchers, scientists & engineers in the total business R&D personnel; (7) Share of Public Credit Appropriation in the defence sector; (8) Strength of the intellectual property rights (IPR) system; (9) Value added in hi-tech manufacturing sector as % of total manufacturing value added,, (10) Summary innovation index; Administrative and institutional R&D enhancing factors; (11) More effective control of public spending growth; (12) Anchoring the budget process in a medium-term perspective; (13) Reduced budget fragmentation and increased transparency; (14) Share of enterprises receiving public funding for innovation.

6. Results

This section presents our results regarding the efficiency of R&D public spending of countries over different time periods. We begin by presenting the estimates based on the Stochastic Frontier Analysis (SFA) and continue with the ones obtained through the DEA non parametric method.

6.1. Guide through the empirical study

Before the results are presented in detail, we briefly describe how this section is organized in more detail. Section 6.2 starts with the application of the Stochastic Frontier Approach (SFA). While this model has the advantage over the DEA analysis that the structural R&D equation and the inefficiency term are simultaneously estimated, it – unlike the DEA – relies on functional form assumptions for the R&D equation and on distributional form assumptions for its error term.

We first consider cross-sectional regressions for each period, and explore the performance of different specifications of the R&D equation. When doing this, we evaluate the unconditional inefficiency, that is, the inefficiency in the models does not depend on observable factors. As it turns out, the cross-sectional regressions do not point to significant inefficiencies. To explore this further, we subsequently estimate panel models instead of separate cross-sections, as the sample in the cross-sectional regressions may have been too small to uncover statistically significant inefficiencies. It turns out, however, that there are no significant inefficiencies in the panel models either. Since we first used only R&D expenses as dependent variable in the analysis, we extend the panel models also to R&D personnel. R&D expenses may go up due to subsidies as wages for R&D employees may increase. As this, however, may have no real effect on the economy unless the wage increase coincides with a productivity increase of the R&D workers, it is desirable to test whether private R&D employment is also positively related to public R&D in form of subsidies or higher education spending and government R&D. We find that the results on the R&D employment are very similar to the models on R&D spending. Again, no significant inefficiencies are detected.

As the unconditional inefficiency term did not report unobserved differences across countries, we proceed by putting more structure on the inefficiency term. While the inefficiency may not vary significantly across countries and years, it may vary across groups of countries or vary systematically due to certain characteristics of the country.

First, we investigate the efficiencies of different groups of countries and then proceed to other determinants of possible inefficiencies. It turns out that indeed some sources of inefficiencies can be identified by putting more structure onto the model.

The specifications of the SFA are then carried over to the DEA analysis in Section 6.3. We start by presenting our benchmark results obtained by applying DEA with variable returns to scale on three inputs and one output for a subset of countries for which information is available for all sub periods of five years from 1980 to 2004. We continue by exploring the evolution of these efficiency scores over time. In a second step, the results of the most recent period are discussed. This allows us to increase substantially the number of countries and to examine the performance of the EU New Member States. In the next subsection, we carry out a sensitivity analysis to assess the robustness of the benchmark results by changing certain parameters of the DEA method, by comparing this method with other non parametric ones, by considering alternative specifications (inputs and outputs) and by testing the stability of the efficiency scores on different samples of countries.

The results of the two stage Tobit regressions are also discussed in this section. This method allows us to investigate the impact of different sets of determinants on the efficiency scores. In a first step, the DEA efficiency scores are regressed on alternative groupings, for example based on different geographic areas, GDP per capita, or the Summary Innovation Index developed for the European Innovation Scoreboard. In a second step, we investigate the effects of different regulatory and macroeconomic stability conditions on the efficiency of public R&D spending. In addition, we analyze the role played by administrative and institutional factors as well as business conditions enhancing R&D activities in the private sector and affecting the efficiency of public R&D policies.

Finally, Section 6.4 summarizes the empirical findings of the study by comparing the favourite results obtained with the two main parametric and non parametric methods implemented in the study.

6.2. Stochastic Frontier Approach

6.2.1 Cross-sections estimates

In this subsection we present the results of the regressions applying the stochastic frontier models as outlined in subsection 4.2. The stochastic frontier analysis was carried out using the software package STATA in particular the cross-sectional *frontier* command and the *xtfrontier* command for the panel regressions. We experimented with different specifications and came to the conclusion that the most sensible choice for the baseline regressions is to use a log-transformation of business sector R&D and the covariates, where all variables that are related to the size of a country are re-scaled by GDP.

The log-transformation is favoured as the stochastic frontier approach was originally developed to estimate production or cost functions of the Cobb-Douglas type which are based on a multiplicative relationship of the covariates. Furthermore, the estimation method only produces consistent estimates if the random error follows a normal distribution. As the distributions of the variables are skewed - as typical for economic data – we use their natural logarithm (except for the B-Index) to approximate the model assumptions empirically. The vector v denotes a “conventional” random error which is assumed to be normally distributed.

The technical efficiency is indicated by the vector u which is a positive half-normally distributed error term (normal distribution truncated at zero). Thus our preferred specification is:

$$ln(BERD/GDP)_{it} = b0 + b1 * ln(BERDBYGOV/GDP)_{it} + b2 * ln(HERD/GDP)_{it} + b3 * ln(GOVERD/GDP)_{it} + b4 * B\text{-}Index_{it} + v_{it} - u_{it}. \quad (5)$$

As the B-Index is only available for a limited number of countries, such regressions were only considered with subsample. Table 7 presents the estimation results for the time periods 1990-1994 and 2000-2004 without the B-index. The estimations for the first period 1980-1984 did not converge.

As one can see, the subsidies (BERDBYGOV) and the R&D conducted in Higher Education (HERD) turn out to be positively significant in both time periods. The term μ in the tables displays the mean of the truncated normal distribution (the efficiency term), and the reported Coelli-Test (Coelli, 1995) in the hypothesis of no inefficiency is reported at the bottom of the tables. If the null hypothesis of no inefficiency is not rejected the model the frontier regression basically reduces to an OLS regression with normally distributed errors. As indicated by the test statistics, we do not find statistically significant inefficiencies. This may have several reasons:
a) Our cross-sectional samples are too small to achieve the necessary precision in the estimations,
b) the model assumptions are not satisfied,
c) there are no inefficiencies.

In order to investigate whether there are outliers in the data that may result in the fact that the error term departs from the normal distribution, we inspected the residuals of OLS regressions instead of using the SFA technique. Indeed, we found that 2 observations, one in the 1980-1984 sample (Iceland) and one in the 2000-2004 sample (Luxembourg), had very high residuals, and took them out of the sample and re-run the regressions form above. Now, the model also converges for the 1980-84 period. However, the results still do not suggest any significant inefficiencies. This is due to the fact that even our simple model fits the data points very well. The estimation results are shown in the following table, and we find that BERDBYGOV and HERD remain positively significant as before.

Table 9 Stochastic Frontier Estimation – Specification using GDP as size denominator#

	Time Period	
Variable	*1990-1994*	*2000-2004*
ln(BERDBYGOV/GDP)	0.427***	0.553***
	(0.093)	(0.104)
ln(HERD/GDP)	0.619***	0.424***
	(0.188)	(0.129)
ln(GOVERD/GDP)	-0.102	0.267
	(0.196)	(0.192)
Intercept	1.028	3.254**
	(1.640)	(1.372)
$\ln\left(\sigma_v^2\right)$	-1.395*	-0.721**
	(0.736)	(0.305)
μ	-0.135	-0.136
	(40.097)	(28.815)
# of obs.	26	42
Log-Likelihood	-18.737	-43.438
χ^2 *Test*	68.48***	63.37***
Coelli-Test: No inefficiency	0.948	3.087
[p-value]	[0.828]	[0.999]

Note: μ *denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses. *** (**, *) denote a significance level of 1% (5%, 10%).*
 # The model for the period 1980-1984 does not converge.

Table 10 Stochastic Frontier Estimation – Specification using GDP as size denominator – Outlier corrected

		Specification	
Variable	*1980-1984*	*1990-1994*	*2000-2004*
ln(BERDBYGOV/GDP)	0.230***	0.427***	0.514***
	(0.082)	(0.093)	(0.072)
ln(HERD/GDP)	0.893***	0.619***	0.894***
	(0.150)	(0.188)	(0.112)
ln(GOVERD/GDP)	-0.214	-0.102	0.215
	(0.170)	(0.196)	(0.133)
Intercept	0.527	1.028	5.309***
	(1.252)	(1.638)	(1.175)
$\ln\left(\sigma_v^2\right)$	-2.075**	-1.395*	-1.467***
	(0.942)	(0.736)	(0.485)
μ	-0.118	-0.135	-0.098
	(31.161)	(40.098)	(29.883)
# of obs.	20	26	41
Log-Likelihood	-7.600	-18.737	-28.074
χ^2 *Test*	124.34	68.48	177.15
Coelli-Test: No inefficiency	0.433	0.948	1.090
[p-value]	[0.668]	[0.828]	[0.862]

Note: μ *denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses. *** (**, *) denote a significance level of 1% (5%, 10%).*

In the specifications presented above, we did not present results concerning the B-Index, as this is only available for a subset of the countries in the sample. We ran all regressions including this index describing the generosity of the governmental policies towards R&D, but it never turned out to have a coefficient significantly different from zero in any specification. Therefore, we decided to omit the presentation of detailed regression tables[34].

6.2.2 Panel data estimates on BERD and R&D personnel

As mentioned above, the sample size of the single cross-sections may be too small for obtaining precise enough estimations for the inefficiency term. Therefore, we now pool all years and estimate panel data regressions including observations from 1980-1984, 1985-1989, 1990-1994, 1995-1999, 2000-2004. We directly show the outlier corrected regressions (the outlier correction does improve the overall fit of the model, but not the results on the inefficiency term, though). The estimations are shown in Table 5. We also experimented with other specifications of the model, but since they did not improve the findings, they are relegated to the appendix of the study (see Table A 3 - Table A 6).

As Table 11 shows, we find meaningful coefficient estimates for the variables measuring public R&D in the regression on BERD. Both subsidies and higher education spending lead to higher investment in R&D in the business sector. On part of the subsidy variable, we can also reject a crowding out effect. Since the dependent variable excludes the amount of subsidies, but comprises only private expenditure, the estimated coefficient and its t-statistic provide a direct test on crowding-out. Since the estimated coefficient is positive and significantly different from zero, we can reject crowding-out effects.

Again, however, we do not find significant inefficiencies in the pooled sample (see Coelli Tests). The hypothesis of no inefficiency is not rejected in the regression model. Furthermore, the time dummies are not jointly significant which indicates that there is no time trend in BERD which is not already captured by the other explanatory variables.
As also shown in Table 11 R&D personnel is significantly positively related to government subsidies and higher education expenditure. We, thus, can also reject clearly that subsidies crowd-out private investment completely. The estimated elasticity is 47%, i.e. if subsidies are increased by 100%, R&D employment in the business sector will grow by 47%. Interestingly, GOVERD is also positively related to R&D employment while it does not show any effect on BERD. As in the case of BERD, though, there is no significant inefficiency.

[34] As a further test, we consider R&D personnel in the business sector as dependent variable. According to a paper by Goolsbee (1998), crowding-out effects may occur even if R&D expenditure in the business sector increases with higher public R&D spending. He argues that it may happen that one observes higher private R&D spending, but that it may be due to wages of R&D personnel. He shows this by correlations of wages and government spending in a large sample of high-skilled employees in the United States. If the wage increase does not coincide with a corresponding productivity increase of the scientists, one may still argue in favor of crowding-out effects as the higher government subsidies only result in higher wages rather than higher employment. The specifications are analogous to the previous subsection but using log of R&D personnel over GDP as dependent variable. As results obtained were very similar – even with respect to the outlier analysis, we only present the regressions using panel data below.

One interesting difference between the models on BERD and R&D personnel is that the time dummies are jointly significant in the latter regression models (see Table 11), while they were not in the BERD regressions. Furthermore the coefficients of the time dummies are increasing over time, that is, there is a positive trend in R&D employment in the business sector that is not captured yet by the other variables in the models.

Table 11 Stochastic Frontier Panel Data Estimation on R&D Personnel in the business sector

	Dependent Variable	
Variable	*ln(BERD/GDP)*	*ln(R&D personnel /GDP)*
ln(BERDBYGOV/GDP)	0.404***	0.465***
	(0.042)	(0.043)
ln(HERD/GDP)	0.826***	0.376***
	(0.074)	(0.073)
ln(GOVERD/GDP)	0.040	0.172**
	(0.082)	(0.082)
Intercept	2.992***	9.949***
	(0.686)	(0.668)
Joint significance of 4 time dummies	0.37	53.21***
[p-value]	(0.985)	(0.000)
$\ln\left(\sigma_v^2\right)$	-1.357***	-1.377***
	(0.247)	(0.297)
μ	-0.089	-0.129
	(10.131)	(15.974)
# of obs.	141	137
Log-Likelihood	-104.310	-99.887
χ^2 *Test*	446.14	328.07
Coelli-Test: No inefficiency	1.346	2.105
[p-value]	[0.911]	[0.982]

*Note: μ denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses. *** (**, *) denote a significance level of 1% (5%, 10%).*

6.2.3 Panel data estimations: conditional mean of inefficiency term depending on covariates

In the former regressions we considered unconditional inefficiency terms. This implicitly assumed that the inefficiency term is identically distributed (following a truncated normal distribution) across all observations. Now we put more structure on the models by making the conditional mean of the truncated normal distribution depend on covariates, such that the inefficiency is a linear combination of some additional regressors *w*:

$$\mu_{it} = w'_{it}\,\delta\,,$$

where δ denote the additional coefficients in the inefficiency term to be estimated. This allows the mean of the inefficiency term to vary across observations depending on the covariates.

That means, if there is heterogeneity among the observations, we can capture this by additional covariates.

As a start, we model the conditional mean as groupwise heterogeneous, i.e. we group the countries in the sample by including dummy variables indicating to which “group of countries” an observation belongs to. The groups are defined as follows[35]:

1. The New EU Member States since 2004 (this serves as base category in the models)
2. The former EU15 Member States
3. European countries, but not EU members (yet)
4. “High-tech” or highly industrialized countries in the rest of the world. Those are Canada, Japan, Korea, and the United States.
5. Other countries in the rest of the world.

Using the New EU Member States as reference category is just a choice. The estimated coefficients in the efficiency term then represent the relative difference of a certain group, e.g. the former EU15 members, to the base category. Any other choice of reference category would result in the same results concerning the interpretations of findings.

Table 12 shows the regression results for our 5-period panel. There are interesting differences across the regressions. While the former results on the coefficients in the structural equation (BERD or personnel) show basically the same results as in the previous models, we now find interesting differences across countries’ efficiencies. In the regression using BERD as dependent variable, we see that basically all country groups – expect “other countries” – perform better than the reference, the (New EU Member States) as the estimated coefficients of the group indicators are significantly negative, i.e. their inefficiency is smaller.

In the regression on R&D personnel, however, we find a positive coefficient of the former EU15 Member States while the other dummy variables are not significant. Only the coefficient of the non-European highly industrialized countries is weakly significant at the 10% level indicating that those countries are more efficient than the new Member States. Thus, the model finds here that the inefficiency is highest in EU15 countries when it comes to R&D employment in the business sector as reaction to public R&D spending either as subsidies or R&D performed in the public sector. One explanation for this result, could be the fact that the former EU15 Member States have a relatively higher stock of researchers than the New Member States. Thus, additional incentives may not increase employment as much as in countries where the stock of researchers is low. In addition, it may be more difficult to find additional highly qualified personnel in countries with a high stock of researchers. If these arguments would apply, it would not be surprising that the former EU15 countries would exhibit less efficiency in hiring new R&D employees due to government spending than the New Member States. It has to be pointed out though that the R&D personnel regression in log-levels without rescaling by GDP delivers other findings on the efficiency term. While the

[35] See Appendix 7 for the lists of countries for the different groupings.

coefficients in the R&D personnel equation are very robust to the change, the model indicates that the EU15 countries are not different from the New Member States, and that the other high-tech countries are more efficient than the reference countries. As the results seem to depend on the specification, one should be careful with final interpretations.

Table 12 Stochastic Frontier Estimation (1)

	Dependent Variable			
Variable	*ln(BERD/GDP)*		*ln(RDPERS/GDP*1000)*	
ln(BERDBYGOV/GDP)	0.407	***	0.480	***
	(0.041)		(0.042)	
ln(HERD/GDP)	0.705	***	0.377	***
	(0.083)		(0.074)	
ln(GOVERD/GDP)	-0.009		0.076	
	(0.082)		(0.079)	
Intercept	2.785		10.201	
	(84.135)		(75.527)	
Time dummies	YES		YES	
	Inefficiency term μ_i (Reference class: NEW-EU)			
Former EU15 members	-0.320	*	0.364	**
	(0.164)		(0.144)	
Rest of Europe	-0.428	**	0.025	
	(0.209)		(0.186)	
Other High-Tech	-0.757	***	-0.306	*
	(0.200)		(0.180)	
Other countries	-0.216		0.147	
	(0.174)		(0.164)	
Intercept	1.192		0.484	
	(84.133)		(75.526)	
# of obs.	141		137	
Log-Likelihood	-96.197		-85.497	
χ^2 Test	347.05		343.95	

*Note: μ denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses. *** (**, *) denote a significance level of 1% (5%, 10%).*

As further grouping of countries, we consider the membership of the European domestic market (Internal Market) and the membership in the Euro area. These results are presented in the following table. Again, we find very robust results concerning the positive impact of subsidies and HERD. While both indicators do not point to heterogeneous inefficiencies across countries in the BERD regression, the R&D personnel equation indicates less efficiency if countries participate in the internal market. This finding is similar to the inefficiency found for the EU15 members. However, we should not over-interpret this results as the IM dummy may capture several other structural characteristics of countries that go beyond the pure internal market membership.

Table 13 Stochastic Frontier Estimation (2)

	Dependent Variable	
Variable	*ln(BERD/GDP)*	*ln(RDPERS/GDP*1000)*
ln(BERDBYGOV/GDP)	0.417 ***	0.516 ***
	(0.042)	(0.042)
ln(HERD/GDP)	0.818 ***	0.353 ***
	(0.074)	(0.068)
ln(GOVERD/GDP)	0.020	0.109
	(0.082)	(0.077)
Intercept	3.136	10.111
	(25.727)	(57.651)
Time dummies	YES	YES
Internal Market	0.159	0.431 ***
	(0.100)	(0.094)
Euro Area	-0.262	-0.351
	(0.330)	(0.298)
Intercept	0.153	0.131
	(25.720)	(57.648)
# of obs.	141	137
Log-Likelihood	-103.039	-89.840
χ^2 *Test*	454.18	393.28

*Note: μ denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses. *** (**, *) denote a significance level of 1% (5%, 10%).*

As these results are not robust across the models using different dependent variables, we split the countries according to their GDP into high income countries (the top 25% of the income per capita distribution), medium income, and low income (the 25% with least income) (see Appendix 7). The high income countries are more efficient in the BERD equations, but not with respect to R&D personnel. Note that we could only estimate a reduced specification for the R&D personnel equation as the model did not converge with the full specification. We had to drop the medium income dummy variable.

Table 14 Stochastic Frontier Estimation (3)

	Dependent Variable	
Variable	*ln(BERD/GDP)*	*ln(RDPERS/GDP*1000)*
ln(BERDBYGOV/GDP)	0.399 ***	0.461 ***
	(0.040)	(0.044)
ln(HERD/GDP)	0.787 ***	0.365 ***
	(0.078)	(0.076)
ln(GOVERD/GDP)	0.048	0.173 **
	(0.078)	(0.082)
Intercept	3.226	10.063
	(28.908)	(35.531)
Time dummies	YES	YES
Medium GDP per capita	0.315	-
	(0.198)	-
High GDP per capita	-0.144	-0.077
	(0.251)	(0.141)
Intercept		0.215
		(35.526)
# of obs.	141	137
Log-Likelihood	-97.534	-99.737
χ^2 *Test*	330.97	258.73

*Note: μ denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses. *** (**, *) denote a significance level of 1% (5%, 10%).*

For the final specification of the SFA models, we turn our attention to indicators of country characteristics as published by the Fraser institute. Due to missing data problems for most subcomponent indicators, we rely on the 5 broad summary indicators: “Size of government: Expenditures, taxes and enterprises”; “Legal structure and security of property rights”; “Access to sound money”; “Freedom to trade internationally”; “Regulation of credit, labor, and business”.

Unfortunately, the indicators are highly correlated so that the model could not be estimated with the full set of variables. The model using BERD as dependent variable shows that quality of a country’s “Legal structure and security of property rights” as well as the “Access to sound money” reduce inefficiencies the better these indicators are. The R&D personnel models do not show the same effects: the legal structure variable is insignificant, and the access to sound money is only weakly significant at the 10% level. However, both variables have the same sign as in the BERD regression and, thus, point into the same direction.

As an interim conclusion on the SFA models, we can conclude that the model performance is very sensitive to the specification of the model. In the cases, where we tried to estimate more sophisticated models with respect to the inefficiency term, the regressions did not converge. Furthermore, the regressions using country groupings rather than variables that are based on more structural characteristics of the countries point into different directions when one compares R&D spending and personnel. Thus it seems that the dummy variables pick-up something more than just the pure group structures. When we use the structural determinants, though, the models on BERD and personnel point to similar conclusions. This evidence seems to be more trustworthy, as R&D spending and R&D personnel are highly related to each other, as most R&D cost is based on wages of personnel.

Table 15 Stochastic Frontier Estimation (4)

	Dependent Variable			
Variable	*ln(BERD/GDP)*		*ln(RDPERS/GDP*1000)*	
ln(BERDBYGOV/GDP)	0.356	***	0.454	***
	(0.039)		(0.054)	
ln(HERD/GDP)	0.686	***	0.280	***
	(0.097)		(0.088)	
ln(GOVERD/GDP)	0.076	***	-0.030	
	(0.025)		(0.031)	
Intercept	1.270		8.796	***
	(13.828)		(0.644)	
Time dummies	YES		YES	
Legal structure and security of property rights	-0.058		-0.078	
	(0.046)		(0.107)	
Access to sound money	-0.085	**	-0.154	*
	(0.040)		(0.080)	
Intercept	1.400		2.071	*
	(13.826)		(3.327)	
# of obs.	140		136	
Log-Likelihood	-91.959		-93.561	
χ^2 Test	273.39		123.42	

*Note: μ denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses. *** (**, *) denote a significance level of 1% (5%, 10%).*

6.2.4. Robustness tests

We performed several robustness checks on the results presented above. We also tried to use other regressors in the SFA inefficiency term, e.g. as described in Table 5, Table 7 and Table 8. Such data, however, is only available for a small subset of countries and time periods. Due to the small sample size the SFA models failed to converge in too many cases, so that we do not show any result here. We only analyze these determinants with the DEA method. The latter has the advantage that the structural equation and the inefficiency term are not estimated simultaneously. Thus the efficiency scores can always be calculated from the full sample, and the analysis of determinants can be done for the subset where data is available. For that we will use a Tobit regression in the second step. As the Tobit model's optimization function is not as complicated as the SFA likelihood function, it will be possible to obtain estimates through the combination of DEA and Tobit analysis, whereas the SFA models did not converge as the model has to rely on the subset of available data for both the structural equation and the efficiency term simultaneously.

Using annual data (in total 512 observations) rather than the 5-year average time periods as observations for the regression models does not change the interpretation of results. However, sometimes we encountered problems with respect to the convergence of the maximum likelihood routine. These are possibly related to the fact that the variables do only change very slowly over time, and are thus basically time constant over several years. Furthermore, an annual panel exhibits more gaps due to missing data, which may also cause convergence problems.

We also tried to use lagged values rather contemporaneous values of the regressors in the model, but that causes large problems in the Maximum Likelihood optimization as there appear may gaps in the time series once we want to include lags. Therefore we do not present the results in more detail.

Finally, we had the idea not to estimate frontier production functions, but use a concept that we label "dynamic efficiency". In this we were interested how R&D expenditure or R&D personnel in the business sector respond to a change in public expenditure on R&D. Thus, we estimated linear regression models in first differences over time, such that a difference in e.g. subsidies should trigger also a positive difference in BERD over time. However, a often the case with macroeconomic data, the values change slowly over time. This caused that the first differences estimations still found positive coefficients of the regressors used in the model, but since the one-period change in the level of subsidies is typically small, the coefficients were not precisely determined, i.e. most are insignificant. We also experimented with two-year differences so that there is more variation in the regressors. While results became marginally better, we face the trade-off between more variation in the differenced regressors and the reduction in sample size. Therefore, we decided not to present these results in more detail in this report.

Due to the poor performance of the SFA models, especially with respect to the convergence of more complicated models, it does not seem to be promising for conclusions towards policy recommendations. It remains to be checked if the DEA method delivers more robust results.

6.3. Non Parametric approach

6.3.1. DEA benchmark results and evolution over time

We implemented a DEA approach as described in Section 4.1 to perform efficiency scores in a one-output three-input framework, where GOVERD, HERD and BERDBYGOV represent the input indicators and BERD is used as output. Due to limited data availability, the B-index is excluded from the analysis and to allow for a better comparability of results with the ones reported in the previous section, variables are, except otherwise notified, taken in natural logarithms and averaged over five sub-periods, i.e. 1980-1984, 1985-1989, 1990-1994, 1995-1999 and 2000-2004.

Table 16 presents our benchmark results, i.e. efficiency scores for the output-oriented DEA with variable returns to scale. Note that efficiency scores are only reported for countries with data available over the whole period investigated to avoid differences due to time variations from one sub-period to the other. It follows that 3 countries out of 21, namely Japan, Switzerland and the United States are ranked in the first position and lie on the production possibility frontier. The other countries are inefficient in the sense that given their combination of inputs they achieve a lower amount of output as compared to the efficient countries which use similar combination of inputs. Among the most inefficient countries, we observe Greece (ranked in the 19th position), Norway (18), Portugal (17) and Spain (16). Iceland (2), Ireland (3), Sweden (4) and Germany (5) come close to the efficiency frontier, while Belgium (6), Finland (7), United Kingdom (8), France (9), Denmark (10), Austria (11), The Netherlands (12), Australia (13), Italy (14) and Canada (15) appear to be in an intermediary position.

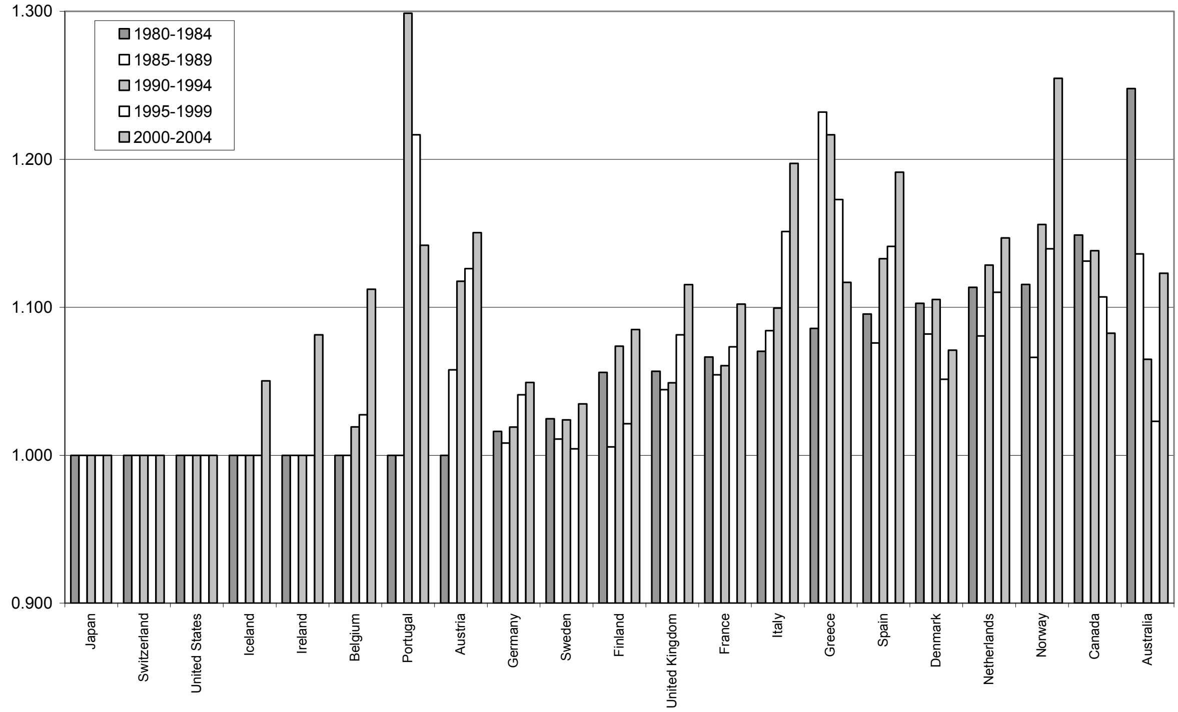
Table 16 DEA output efficiency scores - 3 inputs (lnHERD, lnGOVERD, lnBERDBYGOV), 1 output (lnBERD), variable returns to scale, Average over 5 sub periods, 1980-1984 until 2000-2004

Country	*Efficiency Score*	*Rank*	*Country*	*Efficiency Score*	*Rank*
Australia	1.119	13	*Italy*	1.120	14
Austria	1.090	11	*Japan*	1.000	1
Belgium	1.032	6	*The Netherlands*	1.116	12
Canada	1.122	15	*Norway*	1.146	18
Denmark	1.082	10	*Portugal*	1.131	17
Finland	1.048	7	*Spain*	1.127	16
France	1.071	9	*Sweden*	1.020	4
Germany	1.027	5	*Switzerland*	1.000	1
Greece	1.165	19	*United Kingdom*	1.069	8
Iceland	1.010	2	*United States*	1.000	1
Ireland	1.016	3			

Before performing a sensitivity analysis of these benchmark results in order to check their robustness, it is worth investigating their evolution over time and across countries. Here also, due to limited information at the beginning of the period investigated, it is not possible to consider all countries for all sub-periods. This is in particular the case for the new EU Member States. Figure 10 shows the evolution of efficiency scores of all countries for which information on inputs and outputs is available over the whole period[36]. Japan, Switzerland and the United States are the three countries which are efficient for each of the five sub-periods. This is also the case for Ireland and Iceland, except for the last sub period. For the other countries, efficiency scores appear to decline over time. This drop is more pronounced for countries like Austria, Italy, Spain and Norway. On the contrary, France, Germany and Sweden are characterized by a relative small decline of their efficiency scores. Finally, Canada and Denmark are the only two countries which improve the efficiency of their public R&D over time.

[36]Table A 7 in the Appendix reports the results for all countries.

Figure 10 Efficiency scores DEA output efficiency scores 3 inputs (lnHERD, lnGOVERD, lnBERDBYGOV), 1 output (lnBERD) variable returns to scale, 5 sub-periods (1980-2004)



Greece and Portugal are special cases as these countries exhibit relatively higher efficiency scores at the end of the period investigated and perform worse in the middle of the period. In particular Portugal shows a high inefficiency score during the 1990's. Another special case is Australia which shows relatively good efficiency scores in the middle of the period and yet is embedded by high inefficiencies in the first and the last period. Australia even has the largest inefficiency score among all countries considered during 1980-1984.

6.3.2. DEA results for the most recent period, New Member states and crowding out effects

Table 17 reports DEA efficiency scores based on the output-oriented method with variable returns to scale for the 2000-2004 period. This more recent period covers a larger number of countries among which the New Member States. It follows that 11 countries out of 42, namely Croatia, Cyprus, Estonia, Japan, Lithuania, Luxembourg, Malta, Romania, Switzerland and the United States are ranked in the first position and lie on the efficiency frontier. Note that with respect to the benchmark results and despite the higher number of countries on the frontier, Japan, Switzerland and the United States are still among the top efficient countries. Among the most inefficient ones, we observe Russia (ranked in the 29th position), New Zealand (30), The Slovak Republic (31), Latvia (32) and Poland (33) while France (12), Belgium (13), The United Kingdom (14), Greece (15), Australia (16), Portugal (17) and The Netherlands (18) appear to be in an intermediary position. The right hand-side part of Table 18 presents the group of country peers for each inefficient country. For Austria for instance, the closest efficient countries in terms of input combination are Japan, Luxembourg and Switzerland. These three countries represent in fact the peers of several other countries, i.e. Belgium, The Czech Republic, France, Germany, Israel, Italy, South Korea, Norway, The Slovak Republic, Spain, Sweden and The United Kingdom.

Interestingly, some new Member States are listed among the most efficient countries (Cyprus, Estonia, Lithuania, Malta) but also among the less efficient ones (The Slovak Republic, Latvia and Poland). The most likely explanation rests in the size of these countries in terms of R&D activities both in the public and private sectors and in terms of the R&D public intervention. Indeed all 'small' countries appear to be efficient. Not only do these countries represent a unique combination on inputs and output as compared to larger countries (and as a result are located on the efficiency frontier) but they are also located near the origin of both vertical and horizontal axes of the frontier. In this region, the frontier function is close to zero (and therefore the distance to the horizontal axis is small) and very downward sloping which explains why DMUs are more likely to be efficient. Note however that Latvia represents the only exception to this rule. Yet, if we look at the peers for these country, we see that Latvia is dominated by three other 'small' countries (in terms of R&D efficiency), namely Estonia, Luxembourg, Malta which are able reach a higher output given a similar mix of inputs.

Crowding out (or crowding in) effects and the unique transition situation characterizing some of these countries are two other factors may also explain their relative good (or respectively bad) performance[37]. As discussed in Section 3.3., another issue when using R&D expenditures as a measure for output is the crowding out effect through prices which can arise if the supply of the R&D personnel is inelastic at least in the short term. In order to control for this effect, it is possible to use a volume based indicator as an alternative output such as the R&D personnel in the private sector. The results based on the two output measures, i.e. business R&D expenditures and R&D personnel are reported in Figure A 4 (for the whole period) and Table A 8 (for the sub period 2000-2004) in the Appendix. Over the whole period, some differences can be observed for some countries. Noticeable differences are Croatia, The Czech Republic, Latvia, Portugal, Russia and Switzerland for different sub periods. Switzerland (for the period 2000-2004) for instance, is only ranked in the 14th position when output is measured by the R&D personnel in the private sector. This result can be explained by the crowding in effect through the wages of the researchers in this country. Given the shortage of researchers, an increase of public R&D shows up in higher wages of researchers but not necessarily in an increase of the number of R&D people hired. This effect also appears to be present in Sweden (2000-2004) and more surprisingly in Croatia (2000-2004) and in The Czech Republic (1995-1999). Conversely, given the low wages of the R&D personnel and the high supply of researchers in some countries like Russia (2000-2004), an increase of the public support to R&D will manifest in an increased demand and hiring of the R&D personnel. Therefore, when the number of researchers, scientists and engineers is considered for measuring output, Russia appears to be on the efficiency frontier. Latvia

[37] For Paasi (1998) for instance, the low level of R&D activities in the private sector and of interactions mechanisms and diffusion within transition economies and with other countries are two factors explaining the low efficiency of these countries to transform R&D inputs into economic performance. See also Cincera (2001) for a discussion.

(1995-1999) and (2000-2004) and to a lesser extent Poland (1995-1999) appear to be in a similar situation.

Table 17 DEA output efficiency scores - 3 inputs (lnHERD, lnGOVERD, lnBERDBYGOV), 1 output (lnBERD), variable returns to scale, 2000-2004

Country	*Efficiency Score*	*Rank*	*Peers*
Argentina	1.272	27	Croatia, Japan, Luxembourg
Australia	1.123	16	Croatia, Japan, Luxembourg, Switzerland
Austria	1.151	19	Japan, Luxembourg, Switzerland
Belgium	1.112	13	Japan, Luxembourg, Switzerland
Canada	1.082	10	Croatia, Japan, Switzerland
China	1.033	2	Japan, Luxembourg, United States
Croatia	1.000	1	Croatia
Cyprus	1.000	1	Cyprus
Czech Republic	1.263	26	Japan, Luxembourg, Switzerland
Denmark	1.071	7	Croatia, Japan, Luxembourg, Switzerland
Estonia	1.000	1	Estonia
Finland	1.085	11	Croatia, Japan, Luxembourg, Switzerland
France	1.102	12	Japan, Luxembourg, Switzerland
Germany	1.049	5	Japan, Luxembourg, Switzerland
Greece	1.117	15	Croatia, Japan, Switzerland
Hungary	1.283	28	Croatia, Japan, Luxembourg, Switzerland
Iceland	1.050	6	Croatia, Estonia, Lithuania, Luxembourg
Ireland	1.081	9	Croatia, Japan, Luxembourg, Switzerland
Israel	1.075	8	Japan, Luxembourg, Switzerland
Italy	1.197	22	Japan, Luxembourg, Switzerland
Japan	1.000	1	Japan
Korea	1.048	4	Japan, Luxembourg, Switzerland
Latvia	1.476	32	Estonia, Luxembourg, Malta
Lithuania	1.000	1	Lithuania
Luxembourg	1.000	1	Luxembourg
Malta	1.000	1	Malta
Mexico	1.196	21	Croatia, Japan, Luxembourg
Netherlands	1.147	18	Croatia, Japan, Luxembourg, Switzerland
New Zealand	1.339	30	Croatia, Japan, Luxembourg, Switzerland
Norway	1.255	25	Japan, Luxembourg, Switzerland
Poland	1.492	33	Croatia, Japan, Luxembourg, Switzerland
Portugal	1.142	17	Croatia, Japan, Luxembourg, Switzerland
Romania	1.000	1	Romania
Russia	1.294	29	Japan, Luxembourg, United States
Singapore	1.216	23	Croatia, Japan, Luxembourg, Switzerland
Slovak Republic	1.448	31	Japan, Luxembourg, Switzerland
South Africa	1.241	24	Croatia, Japan, Luxembourg, Switzerland
Spain	1.191	20	Japan, Luxembourg, Switzerland
Sweden	1.035	3	Japan, Luxembourg, Switzerland
Switzerland	1.000	1	Switzerland
United Kingdom	1.115	14	Japan, Luxembourg, Switzerland
United States	1.000	1	United States

For the former Eastern countries, for instance Croatia, The Czech Republic and Romania, it is also important to account for the unique situation of the economies of transition characterizing most of these countries and which may explain why some of them lie on the efficiency frontier. Initially, these states did not provide much financial support to R&D activities, in particular in the private sector and their research base (physical capital, research infrastructure) was wrecked. However, these countries had a relatively well-educated and highly-skilled labour force (human capital), which contributed to attracting R&D investment from abroad and ultimately to increasing the level of R&D activities.

6.3.3. Sensitivity analysis

A sensitivity analysis has been conducted to check for the robustness of the benchmark results. Additional efficiency scores have been performed by changing some parameters of the DEA method, by using alternative methods, e.g. the FDH one. Different specifications have been tested by considering alternative inputs. The sensitivity of results towards different sample compositions in terms of countries has also been investigated. The full results reported in the Appendix are discussed in what follows.

As discussed in sections 3.1 and 4.1, technical efficiency can be measured by considering that a given output is produced by minimizing the use of inputs (input-oriented method). Table A 9 in the Appendix shows the input-oriented variable returns to scale based efficiency scores which rather confirm our findings from the output-oriented approach since they identify the same set of efficient and inefficient countries.

In terms of return to scales, a country which is efficient under constant returns to scale will also be efficient under variable returns to scale but the converse does not necessarily holds. This will be the case when a country is scale efficient. Interestingly, the scale efficiency terms reported in Table A 9 in the Appendix indicate that countries like Japan, the United States and Romania and to a lesser extent Croatia and Lithuania are not operating at the most productive scale size. The scale inefficiency terms of these countries are above one suggesting that they operate at decreasing returns to scale, i.e. a proportional increase of all inputs producing a less than proportional increase in output.

Table A 9 in the Appendix also illustrates the output-oriented FDH results for the 2000-2004 period. The FDH efficiency scores are not really conclusive since almost every country lies on the production possibility frontier. Therefore it is quite reasonable to focus on the DEA approach as it seems like more stringent assumptions are needed to identify efficient and inefficient producers. In fact, a country that is efficient under FDH is not always efficient under DEA, but a country efficient under DEA will be always efficient under FDH.

Finally, Table A 9 in the Appendix also reports efficiency scores performed by mean of a Simple Composite Index (SCI) method[38]. A lower value of this index is associated with a higher efficiency performance. The three most efficient countries under the DEA method are still the most efficient under the SCI one. Yet, this appears not to be the case for smaller

[38] The SCI is defined as an unweighted sum of the three inputs, i.e. HERD, GOVERD and BERDBYGOV divided by the output, i.e. BERD.

countries, in particular among the New Member States. Conversely, some countries that were not (fully) efficient under DEA are now among the ones with the highest efficiency performances. This is in particular the case for Finland, Germany, Israel and Korea. In a nutshell, except for some small New member States, we can conclude that results based on the two methods are globally the same.

Table A 10 in the Appendix compares the efficiency results when the three inputs and the output are taken in levels rather than in natural logarithm. Here also, except for Croatia, Estonia and Lithuania, the group of the most efficient countries is globally the same in both cases. As said before, the B-index was not included in the DEA analysis since this indicator of the fiscal generosity of governments towards R&D is only available for a sub sample of countries and sub-periods. As a result, when we include this input measure, the number of country-observations is much lower as expected. Yet, except for Argentina, the group of the most efficient countries is again globally the same when the B-index is included as an additional input as can be seen from Table A 11 in the Appendix.

As a last test for assessing the robustness of the benchmark efficiency scores, we applied the DEA on different samples of countries (from the full sample of 42 countries to the smallest one composed of the EU15 Member States only). As it can be seen from Table A6 in the Appendix, countries that exhibit the highest efficiency scores remain on the frontier when smaller samples are considered. On the same time, countries that were almost efficient become fully efficient.

6.3.4. Determinants of efficiency scores: Tobit regressions

The objective of this section is to assess the impact of different determinants discussed in Section 2.2 on the efficiency scores. Among these determinants, we can make a distinction between the B-index, the quality of the regulatory framework[39], administrative, institutional as well as business factors enhancing R&D activities and affecting the efficiency of public spending in support of R&D. Thus, we continue the study by discussing the results as regards the determinants of efficiency scores obtained through the DEA analysis[40]. In order to maximize the number of observations, all country's efficiency scores available on the five sub-periods have been taken into account. This leads to an unbalanced panel of 142 observations for 42 countries. The efficiency scores represent the dependent variable which is

[39] Note that the dependent variable, i.e. the efficiency scores, takes values between one and above, one representing the best score. The determinants related to the regulatory framework and which come from the Fraser Institute take values ranging from 1 to 10 according to the level of economic freedom or regulation. A value of 10 indicates the highest level of economic freedom and the lowest level of economic regulation. Hence, a negative estimated coefficient associated with these determinants must be interpreted as having a positive impact on efficiency scores.

[40] All findings unless otherwise notified refer to the DEA scores based on the natural logarithm of R&D expenditures.

left-censored to one. As explained in Section 4.1, this kind of data can be estimated through a Tobit regression method in the context of panel data[41].

Country groupings

In a similar vein as for the SFA analysis, we also investigate the impact on efficiency of a set of dummy variables representing different 'groupings' of countries. The first grouping is defined as in Section 6.2.3. As alternatives, four other grouping of countries have been considered as well[42]. The first one operates a distinction between the level of GDP per capita (low, medium and high GDP per capita[43]), the second one divides countries according to whether they are part of the Internal market[44] or the Euro area[45]. The third and fourth ones split the countries into three groups based on the Summary Innovation Index developed for the European Scoreboard and the size of government. For the SSI, the group of countries with the highest values of this index refers to the most efficient countries in terms of transforming innovation inputs, i.e. education and investment in innovation, into innovation outputs, i.e. turnover coming from new products, employment in high-tech sectors and patents[46]. For the size of government, the grouping is based on general government consumption spending as a percentage of total consumption released by the Fraser Institute.

Note that due to collinearity of data, it was not possible to include all the determinants in the specification. The same issue has been encountered for the B-index whose results are inconclusive. For each regression, log-likelihood ratio tests to discriminate between random effects and no fixed effects have been performed systematically[47]. Except in a few cases, the performed statistics associated with these tests reject the null hypothesis of no fixed effects, i.e. pooled model, hence justifying the use of random effect panel data Tobit models[48].

Table 18 reports the result of the panel data Tobit regression of the impact of the five different groupings of countries, i.e. the EU15 Member states, the new 10 Member States, the rest of Europe, highly industrialized countries and other countries in the rest of the world (column 1); countries belonging to the internal market and the Euroland (column 2); low vs. medium and high GDP per capita countries (column 3); low vs. medium and high values of the SSI (column 4) and size of government (column 5).

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[41] Remember that if the determinants are highly correlated with the inputs and outputs used in the first stage then the estimates are likely to be biased. The correlation matrix reported in Table A 13 in the Appendix indicates that this is indeed the case for some determinants.

[42] See Appendix 7 for the lists of countries for the different groupings.

[43] The threshold for low (respectively high-) GDP per capita has been defined by considering the first (respectively the third) quartile of the GDP per capita series.

[44] A dummy variable has been constructed which takes values zero before the year of a country's adhesion to the EU and one after.

[45] Currently, there are 12 countries in the Euro area, the last Member being Slovenia which joined in 2007.

[46] See http://www.proinno-europe.eu/index.cfm?fuseaction=page.display&topicID=275&parentID=51.

[47] Note, that that for mixed continuous and discrete likelihoods like the Tobit one, log-likelihoods can be positive.

[48] Note that due to practical estimation problems, fixed effect Tobit models (Honoré, 1992) have not been considered here.

The results partly confirm the ones obtained with the SFA analysis as only the high tech countries, i.e. Canada, Japan, Korea and the US, are more efficient as compared to the reference group composed of the new EU10 Members states. The coefficient associated with the dummy variable representing the rest of Europe has also a negative sign but is not statistically significant at the 10 % level. For the DEA scores performed on the basis of the natural logarithm of the R&D personnel as an output, the results of the Tobit regression are the same as the ones performed with SFA method, i.e. the former EU15 Member states are less efficient than the New EU10 ones. This result can be partly explained by the crowding out effect which is more severe in the EU15 countries compared to the new Member states[49]. The countries that belong to the EU and to the Euro zone do not appear to be more or less efficient than the other ones. In terms of GDP per capita, countries in an intermediate position with respect to this indicator are characterized by lower efficiency scores of their public R&D support funding. Unsurprisingly countries that exhibit intermediate and higher values of their SSI are more efficient while higher government expenditures in percentage of total consumption are associated with lower performance in terms of efficiency.

[49] It follows from Table A.8 in the Appendix that the average DEA efficiency score over the 2000-2004 period for the EU15 is higher for the DEA results based on the R&D personnel as an output as compared to the efficiency scores based on R&D expenditures (1.159 against 1.106) and conversely for the new Member states (1.139 against 1.218).

Table 18 Impact of different groupings of countries on DEA efficiency scores
Panel data TOBIT regression

Dependent Variable: DEA unpredicted efficiency scores based on ln(BERD)	(1)	(2)	(3)	(4)	(5)
Former EU15 Member states	0.016				
	(0.051)				
Rest of Europe	-0.082				
	(0.054)				
Other High-Tech	-0.105 *				
	(0.054)				
Other countries	0.091				
	(0.076)				
Internal market		0.004			
		(0.024)			
Euro area		-0.001			
		(0.051)			
Medium GDP per capita			0.205 **		
			(0.094)		
High GDP per capita			0.141		
			(0.100)		
Medium SII				-0.152***	
				(0.054)	
High SII				-0.211***	
				(0.055)	
Medium size of government					0.105***
spending in % of total consumption					(0.027)
Large size					0.094***
spending in % of total consumption					(0.033)
# of obs. [left censored]		143 [44]		26 [26]	102 [34]
Log-Likelihood	52.1	47.9	53.0	7.28	48.4
LR-test for random effects	41.9 ***	50.8 ***	48.7 ***	0	44.5 ***

Notes:
*Annual dummies included; standard errors in parentheses; reference groups: new EU10 Member States, low GDP per capita countries; *** (**, *) denote a significance level of 1% (5%, 10%).*

Regulatory and macroeconomic conditions

Table 19 shows the results of the random effects panel data Tobit regression of five general regulatory framework factors enhancing R&D activities of firms in the private sector and which may explain differences in the observed levels of the efficiency of R&D public support. The composite indicators refereeing to the freedom to trade internationally and the regulation of credit, labour and business are not statistically significant. Nevertheless, if we have a closer look at the main components of these composite indicators[50], we observe a positive and significant impact of a more favourable tax regime to international trade as well as more deregulation in the labour and business markets on the efficiency scores. Access to sound money does not appear to positively affect public R&D efficiency. Yet, none of the

[50] These results are reported in Table A 14 in the Appendix.

components of this factor is significant. The overall impact of the size of governments in terms of expenditures, taxes and enterprises on efficiency appears to be positive. This is particularly the case for transfers and subsidies as a percentage of GDP and the importance of government enterprise and investment in the economy. On the contrary, the share of the general government consumption in percentage of total consumption negatively affects the efficiency scores which confirm the findings of column (5) in Table 18. The last set of regulatory framework conditions concern the legal structure and security of property rights. As regards the former, i.e. judicial independence and impartial courts, a positive impact is found, while an opposite finding holds for the military interference in rule of law and the political process. Interestingly, a higher protection for property rights is associated with a negative impact of R&D efficiency.

The bottom part of Table 19 displays the effects of macro economic conditions, i.e. inflation and average GDP growth on public R&D efficiency. As expected countries with high inflation rates appear to be less efficient while economic growth does not seem to affect efficiency scores.

Table 19 Impact of regulatory and macroeconomic conditions on DEA efficiency scores Panel data TOBIT regression

Dependent Variable: DEA unpredicted efficiency scores based on ln(BERD)		
Size of government: Expenditures, taxes and enterprises	0.022 (0.009)**	
Legal structure and security of property rights	-0.025 (0.012)**	
Access to sound money	0.027 (0.009)***	
Freedom to trade internationally	0.007 (0.013)	
Regulation of credit, labor, and business	-0.020 (0.016)	
Inflation		0.002(0.001)***
GDP growth		0.117(0.260)
# of obs. [left censored]	142 [43]	102 [34]
log-likelihood	56.1	46.1
LR-test for random effects	54.5 ***	40.2 ***

Notes:
Annual dummies included; standard errors in parentheses;
**** (**, *) denote a significance level of 1% (5%, 10%).*

Administrative, institutional and business conditions

Table 20 displays the estimates as regards the impact of administrative, institutional factors as well as business conditions that may enhance the R&D activities in the private sector and affect the efficiency of public R&D policies. Note that here also, given collinearity issues it has not been possible to include all these determinants in the same specification. Therefore their impacts on efficiency are discussed separately. Furthermore, the results should be cautiously interpretated as the number of observations available is limited and sample sizes change from one set of determinants to the other. Among the administrative and institutional determinants, we consider the share of enterprises that benefited from public funds for their innovative activities. Independently from the amounts received, the higher this share, the larger the number of firms supported and the more the administration in charge of the management of such funds can be considered to be efficient. Joumard et al. (2004) discuss different strategies that have been recently implemented by countries to limit the growth of their public spending and establish priorities across their programmes expenditures. Among these measures, we can mention a more effective control of spending growth, to anchor the budget process in a medium-term perspective or less fragmentation in budgets and more transparency. Unfortunately, the information on such budget practices is quite recent and rather coarse which may explain why the results shown in Table 4 appear to be not significant[51].

Among the factors affecting the efficiency of R&D activities, two factors have a positive impact on the public R&D policy efficiency scores. The first indicator is the SII which evaluates and compares the innovation performance of the EU Member states and other industrialized countries in the world. As in the previous table, countries with the best performance in terms of innovative activities are also the ones that exhibit the highest efficiencies of their public R&D support. Second, in terms of industrial structure, economies with a higher share of high-tech manufacturing sectors in the total manufacturing value added benefit from higher efficiency performance of their public R&D supporting policy instruments. Among the factors with a negative and significant impact on public R&D efficiency, we find the importance of public procurement advertised in the Official Journal as a percentage of GDP and as a percentage of total public procurements as well as the strength of the IPR system. Jaumotte and Pain (2005a) obtain a similar result for this last determinant. As emphasized by these authors, a stronger IPR system can encourage firms to carry out more R&D[52] and at the same time can make it more difficult for R&D firms to access knowledge. However for this last determinant, the conclusion must be mitigated as a positive and significant impact on efficiency is detected when the regression is restricted to the EU15 Member states and the most industrialized countries worldwide while a negative effect is observed for the New Member States and countries of the Rest of the world taken alone.

Among the other determinants of efficiency which are not significant, we find the intensity of industry-university linkages, the share of fundamental or basic R&D in total business R&D activities, the importance of public credit appropriation outlays in the defense sector as well as the share of researchers, scientists and engineers in the total population or in the total R&D personnel. These results confirm the idea that the synergies in terms of S&T production, diffusion and absorption between the public and the private sector could be certainly strengthened and their effectiveness could also be improved. Then the risks and uncertainties inherent to more basic R&D limit the efficiency of the public funds for this type of research.

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[51] For this variable, we constructed a dummy variable taking values one if a given measure has been introduced.

[52] Given the amount of public support to R&D, firms will have more incentive to do R&D when the IPR system is stronger. Yet, if the access to the knowledge base is difficult, it will hamper the R&D activities of firms even in the presence of R&D public incentives.

Table 20 Impact of administrative, institutional and business determinants on DEA efficiency scores - Panel data TOBIT regression

Dependent Variable: DEA unpredicted efficiency scores based on ln(BERD)				*# obs.*	*Log-Like-lihood.*	*LR test*	
Administrative and institutional R&D enhancing factors							
More effective control of public spending growth	-0.005	(0.045)		21	4.8	T	
Anchoring the budget process in a medium-term perspective	0.016	(0.035)				T	
Reduced budget fragmentation and increased transparency	-0.013	(0.018)				T	
Share of enterprises receiving public funding for innovation	-0.002	(0.004)		46	6.4	3.1	**
Business R&D enhancing factors							
Summary Innovation Index (SII)	-0.404	(0.199)	**	31	-1.98	T	
Public procurement advertised in the Official Journal as a % of GDP	0.024	(0.008)	***	43	58.3	22.6	***
Public procurement advertised in the Official Journal as a % of total public procurements	0.005	(0.001)	***	42	57.8	21.5	***
Industry university links (business funded R&D performed in other sector than the business one)	-0.001	(0.001)		113	38.4	48	***
Basic R&D performed in the private sector in % of total business R&D	0.016	(0.013)		46	-4.2	11.1	***
Share in % of researchers, scientists & engineers In the private sector as a % of total active population	-0.126	(0.117)		50	13.8	7.1	***
Share in % of researchers, scientists & engineers In the total business R&D personnel	-0.001	(0.003)		50	13.2	8.5	***
Share of Public Credit Appropriation in the defence sector	0.001	(0.001)		84	49.5	43.7	***
Strength of the IPR system							
Full sample	0.030	(0.006)	***	65	34.4	19.2	***
EU15 Member States and most industrialized countries	-0.037	(0.003)	***	41	47.2	24.8	***
New EU Member States and rest of the World	0.132	(0.013)	***	23	8.71	3.62	**
Share in % of high-tech sectors in total manufacturing value added	-0.008	(0.004)	*	35	15.3	T	

Notes:
Annual dummies included; standard errors in parentheses for generalized Tobit pooled regression;
**** (**, *) denote a significance level of 1% (5%, 10%).*

The last set of determinants concerns the supply or the stock of researchers available in the economy which can be measured by the share of researchers as a percentage of the population as well as the quality of the research environment which can be proxied by the share of researchers, scientists and engineers in the total R&D personnel[53]. Here also these two factors do not seem to affect in a particular way the efficiency of the public funds to support the R&D in the private sector.

6.3.5. Predicted efficiency scores

The estimated coefficient from the Tobit regression models obtained for the different sets of determinants are used to predict the DEA efficiency scores of countries. In comparison to the unpredicted (or unconditional) scores, the predicted ones are useful to determine whether countries are performing better (or worse) than it would be expected given the environmental

[53] The higher this share, the less researchers will be assisted for other tasks than pure research.

variables, i.e. given the fact that we control for the role played by the different sets of determinants on the economy.

Figure A 5 compares the unpredicted DEA efficiency scores and the corresponding ones predicted by regulatory framework conditions of the Fraser Institute. We also compare the unpredicted and predicted scores performed by taking the natural logarithm of R&D expenditures and personnel as outputs. Finally, for the predicted scores, we also compare the results based on the pooled and the random effect Tobit models[54].

In all cases, the conditional scores differ quite a lot with respect to the unpredicted ones suggesting that regulatory conditions matter in explaining countries' performance in terms of the efficiency of their public R&D spending. Conversely, predicted scores based on both pooled and random effect Tobit models and on R&D expenditures and personnel do not differ to a great extent. For the later, the main differences are again observed for some new Member States for which, as already discussed, crowding-in effects of their R&D expenditures are likely to be more pronounced.

6.4. Comparison of efficiency scores and determinants: SFA and DEA

In this section, we compare the efficiency scores obtained from the SFA and the DEA methods as well as their determinants.

6.4.1. Efficiency scores

In order to assess the consistency of the results between the two methods, we show the estimated efficiency scores in a scatterplot. Note that these scores should not be interpreted as percentages or related terms of inefficiencies. In order to illustrate the consistency of the results, we standardized the scores of both methods by subtracting the mean value and dividing by the standard deviation of the estimated scores. The overall levels of the scores are not comparable, we are only interested in the correlation of the scores that is, do the efficiency ranks of the countries obtained from the two methods broadly coincide?

Figure 11 shows the correlations of the predicted efficiency scores from the regression of ln(BERD) where the Fraser institute variables are included in the efficiency term (cf. Table 15 for the SFA and Table 19 for the DEA results). Note that this comparison has not been done for the raw or unpredicted efficiency scores as there is basically no variation across countries for these indexes for the SFA method. The predicted or conditional efficiency index reflects the average efficiency observed over the whole time period. The closer a country is located to the origin of the coordinate system, the higher is its efficiency. The graph shows that there is congruence of ranks to a large extent. The vertical and horizontal lines split the countries into a high, medium and low efficiency group according to each method based on the rule that

[54] Note that the likelihood ratio tests of the Tobit panel regression vindicate the use of random effect models rather than pooled cross-sectional models (no countries specific effects). Yet, it may be worth comparing the predicted efficiency scores we get from these two models.

each group contains one third of the countries. As can be seen, the majority of countries is in the same group (high, medium, low) for both methods.

Iceland may be seen as an outlier, as it is highly efficient in the DEA but ranks much lower in the SFA results. Thus it is located far away from the main diagonal "boxes". Similarly, the results of DEA and SFA differ considerably for Belgium, Luxembourg, and Mexico.

The results for most of the other specifications are different and are not presented in detail here. Besides the technical differences between the SFA and the DEA (number of observations, assumptions as regards the form of the specification and the distribution of the error term for the SFA, the collinearity between the determinants and the variables used in the first stage for the DEA method and so on), another source of divergence among the results rests in the significance of the determinants which differs across methods[55].

Similar issues arise when we are interested in comparing the SFA and DEA predicted efficiency scores performed by means of the R&D personnel. The scores conditional to the regulatory conditions for instance are different and lead to a different ranking of countries' efficiencies. Therefore these results are not reported here. Rather, Figure 12 shows the rankings of countries based on the DEA predicted efficiency index obtained for the R&D expenditures and the R&D personnel. We can observe a certain consistency between the two models, the main differences, once again, mainly concern the countries likely to be affected by crowding out and crowding in effects.

In a nutshell, the comparison of the predicted efficiency scores in Figure 11(SFA vs. DEA) leads to a ranking of countries (in alphabetical order) into three groups. Those groups represent the list of countries where efficiency scores obtained from the both models lead to very similar conclusions:

- Top performers: Australia, Canada, Finland, Germany, Japan, Netherlands, New Zealand, Singapore, Switzerland, and the USA.
- Average countries: France, Hungary, Italy, Korea, Norway, Sweden, Spain and the United Kingdom.
- Less efficient countries: China, Croatia, Czech Republic, Israel, Latvia, Poland, Romania, Russia, Slovak Republic.

For other countries, the results indicate that they score differently in the both models. For instance, Austria, Belgium and Denmark are among the top performers in the SFA, but only in the medium category when DEA is used, whereas Iceland and Ireland are top in the DEA, but only medium in the SFA. A large outlier is Mexico that is among the worst three countries

[55] For instance the results from the regressions where the internal market and the Euro area enter the conditional mean function of the efficiency term lead to a large discrepancy among the models. This is due to the fact that the two models do not deliver coherent results. While the SFA detects variation in the efficiency levels, the Tobit regression based on the DEA does not report systematic variations across countries.

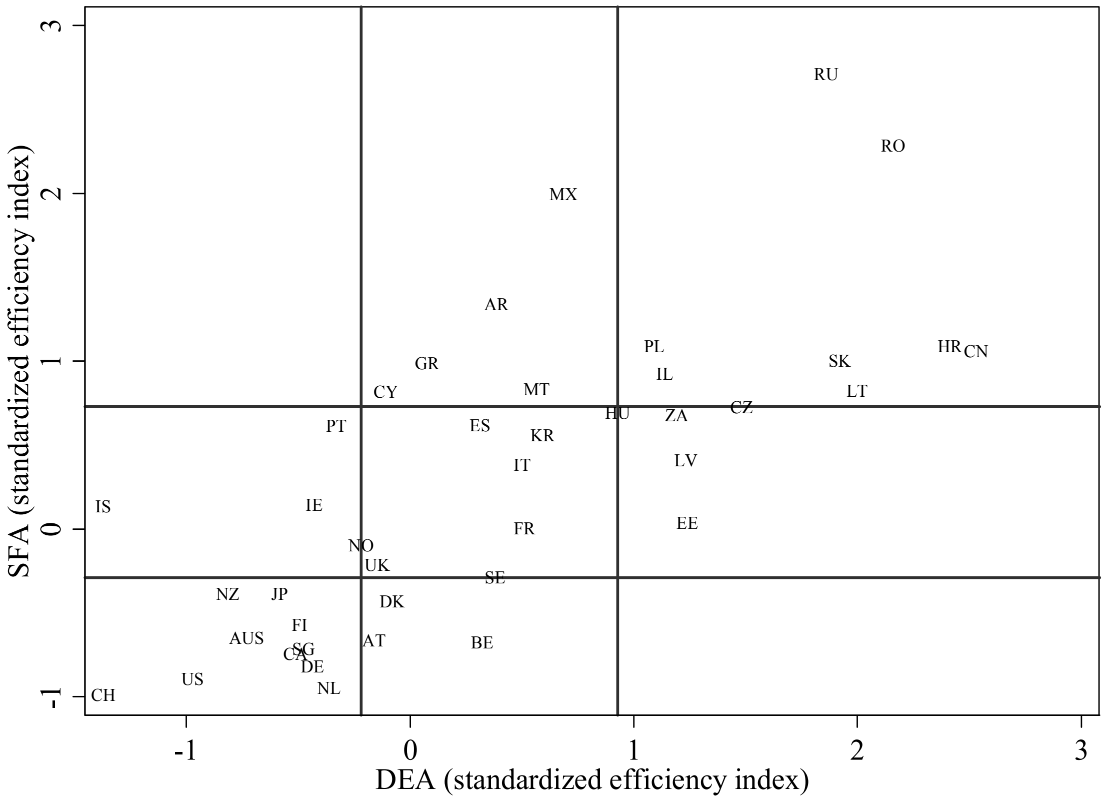
in the SFA but in the medium category in the DEA. Thus, for some countries the model outcome when compared across methods remains inconclusive.

Regarding the comparison in (R&D expenditures vs. personnel) the following countries belong to the three comparable groups for both models:

- Top performers: Australia, Canada, Iceland, Ireland, Japan, New Zealand, Portugal, Singapore, Switzerland and the United States.
- Average countries: Austria, Belgium, Cyprus, Denmark, Greece, Hungary, Italy, Korea, Norway, Spain, Sweden, France.
- Less efficient countries: China, Croatia, Czech Republic, Latvia, Lithuania, Luxembourg, Poland, Romania, Russia and the Slovak Republic.

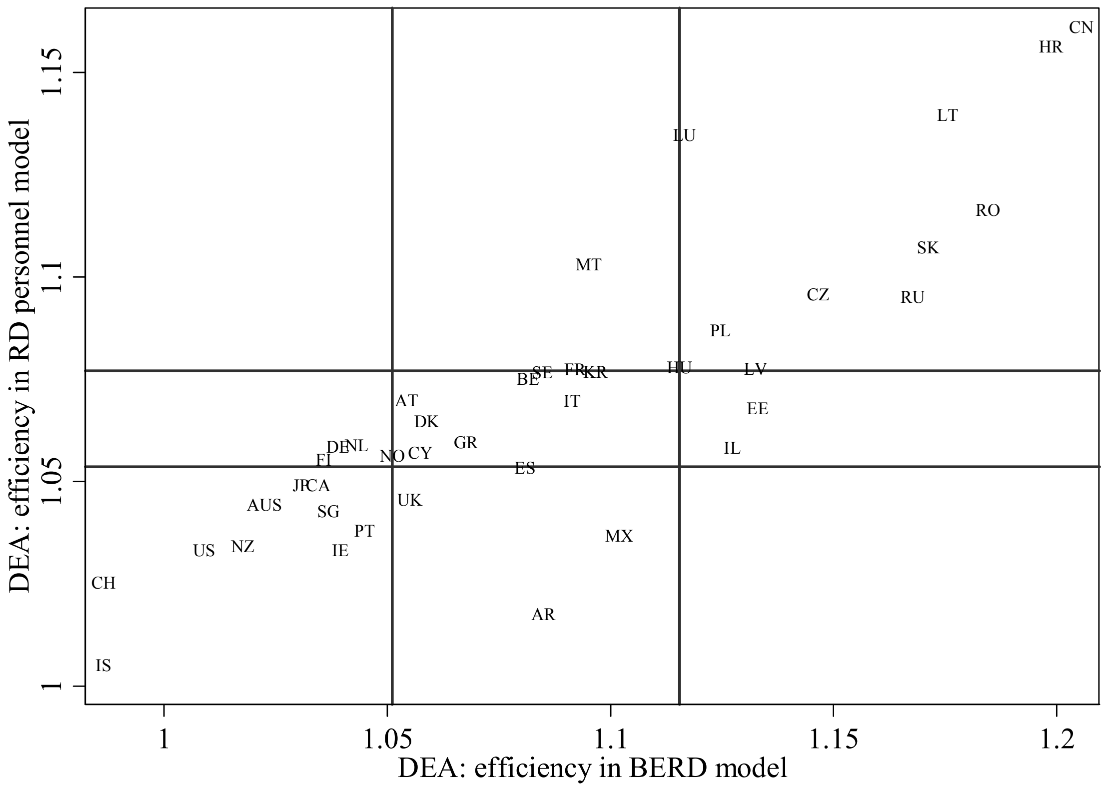
The results of the comparison of BERD and R&D personnel when both scores are obtained from the DEA method shows that the results are more harmonized than in the case when results are compared across models. Even the countries that score differently on BERD and personnel are closer to the "borders" of the comparable efficiency scores of the two models. For example, Finland, Germany and the Netherland score "only" medium on personnel but are in the top third of the BERD results. However, in the BERD's medium group they are just a little above the top performers threshold values. The only larger outliers are Argentina, Mexico and Malta which score somewhat more different on personnel and BERD.

Figure 11 Comparison of efficiency scores obtained from SFA vs. DEA



If one compares a more similar set of countries, such as the old EU Member States, however, we find that they score very similar in both the comparison across methods and across personnel vs. BERD. Even when some of them are mentioned above as having different results in the sense that they end up in the medium group in one case and in the top group in another case, it should be noted (see the two figures summarized above) that they are quite close to border of the top or medium performers, respectively, in all cases. The largest exception is Belgium that scores high in the SFA on BERD but only medium – while being somewhat further away from the threshold to the top – in the DEA on BERD. Otherwise, we do not find larger differences in the efficiencies in the older EU Member States which point to the conclusion that the highly industrialized countries in Europe have somewhat more harmonized policy mixes in comparison to other countries.

Figure 12 Comparison of DEA efficiency scores: R&D expenditures vs. personnel



If we take a closer look at the countries in the top performers with respect to the estimated efficiency scores, it turns out that there is no single policy mix that may ensure that countries score high on the efficiency levels. For instance, the United States turn out as highly efficient in the analysis. Given the fact, however, that many of the top universities in the U.S. are private but not public schools, the HERD is ranging only in the average of the countries considered (taken relative to GDP and averaged across the whole time period for simplicity)[56]. However, the U.S. scores high on government-funded BERD and R&D conducted in the public sector (GOVERD). Compared to, for example, Switzerland, the U.S. has implemented a very different policy mix. Switzerland ranges among the top countries

[56] Compare with Table 3 in the descriptive statistics section.

with respect to HERD, but only below average in government-sponsored BERD and even among lowest countries with respect to GOVERD. Japan, in contrast, is similar to Switzerland in government-sponsored BERD and HERD, but is clearly above average in terms of GOVERD, too. Thus, one cannot identify a single strategy, e.g. high or low public spending on all types of expenditure that leads to high efficiency. It should be noted, however, that the older EU Member States typically range in the upper third of the distribution of countries with respect to all types of public R&D spending (HERD, GOVERD, BERDBYGOV). In terms of efficiency scores with respect to BERD or R&D personnel they also score mainly among the upper third of countries. Again, their policy mix is different from Switzerland, Japan and the US, but it also yields high efficiencies in the models applied.

6.4.2. Determinants

The results as regards the determinants explaining the efficiency scores obtained from the two methods and for the R&D expenditures and personnel are reported in Table 21. On the whole, it appears that for R&D expenditures and SFA results, countries from the former EU15, the rest of Europe, the most industrialized countries and other parts of the world are more efficient as compared to the new Member states. These results are partially confirmed by the DEA method and for the R&D personnel. When this output is considered to perform the efficiency index, former EU Member states are found to be less efficient which can be explained by a crowding out effect of their public R&D support. This result is also observed when the DEA method is performed. When we consider the membership to the European internal market and the Euro area, only the SFA based results are significant. The findings are in line with previous ones, i.e. belonging to the Euro area leads to less inefficiencies for the R&D expenditures and being part to the Internal market to more inefficiencies for the R&D personnel. These results are again consistent with the crowding out effect of public R&D.

Table 21 Determinants of efficiency scores: Comparison of SFA and DEA methods

Method	SFA/panel		DEA/panel	
Output	R	P	R	P
Determinants				
Country groupings				
World regions				
EU15	-	+		+
Rest of Europe	-	-		
High	-	-	-	
Other	-	-		
Internal market and Euroland				
IM		+		
Euro	-			
GDP per capita				
Medium			+	+
High	-	-		
Regulatory conditions				
Size of government	-	-	+	
Legal structure	-		-	
Access to sound money			+	+
Freedom to trade				
Regulation				+

Notes:
R = R&D expenditures; P = R&D personnel; The sign '-' refers to a negative impact of the determinant on inefficiency, i.e. a positive impact on efficiency, and conversely for the sign '+'; Only the signs of the variables that were significant (at the 10% at least) are reported.

The results obtained when we group the countries according to their GDP per capita levels are consistent across outputs (R&D expenditures vs. personnel) and within methods (SFA vs. DEA). With respect to the reference group, countries with the highest GDP per capita are the less inefficient and countries in an intermediary position appear to be more inefficient.

The last set of determinants reported in Table 21 concerns the framework conditions of the Fraser institute. It follows that the results between the SFA and DEA methods are less comparable except for the legal structure which has a positive impact on the level of efficiency. For the size of the government determinant, an opposite effect on efficiency is found between the two methods. However, when this variable is further decomposed a negative sign is also observed for the DEA model. A negative impact on efficiency of a better access to sound money and a higher level of deregulation are also observed for the DEA model. Yet, here also, the findings are not confirmed by the specifications based on the sub-components of these determinants.

Note that the comparison of results for the administrative, institutional and business conditions that may directly enhance R&D activities in the private sector and indirectly affect the efficiency of public R&D spending is not reported here since no results as regards the impact of these determinants were found for the SFA. This is a main limitation of the SFA method stemming from the poor availability of data for this kind of indicators[57].

7. Conclusions

The objective of this study was to develop a methodological framework to assess the efficiency of the main public R&D instruments implemented by countries to support R&D activities in the private sector. Among these policy measures, we made a distinction between four main categories of instruments, i.e. direct subsidies, tax incentives and R&D performed in the public sector (higher education and government sectors).

The study rests on the concept of efficiency which is based on the relationship between policy instruments to increase firms' R&D activities (inputs) and the additional R&D induced by such measures (output). As such the study can be considered as a first step of the analysis of the effects of R&D on the outcomes of such activities, e.g. GDP or TFP growth. Various indicators and statistics mainly from EUROSTAT and the OECD have been collected to measure the level of efficiency of these instruments and compare them across countries for the last two decades. The analysis is not restricted to EU Member States, but also takes other OECD countries into account. Especially, the comparison to Japan and the United States is interesting as a benchmark.

The differences observed in the efficiency performance across countries have been investigated and explained by control variables (exogenous framework conditions), e.g. the nature of competition, the quality of the business environment, the IPR regime, the access to markets and to external financing conditions, and administrative and institutional factors possibly influencing the effectiveness of public R&D with respect to stimulating R&D activities in the business sector.

At the macro economic level, the assessment of the efficiency of public policies and of their determinants are generally achieved by means of parametric and non- parametric econometric methods. Among these, the Data Envelope Analysis (DEA) and the Stochastic Frontier Analysis (SFA) have been the most widely used in the literature. Each method has its own advantages and drawbacks. SFA is sometimes preferred as it accounts for measurement errors and other statistical noise. Unlike the DEA approach, it also delivers the possibility to test for statistically significant inference on the estimated inefficiencies. However, it requires – compared to DEA – quite restrictive assumptions on functional forms and the distribution of error terms, in particular the distribution of the inefficiency term. This method, in order to be fully operational, also requires a quite large number of observations.

57 Data are in general only available over a short and recent time period.

The results obtained as regards the efficiency scores have been investigated by considering not only the two methods (SFA vs. DEA), but other methods as well (FDH, Simple Composite Method), dependent variables (BERD and R&D personnel in the business sector), and different data samples (cross-sectional versus panel data; sub-periods vs. averaged data). With respect to the estimated inefficiencies, unconditional and conditional mean estimates have been applied. The latter allow to explain possible inefficiencies of countries by a set of determinants, e.g. country groupings (EU vs. non-EU; high, medium, low income) or more structural variables, such as regulatory framework, administrative, institutional and business conditions and other indices. Several different sets of these determinants have been tested in the study.

A first result that can be concluded from the exploration of the SFA versus the DEA method is that the SFA technique is very sensitive to the model specification. Given our data, it frequently happened that the estimation did not converge at all. Thus, the suitability of the SFA for efficiency analysis turned out to be quite limited. Although several results are comparable to the DEA analysis, the SFA could only be applied to a limited set of determinants explaining potential inefficiencies of countries. On the one hand, a large number of interesting indicators was only available for a few countries so that the small sample size explains the undesirable property of not converging estimations in SFA applications. On the other hand, even if determinants were available for the full set of observations, it frequently happened that the SFA did not converge. Therefore, the DEA seems to be a more suitable method in practice, as it always converges and does not suffer from as restrictive assumptions as the SFA that may make its application fail.

Turning to the economic results, it turned out that the comparability of the DEA and the SFA is not fully satisfactory. While several results are robust and consistent across the different methods and model specifications, some efficiency determinants are found to have opposite signs in the SFA and DEA (although they may not be significant in one of the methods). Nevertheless, for a large set of countries similar efficiency indices can be found when comparing SFA and DEA. In the case of the models on BERD, it turns out that following countries are ranked as most efficient by both methods: Australia, Canada, Finland, Germany, Japan, Netherlands, New Zealand, Singapore, Switzerland, and the United States. The investigation of R&D personnel in comparison to BERD using the DEA method led to the result that following countries are among the most efficient for both outcome variables: Australia, Canada, Iceland, Ireland, Japan, New Zealand, Portugal, Singapore, Switzerland and the United States. In a nutshell, the different models and specifications find the coherent results that the Finland, Germany and the Netherlands for the EU Member States and the United States, Japan and Switzerland can be seen as highly efficient countries, irrespectively of model specification or method used. Also Austria, Denmark, Ireland and the United Kingdom for the EU and Australia, Canada, New Zealand and Singapore score high in each of the models.

In terms of the determinants that influence the efficiency of a country, the possibility of comparisons across methods are limited as the SFA does not work in many cases. However, when looking at the whole set of results, two factors emerge as positively affecting efficiency levels: the strength of the IPR system, and, the alternative measure from the Fraser institute's data, the composite indicator of legal structure and security of property rights. When looking at the values of these factors for the highly efficient countries mentioned above, it turns out that they all score high on these. While many country characteristics certainly play a role for the incentives to invest in R&D, the results of this study clearly refer to the importance of a well functioning system for securing intellectual property. For Europe, the results obtained give clue that while the strength of the IPR system in Europe still varies considerably even among European member states in recent time periods (at least in the indicators we used), an improvement and harmonization of such a system will possibly support efficiency improvements of public R&D spending. Especially the less developed economies of the old Member States and even more the New Member States show lower scores on the quality of the IPR system.

Keeping in mind that R&D investment of a firm is possibly one of the riskiest investment decisions managers have to make, it is highly plausible that well-established appropriation mechanisms help to facilitate positive investment decision. Arguments for this are deeply rooted in economic theory since decades: R&D by its nature has an inherent uncertainty of outcome. On top of uncertain returns, R&D is typically seen as a knowledge generating process, and as Arrow (1962) pointed out already, knowledge is basically information, and something intangible as information can never be kept secret. Knowledge as result of an investment in R&D will always spill-over to third parties, in the worst case rivals that can free-ride on an inventor's investment to generate own returns.

Therefore it is well-known and established in both economic theory and empirical research that firms seek for solutions to improve the appropriation possibilities of R&D. Of course, most industrialized countries have patent systems in place to increase the appropriability of R&D results, but it is also known that institutional differences in the patent systems lead to varying appropriability conditions, and that none of the patent systems is guaranteeing a 100% allocation of returns of R&D to the inventor. Third parties can invent around the patent, or possible infringement has to be detected, and can appropriately be sued and proven so that inventors will be compensated for potential losses. Thus, a strong legal system offers much beyond the pure patent systems that determines appropriation conditions in an economy, and in the end will result more R&D investment in the economy.

Finally, more general conclusions about "optimal" policy mixes with respect to public R&D can not be drawn easily from this study relying on macroeconomic indices. It turns out that the top performing countries, Japan, Switzerland and the united States actually rely on very different public R&D strategies. While the United States spends relatively less on higher education expenditure (in relation to GDP) than the other top performers, Switzerland conducts very little government R&D, and the United States employ more government-sponsored business R&D than both Switzerland and Japan. The latter is to a large extent driven by defense-related investments, though. Yet, there seems to be no unique public strategy that determines high efficiency levels.

In order to derive conclusions on the success of a policy mix, it would be necessary to go beyond the pure macroeconomic level. For instance, investigate how well matched the focus of public and private research is in an economy. For example, is there a special interest in certain technology developments in the public sector? Several countries maintain public research institutions for specialized technologies which are important for their national industry. It would be interesting to investigate if such public engagements in the end lead to a better link between science and industry in the country? If so, will this ensure higher efficiencies in translating public research results into private R&D investment?

Another question concerns the interactions between the different innovation policy measures. Are they complement or substitute, what is the optimal mix of R&D instruments associated with allocative efficiency of inputs? Given the increasing power of decision devolved to regions in the field of S&T policy, what are the interactions between different spatial levels of public intervention, i.e. national, regional vs. supranational ? To what degree are, for instance, the S&T collaborative agreements funded through the successive Framework programmes complementary to national initiatives?

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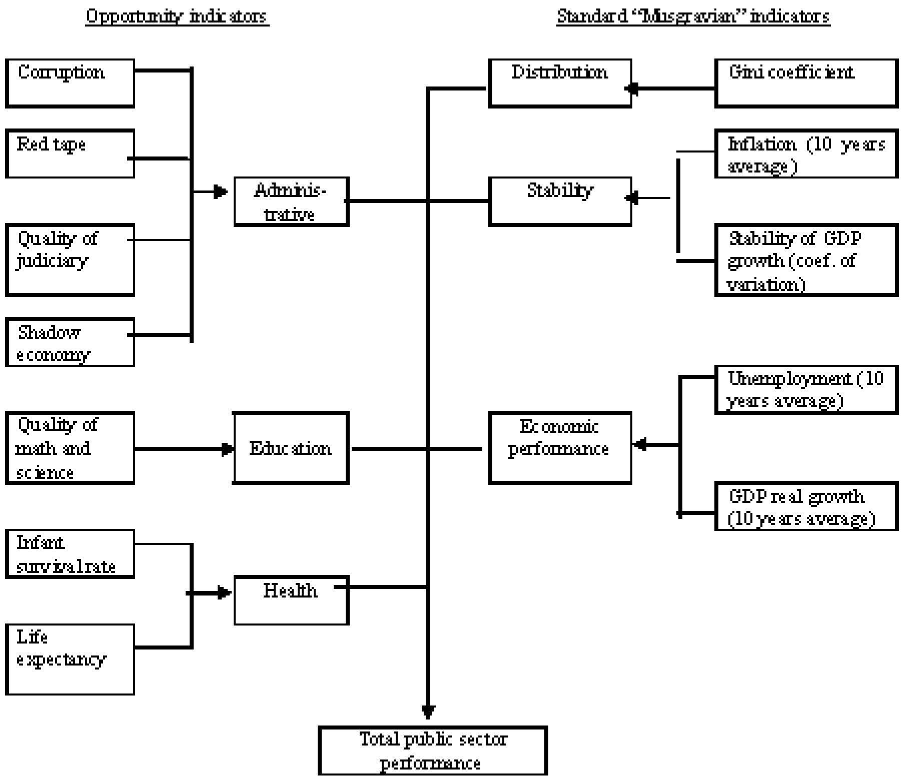
Appendix 1 Review of the empirical literature assessing the efficiency of public spending

			Indicators		
Authors	*Period*	*Countries*	*Input*	*Output*	*Methods*
Afonso et al. (2003)	1990 and 2000	23 industrialized OECD countries	Public spending as a percentage of GDP	PSP indicator	FDH
Afonso et al. (2006)	2001	24 countries	PSP composite indicator	Total government spending as a ratio of GDP	DEA (output-oriented), Tobit regression (evaluation of the importance of non-discretionary inputs)
Gupta and Verhoven (2001)	1984 – 1995	37 countries	Per capita education, health spending by the government	life expectancy, infant mortality; adult illiteracy, primary/secondary school enrolment	FDH
Clements (2002)	1996	20 OECD countries	Spending per student as a share of per capita GDP, the share of educational expenditure to GDP	Percentage of people that completes secondary education at a normal graduation age, test scores on international examinations at the eight grade	FDH
Afonso and St. Aubyn (2005b)	2000	OECD countries	Teachers per student, hours per year in school; number of doctors, of nurses and of in-patient beds per thousand inhabitants	Performance of 15-year-olds on the PISA reading, mathematics and science literacy scales; infant survival and life expectancy	FDH, DEA
Herrera and Pang (2005)	1996 – 2002	140 countries	Nine Public spending per capita on education and health	Nine education and four health output indicators	FDH, DEA
Evans et al. (2000)	1993 – 1997	191 WHO countries	Total health expenditures per capita, average education attainment in the adult population	Indicator of healthy life expectancy (DALE)	COLS
St. Aubyn (2002)	1997	OECD countries	Total health expenditure per head; cumulative expenditure per student, expenditure in primary and secondary education per habitant aged between 5 and 19	DALE, infant mortality; PISA results, graduation rates in upper secondary	FDH, COLS
Wang and Huang (2007)	1997 – 1999	30 countries (23 OECD and 7 non-OECD)	R&D capital stocks and manpower	Patents and academic publications	DEA, Tobit regression
Lee and Park (2005)	1999	27 countries	R&D expenditure, average number of researchers	Technology balance of receipts, number of scientific and technical journal articles published and number of triadic patent families	DEA (output-oriented), cluster analysis
Zabala-Iturriagagoitia et al. (2007)	2002 and 2003	European regions	Higher education, lifelong learning, medium/high-tech employment in manufacturing, public R&D expenditure, business R&D expenditure and high-tech patent applications to the European Patent Office (EPO)	Regional GDP per capita	DEA

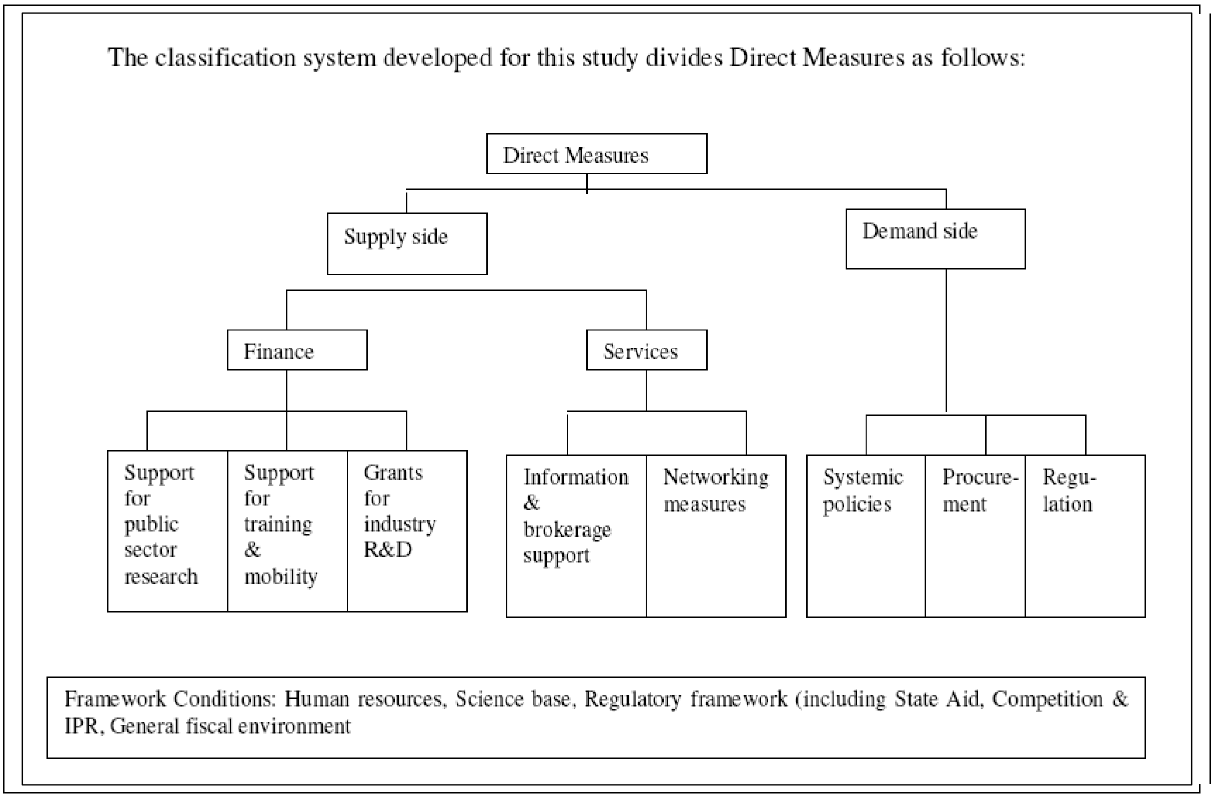
Appendix 2 Total public sector performance (PSP) indicator



Source: Afonso et al. (2006).

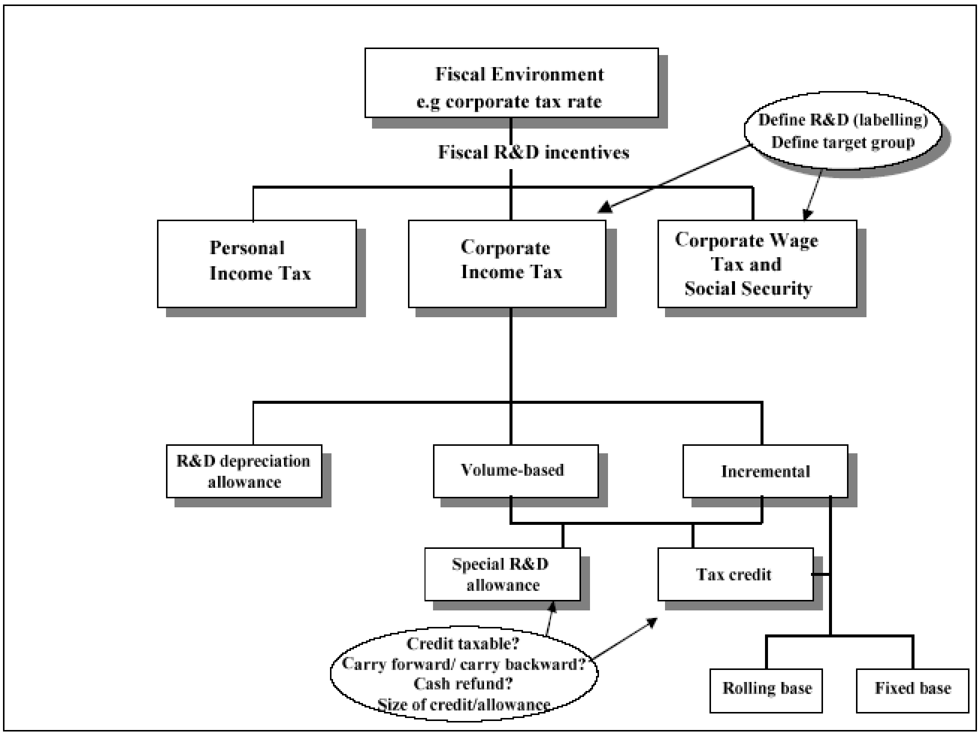
Appendix 3 Main STI Policy Measures

Direct measures



Source: CEC (2003a)

Indirect measures



Source: EC (2003b)

Other measures

- Direct Measures, i.e. measures involving the direct transfer of financial support from the public to the private sector via grants, loans etc.;
- Fiscal Measures, i.e. measures whereby the public sector foregoes tax income from the private sector in exchange for approved R&D investment behaviour;
- Risk Capital Measures, i.e. public measures affecting the flow and use of risk capital for innovation-related activities likely to increase R&D investment levels;
- Loan and Equity Guarantee Measures, i.e. measures whereby the public sector tries to encourage additional investment in R&D by offering to share part of the risk involved in the provision of support for innovation-related activities.

Source: CEC (2003b)

Appendix 4 Methods for ex-post evaluation of RTD programmes and policies

Statistical data analysis:
• Innovation Surveys: provides basic data to describe the innovation process, summarised using descriptive statistics. • Benchmarking/Ranking: allows performing comparisons based on a relevant set of indicators across entities providing a reasoned explanation their values.
Modelling methodologies:
• Macroeconomic modelling and simulation approaches: allows estimating the broader socio-economic impact of policy interventions. • Microeconometric modelling: permits to study the effect of policy intervention at the level of individuals or firms. There are mechanisms to control for the counterfactual by specifying a model which allows estimating the effects on the outcome of the participant had the programme not taken place. • Productivity analysis: permits to assess the impact of R&D on productivity growth at different levels data aggregation. This is particularly relevant to analyze the broader effects of R&D on the economy. • Control group approaches: allows capturing the effect of the programme on participants using statistical sophisticated techniques.
Qualitative and semi-quantitative methodologies:
• Interviews and case studies: uses direct observation of naturally occurring events to investigate behaviours in their indigenous social setting. • Cost-benefit analysis: allows establishing whether a programme or project is economically efficient by appraising all its economic and social effects. • Expert Panels/Peer Review: measures scientific output relying on the perception scientists have of the scientific contributions made by other peers. Peer review is the most widely used method for the evaluation of the output of scientific research. • Network Analysis: allows analyzing the structure of cooperation relationships and the consequences for individuals' decisions' on actions providing explanations for the observed behaviors by analyzing their social connections into networks. • Foresight/ Technology Assessment: used to identify potential mismatches in the strategic efficiency of projects and programmes.

Source: Rojo and Polt (2002).

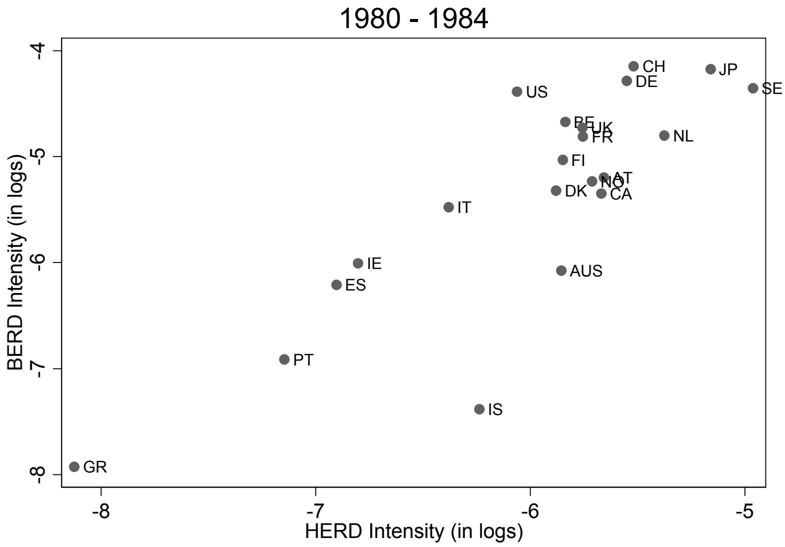
Appendix 5 Description of the different variables used in this study

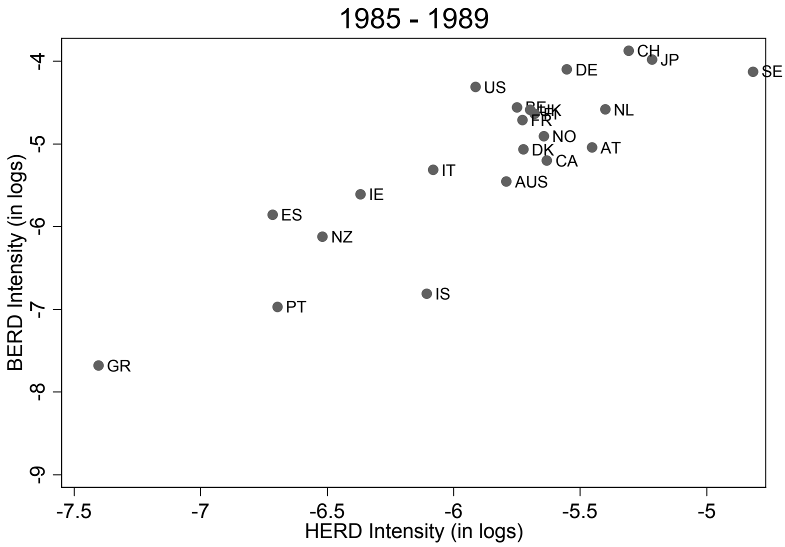
NAME	*DESCRIPTION*	*SOURCE*
BERD	Business expenditures on R&D All R&D expenditures in the business sector, according to the Frascati Manual definitions. BERD refers to all R&D activities performed by businesses within a particular sector and territory, regardless of the location of the business's headquarters, and regardless of the sources of finance. Note that BERD as we use it in this study measures the business R&D expenditure financed by the private sector. Thus, the data represent BERD net of subsidies.	Eurostat, OECD
HERD	Expenditure on R&D in the higher education sector	Eurostat, OECD
GOVERD	Government Intramural Expenditure on R&D	Eurostat, OECD
BERDBYGOV	Expenditure on R&D in the Business Enterprise Sector by the Government	Eurostat, OECD
R&D personnel	R&D personnel, according to the Frascati Manual definitions are expressed in full-time equivalent (FTE), i.e. a person working half-time on R&D is counted as 0.5 person years, and headcount.	OECD
B-Index	The B index is defined as the present value of before tax income necessary to cover the initial cost of R&D investment and to pay corporate income tax, so that it becomes profitable to perform research activities (see Warda 2001 for further details).	OECD
Strength of the IPR system	The index is based on five categories: (1) coverage (the subject matter that can be patented); (2) duration (the length of protection); (3) enforcement (the mechanisms for enforcing patent rights); (4) membership in international patent treaties; and (5) restrictions or limitations on the use of patent rights. For each of these categories, a country is given a score (ranging from 0 to 1) indicating the extent to which a country is strong in that aspect. The overall score for patent rights is the unweighted sum of the scores of the five individual categories.	Park (2001), Park and Wagh (2002)
Share of firms that received public funds for R&D	Number of innovative enterprises that have received public funding. Public funding includes financial support in terms of grants and loans, including a subsidy element, and loan guarantees. Ordinary payments for orders of public customers are not included. This number is divided by total number of enterprises, thus both innovating and non-innovating enterprises (Community Innovation Survey).	European Innovation Scoreboard (EIS)
Summary Innovation Index	The Summary Innovation Index (SII) gives an "at a glance" overview of aggregate national innovation performance. The SII is calculated using the most recent statistics from Eurostat and other internationally recognised sources as available at the time of analysis, e.g. population with tertiary education, innovation expenditures, employment in high-tech services (% of total workforce), Triad patents per million population etc.	European Innovation Scoreboard (EIS)
Public procurement advertised in the Official Journal as a % of GDP	The numerator is the value of public procurement, which is openly advertised. For each of the sectors works, supplies and services, the number of calls for competition published is multiplied by an average based, in general, on all the prices provided in the contract award notices published in the Official Journal of the European Communities, Supplement S during the relevant year. The denominator is the GDP (gross domestic product).	Eurostat
Public procurement advertised in the Official Journal as a % of total public procurements	The numerator is the same as for the previous indicator. The denominator is the total value of public procurement.	Eurostat
Composite Indicators of the Fraser Institute	For a detailed description of the different areas and components of the Fraser Institute composite indicators see: http://www.freetheworld.com/2007/4EFW2007app1.pdf	The Fraser Institute, Economic Freedom of the World, 2007.
More effective control of public spending growth	Based on Joumard et al (2004), table 2, p.14.	Joumard et al (2004)
Anchoring the budget process in a medium-term perspective	Based on Joumard et al (2004), table 2, p.14.	Joumard et al (2004)
Reduced budget fragmentation and increased transparency	Based on Joumard et al (2004), table 2, p.14.	Joumard et al (2004)
Basic R&D performed in the private sector in % of total business R&D	Basic R&D as defined in the Frascati Manual (OECD, 2002)	Eurostat
Share in % of researchers, scientists & engineers in the private sector as a % of total active population	Researchers, scientists and engineers as defined in the Frascati Manual (OECD, 2002)	Eurostat
Share in % of researchers, scientists & engineers in the total	Total business R&D personnel as defined in the Frascati Manual (OECD, 2002)	Eurostat

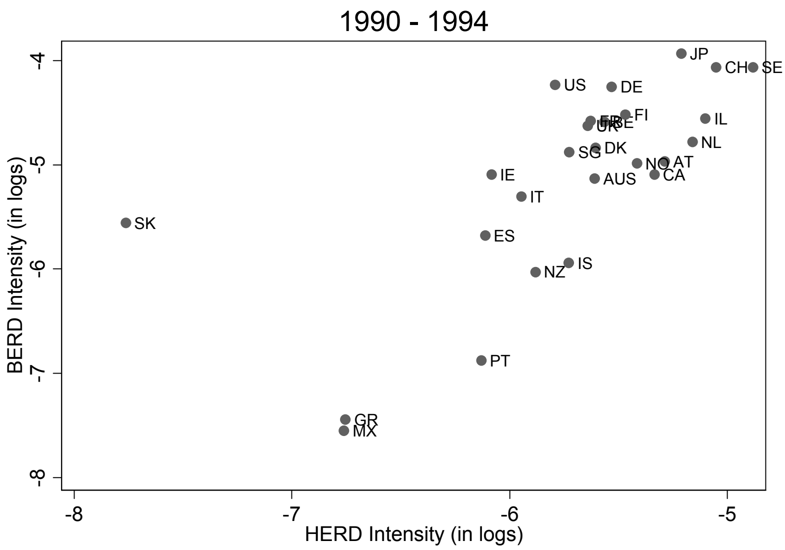
business R&D personnel		
Share of Public Credit Appropriation in the defence sector	Total business R&D personnel as defined in the Frascati Manual (OECD, 2002) Government Budget Appropriations or Outlays on R&D (GBAORD) broken down in accordance to the nomenclature for the analysis and comparison of scientific programmes and budgets (NABS) at chapter level (Chapter 13 – Defence) as defined in the Frascati Manual (OECD, 2002).	Eurostat
Share in % of high-tech sectors in total manufacturing value added	Based on the EU R&D Scoreboard (Company data) following the ICB and NACE sector classifications. Note that the Scoreboard refers to all R&D financed by a particular company from its own funds, regardless of where that R&D activity is performed while BERD refers to all R&D activities performed by businesses within a particular sector and territory, regardless of the location of the business's headquarters, and regardless of the sources of finance (Eurostat website).	Eurostat
Industry university links (business funded R&D performed in other sector than the business one)	100-(R&D expenditures funded and performed in the private sector in % of R&D expenditures funded in the private sector and performed in all sectors).	Eurostat

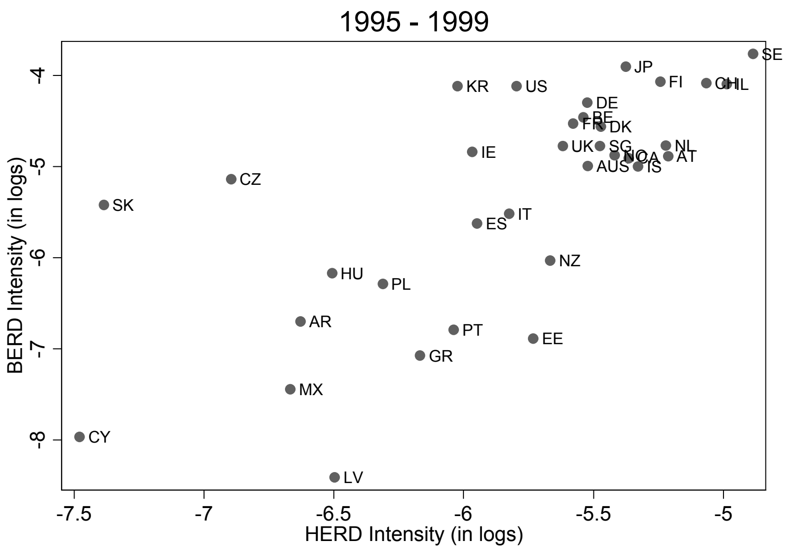
Appendix 6: Additional results

Figure A 1 BERD intensity vs. HERD intensity (both in logs) for all sub periods






1990 - 1994
BERD Intensity (in logs)
HERD Intensity (in logs)
-4
-5
-6
-7
-8
-8
-7
-6
-5
JP
CH
SE
US
DE
FI
IL
NL
DK
SG
NO
AT
IE
AUS
CA
IT
SK
ES
IS
NZ
PT
GR
MX


1995 - 1999
BERD Intensity (in logs)
HERD Intensity (in logs)
-4
-5
-6
-7
-8
-7.5
-7
-6.5
-6
-5.5
-5
SE
JP
FI
KR
US
DE
DK
IE
UK
SG
NL
AT
AUS
IS
CZ
SK
IT
ES
NZ
HU
PL
AR
PT
EE
GR
MX
CY
LV

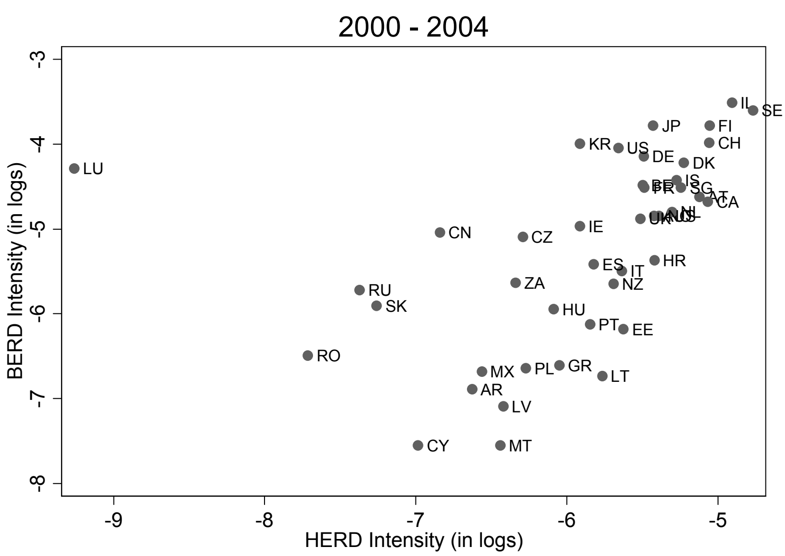
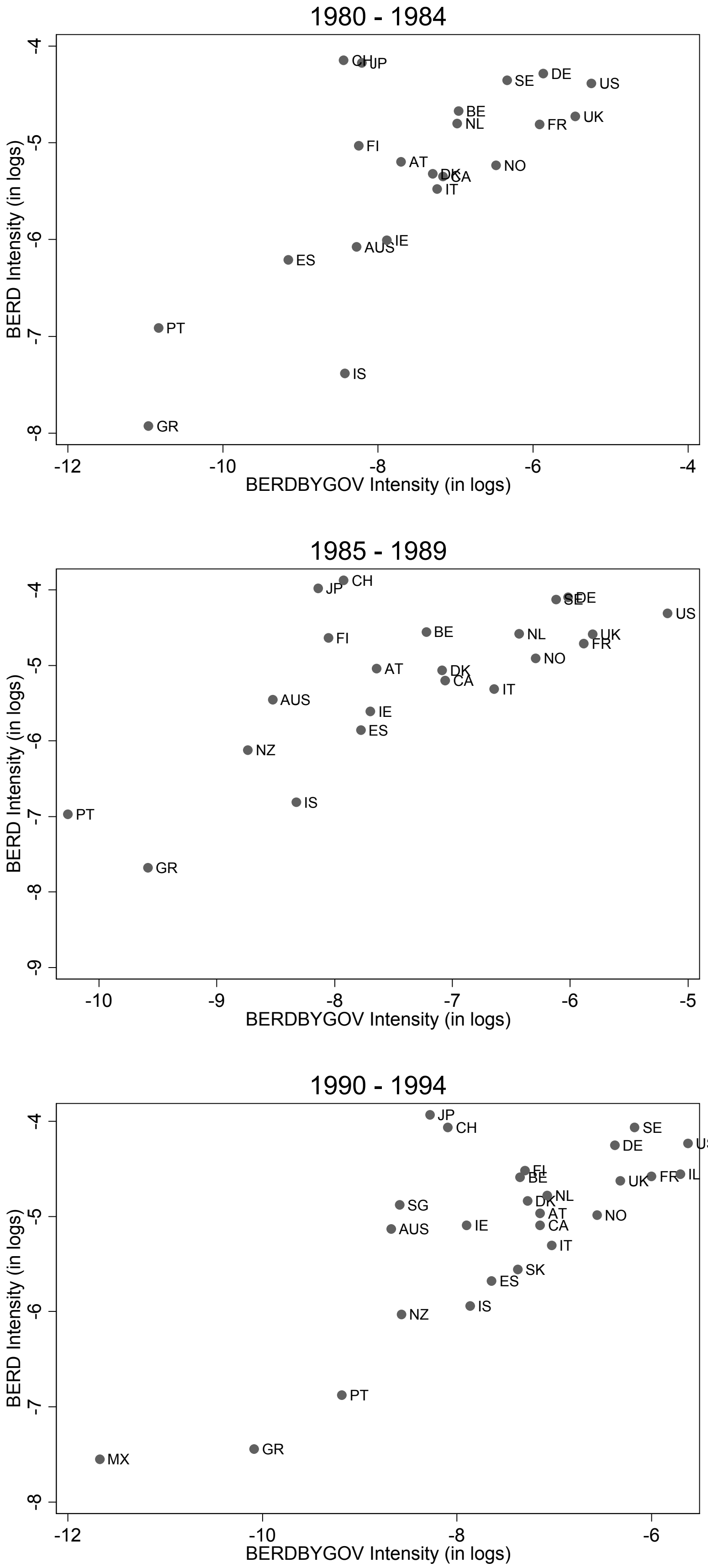
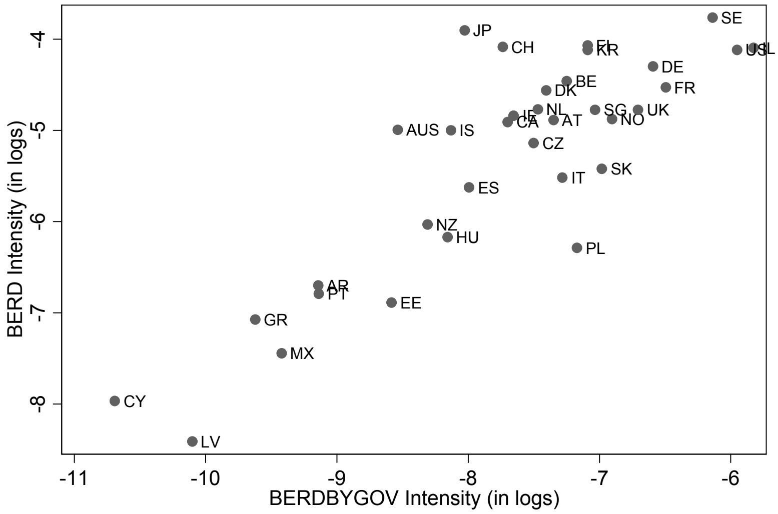

2000 - 2004
BERD Intensity (in logs)
HERD Intensity (in logs)
-3
-4
-5
-6
-7
-8
-9
-8
-7
-6
-5
IL
SE
JP
FI
CH
KR
US
DE
DK
LU
IS
CA
IE
CN
CZ
HR
ES
IT
ZA
NZ
RU
SK
HU
PT
EE
RO
MX
PL
GR
LT
AR
LV
CY
MT

Figure A 2 BERD vs. BERDBYGOV (both in logs) for all sub periods



1995 - 1999



2000 - 2004

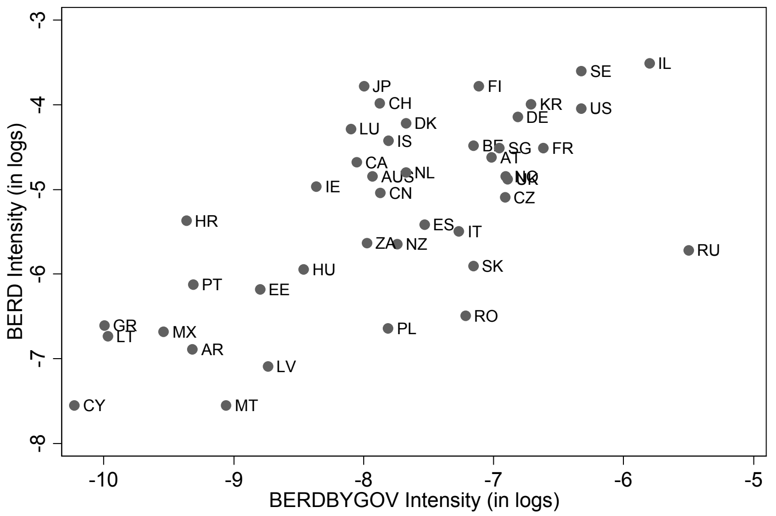
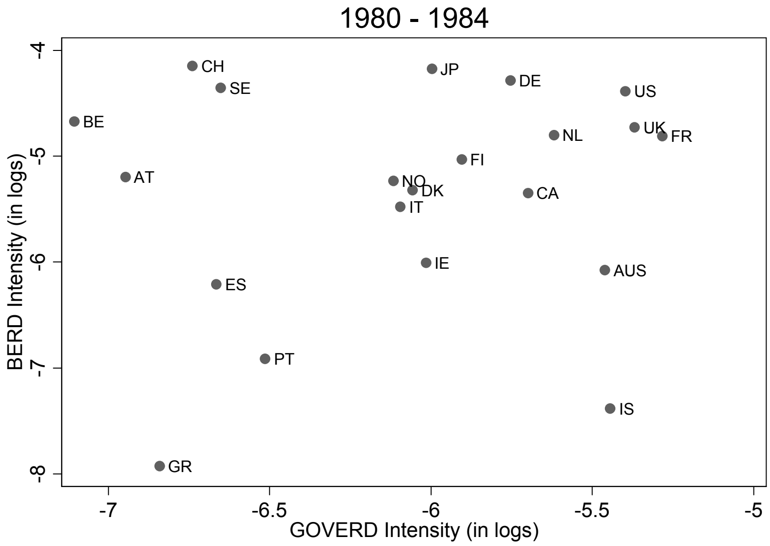
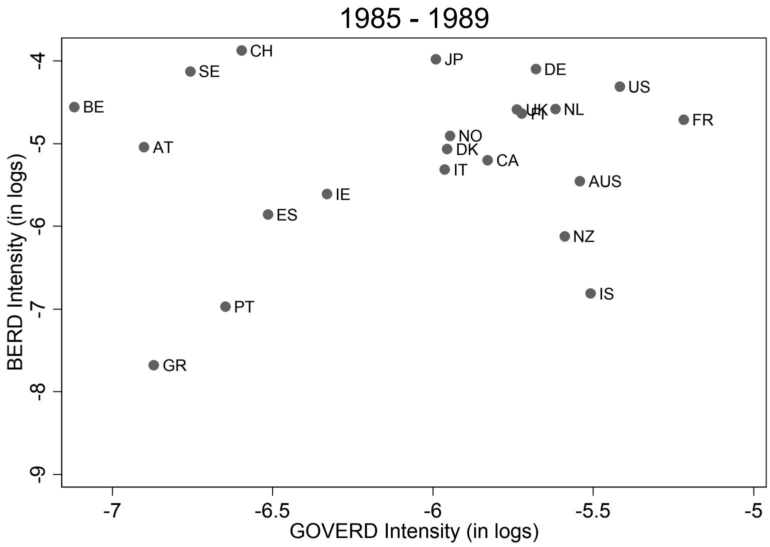
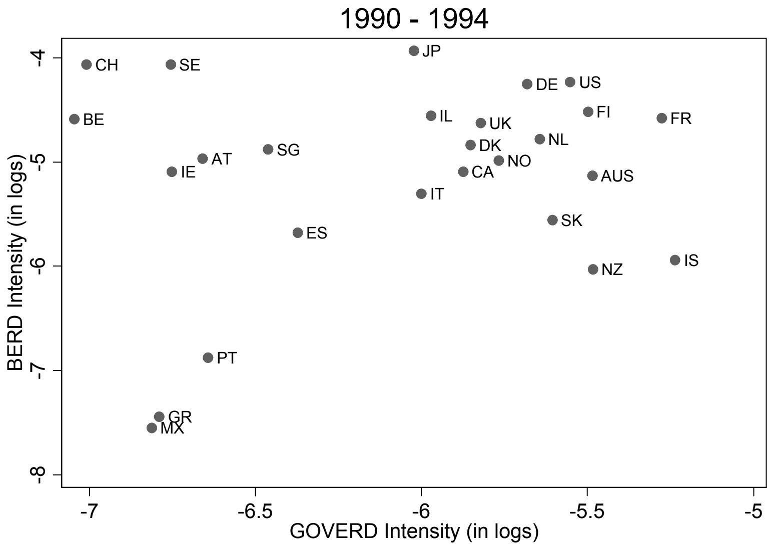
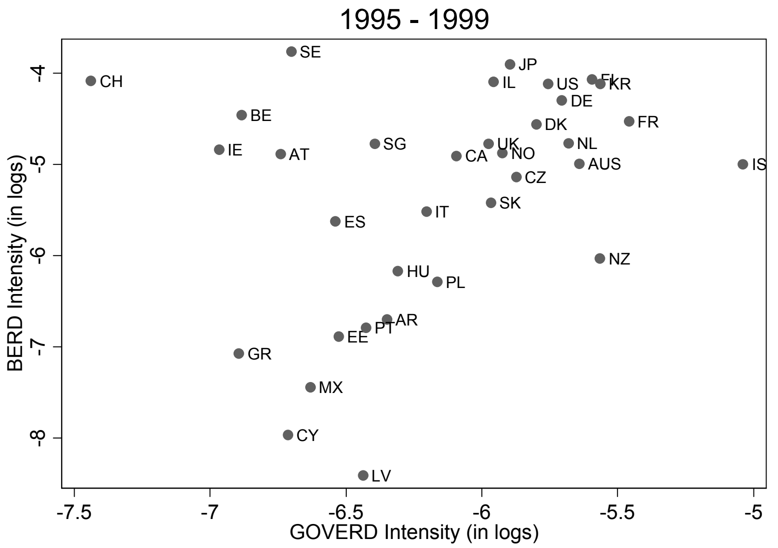


Figure A 3   BERD vs. GOVERD (both in logs) for all sub periods








1995 - 1999
BERD Intensity (in logs)
GOVERD Intensity (in logs)
-4
-5
-6
-7
-8
-7.5
-7
-6.5
-6
-5.5
-5
SE
CH
JP
IL
US
FI
KR
DE
BE
FR
DK
IE
AT
SG
UK
NO
NL
CA
AUS
IS
CZ
SK
IT
ES
NZ
HU
PL
AR
PT
EE
GR
MX
CY
LV

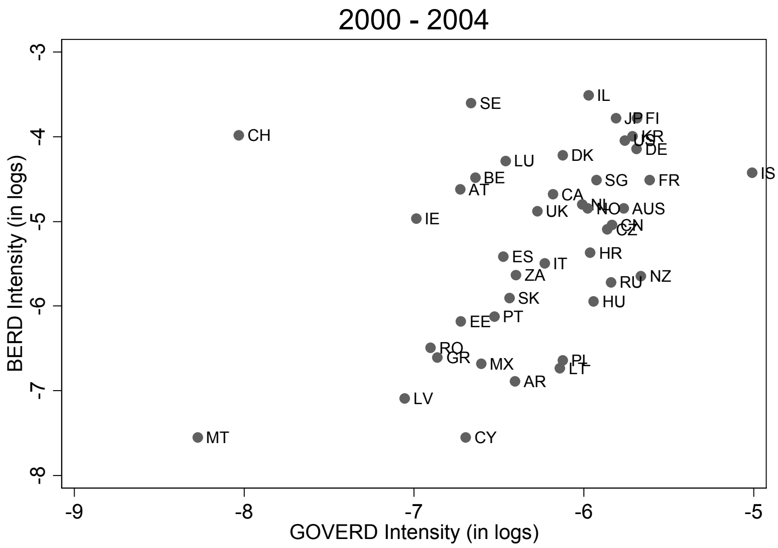

2000 - 2004
BERD Intensity (in logs)
GOVERD Intensity (in logs)
-3
-4
-5
-6
-7
-8
-9
-8
-7
-6
-5
IL
SE
JP
FI
CH
KR
US
DE
DK
LU
IS
BE
SG
FR
AT
CA
NL
NO
AUS
UK
IE
CN
CZ
HR
ES
IT
ZA
RU
NZ
SK
HU
PT
EE
RO
GR
MX
PL
LT
AR
LV
MT
CY

Table A 1 R&D personnel for three sub periods 1980-1984, 1990-1994 and 2000-2004

Country	*R&D personnel*		
	1980 – 1984	*1990 - 1994*	*2000 - 2004*
Argentina			3200
Australia	4681	13742	19936
Austria	3120	6995	16255
Belgium	5659	10106	16778
Bulgaria		3527	1128
Canada	17228	35240	70034
China		151225	439779
Croatia			1060
Cyprus		27	98
Czech Republic			6266
Denmark	2719	5336	14002
Estonia			463
Finland	3033	5312	21663
France	38061	62896	94374
Germany	79442	134880	158143
Greece		1181	3836
Hungary	12574	4705	4221
Iceland	47	208	856
Ireland	714	2354	5961
Israel			
Italy	20724	29149	27026
Japan	212265	354426	439591
Korea			100698
Latvia		755	653
Lithuania			379
Luxembourg			1513
Malta			99
Mexico		1311	8726
Netherlands	8819	12243	21082
New Zealand		1420	3256
Norway	3590	6933	11279
Poland	49450	14870	7863
Portugal	667	1002	3217
Romania		25608	10733
Russia		366982	274878
Singapore		4059	9879
Slovak Republic		2648	2115
Slovenia		1211	1537
South Africa			
Spain	3545	11310	24819
Sweden	9957	14410	28144
Switzerland	6048	9800	14458
Turkey		1510	4190
United Kingdom	77500	80000	93738
United States	547500	766160	1054500

Note: Data sorted in alphabetical order.

Table A 2 Correlation matrix

	BERD intensity	*Growth of BERD intensity*	*HERD intensity*	*Growth of HERD intensity*	*GOVERD intensity*	*Growth of GOVERD intensity*	*BERDBYGOV intensity*
BERD intensity	1.0000						
Growth of BERD intensity	-0.0056	1.0000					
HERD intensity	0.7249*	0.0669	1.0000				
Growth of HERD intensity	-0.4529*	0.2158	-0.3587	1.0000			
GOVERD intensity	0.1372	0.7026*	0.0781	-0.1825	1.0000		
Growth of GOVERD intensity	0.1363	0.4064	0.0979	0.1140	0.3885	1.0000	
BERDBYGOV intensity	0.4215*	-0.2243	0.2415*	-0.4412*	0.3686*	0.0531	1.0000

*Note: * indicates significance on the 5% level.*

Supplemental Stochastic frontier regressions
Cross-sectional estimations using different model specifications

In the main text body, we show regressions, where all regressors are divided by GDP to take out pure country size effects in the regressions. However, we also estimated the models with other specifications. Specification A uses the log of the levels of the variables, and B just rescales the regressors HERD and GOVERD by BERDBYGOV to reduce multicollinearity among them. Model C is the specification as shown in the main text.

A) is the regression of ln(BERD) on ln(BERDBYGOV), ln(HERD) and ln(GOVERD). Similarly,
B) refers to ln(BERD) on ln(BERDBYGOV), ln(HERD/BERDBYGOV) and ln(GOVERD/BERDBYGOV), and
C) is the regression of ln(BERD/GDP) on ln(BERDBYGOV/GDP), ln(HERD/GDP) and ln(GOVERD/GDP).

Table A 3 Stochastic Frontier Estimation – Basic specification A

		Time Period	
Variable	*1980-1984*	*1990-1994*	*2000-2004*
ln(BERDBYGOV)	0.142*	0.402***	0.512***
	(0.076)	(0.089)	(0.103)
ln(HERD)	1.144***	0.675***	0.381***
	(0.131)	(0.134)	(0.114)
ln(GOVERD)	-0.175	-0.029	0.199
	(0.128)	(0.135)	(0.145)
Intercept	0.486	1.008	1.137*
	(0.593)	(0.839)	(0.675)
$\ln\left(\sigma_v^2\right)$	2.045	-1.415***	-0.760***
	(6.055)	(0.553)	(0.271)
μ	-20.219	-0.104	-0.086
	(130.211)	(23.345)	(18.327)
# of obs.	21	26	42
Log-Likelihood	-10.887	-18.476	-43.616
χ^2 *Test*	506.78***	380.18***	519.41***
Coelli-Test: No inefficiency	-0.918	1.148	3.221
[p-value]	[0.179]	[0.874]	[0.999]

*Note: μ denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses. *** (**, *) denote a significance level of 1% (5%, 10%).*

Table A 4 Stochastic Frontier Estimation – Basic specification B

Variable	Time Period 1980-1984	1990-1994	2000-2004
ln(BERDBYGOV)	1.111***	1.048***	1.093***
	(0.067)	(0.063)	(0.052)
ln(HERD/BERDBYGOV)	1.114***	0.675***	0.381***
	(0.131)	(0.134)	(0.114)
ln(GOVERD/BERDBYGOV)	-0.175	-0.029	0.199
	(0.128)	(0.135)	(0.145)
Intercept	0.486	1.007	1.137*
	(0.593)	(0.640)	(0.630)
$\ln\left(\sigma_v^2\right)$	2.049	-1.415***	-0.760***
	(5.918)	(0.400)	(0.257)
μ	-20.298	-0.112	-0.082
	(127.752)	(14.687)	(12.784)
# of obs.	21	26	42
Log-Likelihood	-10.887	-18.476	-43.616
χ^2 *Test*	506.83***	380.18***	519.43***
Coelli-Test: No inefficiency	-0.918	1.148	3.221
[p-value]	[0.179]	[0.874]	[0.999]

*Note: μ denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses. *** (**, *) denote a significance level of 1% (5%, 10%).*

The following tables show the panel regressions for specifications A, B and C for both BERD and R&D personnel in the business sector.

Table A 5 Stochastic Frontier Panel Data Estimation on BERD

Variable	Specification A	B	C
BERDBYGOV	0.453***	1.091***	0.492***
	(0.049)	(0.030)	(0.049)
HERD	0.619***	0.619***	0.601***
	(0.067)	(0.067)	(0.081)
GOVERD	0.020	0.020	-0.007
	(0.069)	(0.069)	(0.099)
Intercept	0.753**	0.753**	1.938***
	(0.350)	(0.351)	(0.736)
Joint significance of 4 time dummies	2.80	2.80	1.84
[p-value]	[0.592]	[0.592]	[0.765]
$\ln\left(\sigma_v^2\right)$	-1.027***	-1.027***	-0.968***
	(0.186)	(0.186)	(0.192)
μ	-0.145	-0.145	-0.128
	(15.705)	(15.782)	(22.74)
# of obs.	145	145	145
Log-Likelihood	-131.214	-131.21	-135.49
χ^2 *Test*	1911.53***	1911.53***	301.24***
Coelli-Test: No inefficiency	6.143	6.143	4.223
[p-value]	[1.000]	[1.000]	[1.000]

*Note: μ denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses unless indicated otherwise. *** (**, *) denote a significance level of 1% (5%, 10%).*

Table A 6 Stochastic Frontier Panel Data Estimation on R&D Personnel in the business sector

		Specification	
Variable	*A*	*B*	*C*
BERDBYGOV	0.605***	0.918***	0.572***
	(0.054)	(0.032)	(0.053)
HERD	0.213***	0.213***	0.184**
	(0.072)	(0.072)	(0.087)
GOVERD	0.101	0.101	0.065
	(0.077)	(0.077)	(0.104)
Intercept	3.688***	3.687***	8.940***
	(0.350)	(0.392)	(0.805)
Joint significance of 4 time dummies	49.03***	49.03***	49.70***
[p-value]	[p<0.001]	[p<0.001]	[p<0.001]
$\ln\left(\sigma_v^2\right)$	-0.890***	-0.890***	-0.860***
	(0.158)	(0.156)	(0.175)
μ	-0.101	-0.101	-0.100
	(10.423)	(10.277)	(20.89)
# of obs.	141	141	145
Log-Likelihood	-137.301	-137.301	-135.49
χ^2 *Test*	1291.27***	1291.27***	301.24***
Coelli-Test: No inefficiency	5.672	5.672	4.223
[p-value]	[1.000]	[1.000]	[1.000]

*Note: μ denotes the mean of the truncated normal distribution (inefficiency term). Standard errors in parentheses unless indicated otherwise. *** (**, *) denote a significance level of 1% (5%, 10%).*

Table A 7 DEA output efficiency scores, 3 inputs (HERD, GOVERD, BERDBYGOV), 1 output (BERD)

	Variable Returns to Scale					*Constant Returns to Scale*					*Scale Inefficiency*				
	80-84	*85-89*	*90-94*	*95-99*	*00-04*	*80-84*	*85-89*	*90-94*	*95-99*	*00-04*	*80-84*	*85-89*	*90-94*	*95-99*	*00-04*
Argentina				1.168	1.272				1.264	1.889				1.082	1.485
Australia	1.248	1.136	1.065	1.023	1.123	1.255	1.149	1.187	1.146	1.579	1.005	1.012	1.115	1.121	1.406
Austria	1.000	1.058	1.118	1.126	1.151	1.107	1.100	1.132	1.150	1.343	1.107	1.040	1.013	1.022	1.167
Belgium	1.000	1.000	1.019	1.027	1.112	1.011	1.000	1.026	1.053	1.335	1.011	1.000	1.007	1.025	1.201
Canada	1.149	1.131	1.138	1.107	1.082	1.164	1.148	1.226	1.186	1.501	1.013	1.015	1.078	1.071	1.387
China					1.033					1.620					1.568
Croatia					1.000					1.176					1.176
Cyprus				1.000	1.000				1.000	1.000				1.000	1.000
Czech Republic				1.000	1.263				1.037	1.555				1.037	1.231
Denmark	1.103	1.082	1.105	1.051	1.071	1.106	1.092	1.136	1.099	1.355	1.003	1.009	1.027	1.046	1.265
Estonia				1.000	1.000				1.184	1.016				1.184	1.016
Finland	1.056	1.006	1.074	1.021	1.085	1.061	1.017	1.118	1.067	1.368	1.005	1.011	1.041	1.044	1.261
France	1.066	1.054	1.061	1.073	1.102	1.087	1.078	1.180	1.193	1.578	1.020	1.023	1.113	1.112	1.432
Germany	1.016	1.008	1.019	1.041	1.049	1.057	1.039	1.130	1.161	1.518	1.040	1.030	1.109	1.116	1.447
Greece	1.086	1.232	1.217	1.173	1.117	1.113	1.262	1.242	1.315	1.587	1.025	1.024	1.021	1.121	1.421
Hungary				1.163	1.283				1.188	1.746				1.022	1.361
Iceland	1.000	1.000	1.000	1.000	1.050	1.612	1.000	1.000	1.000	1.143	1.612	1.000	1.000	1.000	1.089
Ireland	1.000	1.000	1.000	1.000	1.081	1.013	1.034	1.015	1.000	1.260	1.013	1.034	1.015	1.000	1.165
Israel			1.105	1.069	1.075			1.134	1.099	1.271			1.026	1.029	1.182
Italy	1.070	1.084	1.099	1.151	1.197	1.089	1.108	1.205	1.258	1.641	1.018	1.022	1.096	1.093	1.371
Japan	1.000	1.000	1.000	1.000	1.000	1.096	1.071	1.106	1.099	1.463	1.096	1.071	1.106	1.099	1.463

	Variable Returns to Scale					*Constant Returns to Scale*					*Scale Inefficiency*				
	80-84	*85-89*	*90-94*	*95-99*	*00-04*	*80-84*	*85-89*	*90-94*	*95-99*	*00-04*	*80-84*	*85-89*	*90-94*	*95-99*	*00-04*
Korea				1.000	1.048				1.075	1.450				1.075	1.383
Latvia				1.408	1.476				1.557	1.643				1.105	1.114
Lithuania					1.000					1.056					1.056
Luxembourg					1.000					1.000					1.000
Malta					1.000					1.000					1.000
Mexico			1.000	1.288	1.196			1.033	1.393	1.776			1.033	1.082	1.486
Netherlands	1.114	1.081	1.129	1.110	1.147	1.121	1.088	1.205	1.189	1.527	1.007	1.007	1.068	1.071	1.332
New Zealand		1.000	1.218	1.221	1.339		1.015	1.219	1.292	1.755		1.015	1.001	1.058	1.311
Norway	1.116	1.066	1.156	1.140	1.255	1.119	1.077	1.187	1.177	1.506	1.003	1.010	1.027	1.033	1.200
Poland				1.277	1.492				1.342	1.923				1.050	1.289
Portugal	1.000	1.000	1.299	1.217	1.142	1.000	1.000	1.370	1.333	1.653	1.000	1.000	1.055	1.096	1.448
Romania					1.000					1.412					1.412
Russia					1.294					1.686					1.303
Singapore			1.000	1.100	1.216			1.000	1.104	1.444			1.000	1.004	1.187
Slovak Republic			1.000	1.000	1.448			1.000	1.000	1.543			1.000	1.000	1.065
South Africa					1.241					1.576					1.270
Spain	1.095	1.076	1.133	1.141	1.191	1.099	1.076	1.211	1.211	1.565	1.003	1.000	1.069	1.061	1.314
Sweden	1.025	1.011	1.024	1.004	1.035	1.063	1.014	1.034	1.029	1.207	1.037	1.003	1.009	1.025	1.167
Switzerland	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
United Kingdom	1.057	1.044	1.049	1.081	1.115	1.078	1.071	1.151	1.190	1.530	1.020	1.026	1.098	1.100	1.372
United States	1.000	1.000	1.000	1.000	1.000	1.030	1.041	1.139	1.144	1.524	1.030	1.041	1.139	1.144	1.524

Table A 8 DEA output efficiency scores - 3 inputs (HERD, GOVERD, BERDBYGOV), 1 output (BER vs. BERD), variable returns to scale, 2000-2004, BER vs. BERD

Country	*ln BER* Efficiency Score	*ln BER* Rank	*ln BERD* Efficiency score	*ln BERD* Rank
Argentina	1.299	32	1.272	25
Australia	1.173	18	1.123	15
Austria	1.204	23	1.151	18
Belgium	1.203	22	1.112	12
Canada	1.068	4	1.082	9
China	1.008	3	1.033	2
Croatia	1.119	7	1.000	1
Cyprus	1.003	2	1.000	1
Czech Republic	1.298	31	1.263	24
Denmark	1.147	16	1.071	7
Estonia	1.000	1	1.000	1
Finland	1.131	9	1.085	10
France	1.140	11	1.102	11
Germany	1.097	5	1.049	5
Greece	1.142	13	1.117	14
Hungary	1.184	21	1.283	26
Iceland	1.146	15	1.050	6
Ireland	1.178	20	1.081	8
Italy	1.245	28	1.197	21
Japan	1.000	1	1.000	1
Korea	1.100	6	1.048	4
Latvia	1.141	12	1.476	30
Lithuania	1.000	1	1.000	1
Luxembourg	1.000	1	1.000	1
Malta	1.000	1	1.000	1
Mexico	1.135	10	1.196	20
Netherlands	1.173	17	1.147	17
New Zealand	1.293	30	1.339	28
Norway	1.218	25	1.255	23
Poland	1.252	29	1.492	31
Portugal	1.227	27	1.142	16
Romania	1.000	1	1.000	1
Russia	1.000	1	1.294	27
Singapore	1.222	26	1.216	22
Slovak Republic	1.374	33	1.448	29
Spain	1.204	24	1.191	19
Sweden	1.174	19	1.035	3
Switzerland	1.144	14	1.000	1
United Kingdom	1.126	8	1.115	13
United States	1.000	1	1.000	1

Table A 9 Output efficiency scores, 3 inputs (HERD, GOVERD, BERDBYGOV), 1 output (BERD), 2000-2004, Variable vs. Constant returns to scale and DEA vs. SCI and FDH

Country	*SCI*	*DEA*				*FDH*
		Output-Oriented VRS Efficiency	*Output-Oriented CRS Efficiency*	*Scale Inefficiency*	*Input-Oriented VRS Efficiency*	*Output-Oriented FDH Efficiency*
Argentina	3.020	1.272	1.889	1.485	0.598	1.104
Australia	1.006	1.123	1.579	1.406	0.821	1.012
Austria	0.818	1.151	1.343	1.167	0.764	1.000
Belgium	0.550	1.112	1.336	1.201	0.819	1.000
Canada	0.938	1.083	1.501	1.387	0.879	1.000
China	0.680	1.033	1.620	1.568	0.939	1.000
Croatia	1.526	1.000	1.176	1.176	1.000	1.000
Cyprus	4.188	1.000	1.000	1.000	1.000	1.000
Czech Republic	0.928	1.263	1.555	1.231	0.644	1.000
Denmark	0.546	1.071	1.355	1.265	0.882	1.000
Estonia	2.394	1.000	1.016	1.016	1.000	1.000
Finland	0.465	1.085	1.368	1.261	0.867	1.000
France	0.832	1.102	1.579	1.432	0.853	1.000
Germany	0.543	1.049	1.518	1.447	0.927	1.000
Greece	2.553	1.117	1.587	1.421	0.773	1.000
Hungary	1.954	1.283	1.746	1.361	0.634	1.125
Iceland	1.024	1.050	1.143	1.089	0.935	1.000
Ireland	0.556	1.081	1.260	1.165	0.857	1.000
Israel	0.434	1.075	1.271	1.182	0.872	1.000
Italy	1.519	1.197	1.641	1.371	0.732	1.104
Japan	0.339	1.000	1.463	1.463	1.000	1.000
Korea	0.393	1.048	1.450	1.383	0.924	1.000
Latvia	3.189	1.476	1.643	1.114	0.609	1.000
Lithuania	4.499	1.000	1.056	1.056	1.000	1.000
Luxembourg	0.143	1.000	1.000	1.000	1.000	1.000
Malta	3.754	1.000	1.000	1.000	1.000	1.000
Mexico	2.272	1.196	1.776	1.486	0.677	1.075
Netherlands	0.961	1.147	1.527	1.332	0.791	1.027
New Zealand	2.066	1.339	1.755	1.311	0.600	1.043
Norway	1.032	1.255	1.506	1.200	0.664	1.026
Poland	3.439	1.492	1.923	1.289	0.523	1.139
Portugal	2.025	1.142	1.653	1.448	0.741	1.000
Romania	1.442	1.000	1.412	1.412	1.000	1.000
Russia	2.323	1.294	1.686	1.303	0.593	1.000
Singapore	0.814	1.216	1.444	1.187	0.699	1.000
Slovak Republic	1.135	1.448	1.543	1.065	0.652	1.198
South Africa	1.056	1.241	1.576	1.270	0.665	1.000
Spain	1.135	1.191	1.565	1.314	0.729	1.074
Sweden	0.425	1.035	1.207	1.167	0.940	1.000
Switzerland	0.379	1.000	1.000	1.000	1.000	1.000
United Kingdom	0.911	1.115	1.530	1.372	0.833	1.017
United States	0.481	1.000	1.524	1.524	1.000	1.000

Table A 10 DEA output efficiency scores - 3 inputs (HERD, GOVERD, BERDBYGOV), 1 output (BERD), variable returns to scale, 2000-2004, Levels of variables vs. Natural logarithms and % in terms of GDP

Country	*level* *Efficiency Score*	*Rank*	*ln* *Efficiency score*	*Rank*	*in %* *Efficiency score*	*Rank*
Argentina	5.914	30	1.272	27	4.060	25
Australia	2.994	23	1.123	16	2.903	21
Austria	2.119	14	1.151	19	2.197	14
Belgium	1.449	6	1.112	13	1.715	9
Canada	2.096	13	1.082	10	2.100	12
China	1.000	1	1.033	2	2.457	17
Croatia	1.079	3	1.000	1	1.000	1
Cyprus	1.000	1	1.000	1	1.000	1
Czech Republic	2.431	18	1.263	26	2.872	20
Denmark	1.603	7	1.071	7	1.502	8
Estonia	2.681	19	1.000	1	3.745	23
Finland	1.354	4	1.085	11	1.065	3
France	2.093	12	1.102	12	2.055	11
Germany	1.402	5	1.049	5	1.418	6
Greece	2.161	15	1.117	15	1.000	1
Hungary	5.015	29	1.283	28	4.733	28
Iceland	1.856	11	1.050	6	1.928	10
Ireland	1.770	8	1.081	9	1.495	7
Israel	1.021	2	1.075	8	1.000	1
Italy	4.108	27	1.197	22	4.888	29
Japan	1.000	1	1.000	1	1.000	1
Korea	1.000	1	1.048	4	1.061	2
Latvia	8.318	32	1.476	32	6.563	32
Lithuania	1.780	10	1.000	1	1.225	5
Luxembourg	1.000	1	1.000	1	1.000	1
Malta	1.000	1	1.000	1	1.000	1
Mexico	3.845	26	1.196	21	2.375	16
Netherlands	2.761	21	1.147	18	2.737	18
New Zealand	6.263	31	1.339	30	5.867	31
Norway	2.923	22	1.255	25	2.933	22
Poland	9.208	33	1.492	33	13.456	33
Portugal	2.714	20	1.142	17	2.133	13
Romania	1.000	1	1.000	1	1.000	1
Russia	1.780	9	1.294	29	4.549	27
Singapore	2.336	17	1.216	23	2.217	15
Slovak Republic	4.221	28	1.448	31	5.491	30
South Africa	3.089	24	1.241	24	4.530	26
Spain	3.102	25	1.191	20	4.020	24
Sweden	1.000	1	1.035	3	1.000	1
Switzerland	1.000	1	1.000	1	1.000	1
United Kingdom	2.166	16	1.115	14	2.760	19
United States	1.000	1	1.000	1	1.213	4

Table A 11 DEA output efficiency scores - 3 inputs (HERD, GOVERD, BERDBYGOV), 1 output (BERD), variable returns to scale, 2000-2004, B-index

Country	*B-index incl.* *Efficiency Score*	*Rank*	*B-index excl.* *Efficiency score*	*Rank*
Argentina	1.000	1	1.272	22
Australia	1.079	12	1.123	14
Austria	1.097	14	1.151	17
Belgium	1.055	11	1.112	11
Canada	1.050	10	1.082	8
Denmark	1.008	2	1.071	6
Finland	1.013	3	1.085	9
France	1.081	13	1.102	10
Germany	1.036	8	1.049	4
Greece	1.025	6	1.117	13
Hungary	1.140	19	1.283	23
Iceland	1.000	1	1.050	5
Ireland	1.015	4	1.081	7
Italy	1.176	20	1.197	20
Japan	1.000	1	1.000	1
Korea	1.000	1	1.048	3
Mexico	1.112	17	1.196	19
Netherlands	1.101	16	1.147	16
New Zealand	1.215	21	1.339	24
Norway	1.124	18	1.255	21
Portugal	1.029	7	1.142	15
Spain	1.048	9	1.191	18
Sweden	1.021	5	1.035	2
Switzerland	1.000	1	1.000	1
United Kingdom	1.098	15	1.115	12
United States	1.000	1	1.000	1

Table A 12 DEA output efficiency scores - 3 inputs (lnHERD, lnGOVERD, lnBERDBYGOV), 1 output (lnBERD), variable returns to scale, 2000-2004 different samples

	all countries	all countries less former eastern countries	EU27+ JP+US	EU27	EU15+ JP+US	EU15
Argentina	1.272	1.179				
Australia	1.123	1.110				
Austria	1.151	1.065	1.151	1.101	1.033	1.029
Belgium	1.112	1.069	1.112	1.108	1.045	1.037
Canada	1.082	1.019				
China	1.033	1.000				
Croatia	1.000					
Cyprus	1.000		1.000	1.003		
Czech Republic	1.263		1.263	1.216		
Denmark	1.071	1.030	1.067	1.086	1.024	1.007
Estonia	1.000		1.000	1.000		
Finland	1.085	1.026	1.083	1.060	1.013	1.000
France	1.102	1.085	1.102	1.034	1.081	1.026
Germany	1.049	1.060	1.049	1.000	1.056	1.000
Greece	1.117	1.000	1.078	1.136	1.000	1.000
Hungary	1.283		1.260	1.158		
Iceland	1.050	1.000				
Ireland	1.081	1.007	1.074	1.139	1.000	1.000
Israel	1.075					
Italy	1.197	1.167	1.197	1.131	1.156	1.106
Japan	1.000	1.000	1.000		1.000	
Korea	1.048	1.007				
Latvia	1.476		1.476	1.141		
Lithuania	1.000		1.000	1.000		
Luxembourg	1.000	1.000	1.000	1.000	1.000	1.000
Malta	1.000	1.000	1.000	1.000		
Mexico	1.196	1.026				
Netherlands	1.147	1.096	1.145	1.088	1.089	1.039
New Zealand	1.339	1.143				
Norway	1.255	1.084				
Poland	1.492		1.490	1.175		
Portugal	1.142	1.091	1.115	1.200	1.090	1.078
Romania	1.000		1.000	1.000		
Russia	1.294					
Singapore	1.216	1.092				
Slovak Republic	1.448		1.448	1.312		
South Africa	1.241					
Spain	1.191	1.114	1.191	1.105	1.101	1.064
Sweden	1.035	1.021	1.035	1.044	1.000	1.000
Switzerland	1.000	1.000	1.000			
United Kingdom	1.115	1.051	1.115	1.012	1.042	1.000
United States	1.000	1.000	1.000		1.000	

Table A 13 Correlation matrix between the variables used in the first stage (DEA analysis) and the determinants used in the second stage (Tobit regression)

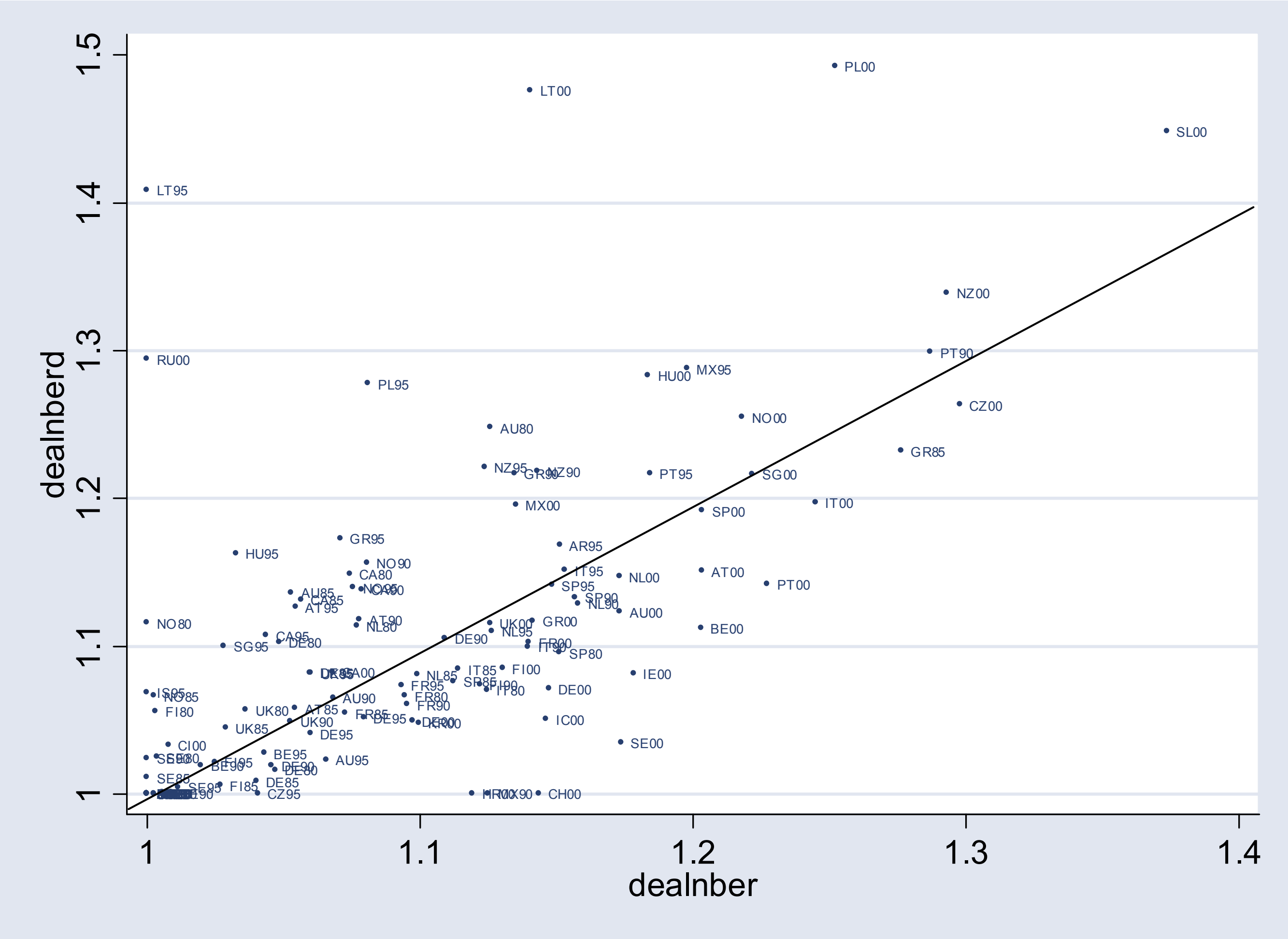
	lnberd	*lnberdbygov*	*lngoverd*	*lnherd*	*# of obs.*
ln BERD	1				144
ln BERDBYGOV	0.926	1			
ln GOVERD	0.881	0.875	1		
ln HERD	0.932	0.871	0.894	1	
Size of government: Expenditures, taxes and enterprises	-0.055	-0.176	-0.001	0.000	143
Legal structure and security of property rights	0.324	0.222	0.119	0.273	
Access to sound money	0.500	0.346	0.274	0.446	
Freedom to trade internationally	0.258	0.220	0.030	0.181	
Regulation of credit, labour, and business	0.169	0.081	0.062	0.139	
More effective control of public spending growth	-0.236	-0.156	-0.208	-0.344	21
Anchoring the budget process in a medium-term perspective	-0.141	-0.040	-0.003	-0.152	
Reduced budget fragmentation and increased transparency	-0.100	0.005	0.090	-0.196	
Share of enterprises receiving public funding for innovation	0.506	0.409	0.486	0.494	46
Public procurement advertised in the Official Journal as a % of GDP	-0.291	-0.307	-0.193	-0.136	43
Public procurement advertised in the Official Journal as a % of total public procurements	-0.443	-0.433	-0.262	-0.232	42
Industry university links (business funded R&D performed in other sector than the business one)	0.631	0.528	0.436	0.496	113
Basic R&D performed in the private sector in % of total business R&D	0.271	0.199	0.041	0.156	46
Share in % of researchers, scientists & engineers In the private sector as a % of total active population	0.451	0.313	0.182	0.190	50
Share in % of researchers, scientists & engineers In the total business R&D personnel	-0.269	-0.304	-0.403	-0.253	50
Share in % of high-tech sectors in total manufacturing value added	0.545	0.395	0.328	0.446	35
Strength of the IPR system	0.655	0.665	0.415	0.544	65
Share of Public Credit Appropriation in the defence sector	0.565	0.705	0.603	0.531	84

Table A 14 Impact of detailed regulatory conditions on DEA efficiency scores: Panel data TOBIT regression

	Dependent Variable: DEA efficiency scores		
Size of Government: Expenditures, Taxes, and Enterprises			
General government consumption spending as a % of total consumption	-0.020	(0.005)	***
Transfers and subsidies as a percentage of GDP	0.021	(0.007)	***
Government enterprises and investment	0.012	(0.004)	***
Top marginal tax rate	-0.001	(0.006)	
# of obs. [left censored]	140	[42]	
log-likelihood	59.9		
LR-test for random effects	63.4		***
Legal Structure and Security of Property Rights			
Judicial independence	-0.038	(0.018)	**
Impartial courts	-0.024	(0.024)	
Protection of property rights	0.028	(0.023)	
Military interference in rule of law and the political process	0.045	(0.010)	***
# of obs. [left censored]	72	[18]	
log-likelihood	18.7		
LR-test for random effects	12.2		***
Access to Sound Money			
Money growth	-0.014	(0.012)	
Standard deviation of inflation	0.014	(0.013)	
Inflation: most recent year	0.002	(0.014)	
Freedom to own foreign currency bank accounts	0.005	(0.004)	
# of obs. [left censored]	142	[43]	
log-likelihood	52.1		
LR-test for random effects	49.8		***
Freedom to Trade Internationally			
Taxes on international trade	-0.074	(0.031)	**
Regulatory trade barriers	0.002	(0.027)	
Size of the trade sector relative to expected	0.017	(0.012)	
Black-market exchange rates	3.305	(0.022)	***
International capital market controls	0.027	(0.013)	**
# of obs. [left censored]	72	[18]	
log-likelihood	22.5		
LR-test for random effects	13.4		***
Regulation of Credit, Labour, and Business			
Credit market regulations	0.020	(0.026)	
Labour market regulations	-0.013	(0.019)	
Business regulations	-0.012	(0.026)	
# of obs. [left censored]	72	[18]	
log-likelihood	16.5		
LR-test for random effects	9.2		***

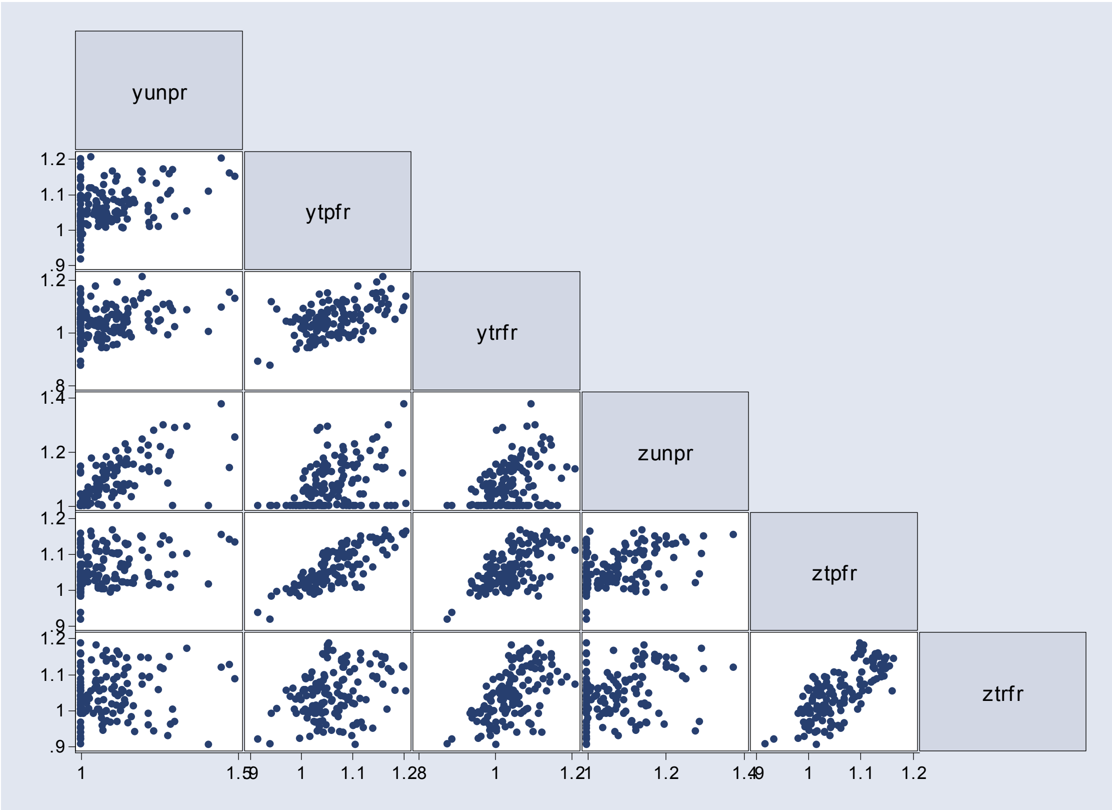
Notes:
Annual dummies included; standard errors in parentheses;
*** (**, *) denote a significance level of 1% (5%, 10%).*

Figure A 4 Comparison of efficiency scores (DEA analysis) obtained from R&D expenditures (ln BERD) vs. R&D personnel (ln BER)



Notes
80 = 1980-1984
85 = 1985-1989
90 = 1990-1994
95 = 1995-1999
00 = 2000-2005

Figure A 5 Scatterplot of DEA predicted and unpredicted scores (ln berd vs. ln ber as output) based on the Fraser Institute regulatory conditions



Notes
y = ln business R&D expenditures; z = ln business R&D personnel; unpr = unpredicted; tp = Tobit pooled; tr = Tobit random; fr = 5 Fraser summary regulatory conditions

Appendix 7: List of countries groupings

Grouping	*(1)*					*(2)*			*(3)*	*(4)*	*(5)*			*(6)*		
	geographic areas					*GDP per capita*			*IM*	*EURO*	*Size of government*			*SII*		
Country	*EU15*	*EU10*	*REU*	*HIC*	*RW*	*L*	*M*	*H*			*L*	*M*	*H*	*L*	*M*	*H*
Argentina	0	0	0	0	1	0	1	0	0	0	0	0	1			
Australia	0	0	0	0	1	0	1	0	0	0	0	1	0			
Austria	1	0	0	0	0	0	1	1	1	0	1	0	0	0	1	0
Belgium	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1
Bulgaria	0	1	0	0	0	1	0	0	0	0	0	0	1	1	0	0
Canada	0	0	0	1	0	0	1	0	0	0	1	0	0			
China	0	0	0	0	1	1	0	0	0	0	0	0	1			
Croatia	0	0	1	0	0	1	1	0	0	0	1	0	0	1	0	0
Cyprus	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0
Czech Republic	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0
Denmark	1	0	0	0	0	0	1	1	1	0	1	0	0	0	0	1
Estonia	0	1	0	0	0	1	1	0	0	0	1	0	0	0	1	0
Finland	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1
France	1	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0
Germany	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1
Greece	1	0	0	0	0	0	1	0	1	0	0	0	1	1	0	0
Hungary	0	1	0	0	0	0	1	0	0	0	0	0	1	1	0	0
Iceland	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1
Ireland	1	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0
Israel	0	0	0	0	1	0	1	0	0	0	1	0	0			
Italy	1	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0
Japan	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1
Korea	0	0	0	1	0	0	0	0	0	0	0	0	1			
Latvia	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Lithuania	0	1	0	0	0	1	0	0	0	0	0	1	0	1	0	0
Luxembourg	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1
Malta	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0
Mexico	0	0	0	0	1	1	0	0	0	0	0	0	1			
Netherlands	1	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0
New Zealand	0	0	0	0	1	0	1	0	0	0	0	1	0			
Norway	0	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0
Poland	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0
Portugal	1	0	0	0	0	0	1	0	1	0	0	0	1	1	0	0
Romania	0	1	0	0	0	1	0	0	0	0	0	0	1	1	0	0
Russia	0	0	0	0	1	1	0	0	0	0	1	0	0			
Singapore	0	0	0	0	1	0	0	0	0	0	0	0	1			
Slovak Republic	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0
Slovenia	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0
South Africa	0	0	0	0	1	1	0	0	0	0	0	1	0			
Spain	1	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0
Sweden	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1
Switzerland	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1
Turkey	0	0	1	0	0	1	0	0	0	0	0	0	1	1	0	0
United Kingdom	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0	1
United States	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	1

Notes: L = Low, M = Medium and H = High.