An analysis of the efficiency of public spending and national policies in the area of R&D

Andrea Conte and Philip Schweizer and Adriaan Dierx and Fabienne Ilzkovitz

European Commission - General Directorate Economic and Financial Affairs

September 2009

EUROPEAN ECONOMY

Occasional Papers 54 | September 2009

An analysis of the efficiency of public spending and national policies in the area of R&D

Andrea Conte, Philip Schweizer, Adriaan Dierx and Fabienne Ilzkovitz

Economic
and Financial Affairs
DIRECTORATE-GENERAL

EUROPEAN COMMISSION

Occasional Papers are written by the Staff of the Directorate-General for Economic and Financial Affairs, or by experts working in association with them. The "Papers" are intended to increase awareness of the technical work being done by the staff and cover a wide spectrum of subjects. Views expressed do not necessarily reflect the official views of the European Commission. Comments and enquiries should be addressed to:

European Commission
Directorate-General for Economic and Financial Affairs
Publications
B-1049 Brussels
Belgium
E-mail: mailto:Ecfin-Info@ec.europa.eu

This paper exists in English only and can be downloaded from the website
http://ec.europa.eu/economy_finance/publications

A great deal of additional information is available on the Internet. It can be accessed through the Europa server (http://europa.eu)

ISBN 978-92-79-11268-3
DOI: 10.2765/51663

European Commission
Directorate-General for Economic and Financial Affairs

AN ANALYSIS OF THE EFFICIENCY OF PUBLIC SPENDING AND NATIONAL POLICIES IN THE AREA OF R&D

EUROPEAN ECONOMY

Occasional Papers No. 54

ACKNOWLEDGEMENTS

The authors are grateful to the members of the Working Group on the Quality of Public Finances (WGQPF) attached to the Economic Policy Committee for having provided information on R&D policy measures and useful comments. Comments and suggestions by colleagues in the Directorate-General for Economic and Financial Affairs as well as by other services of the Commission are gratefully acknowledged.

The views expressed in this paper are those of the authors and should not be attributed to the European Commission or Member States.

Key words: Public Finance, Efficiency, R&D spending, patents, innovation policy.

JEL classification: O33 - H50 - C23

Executive Summary

Improving the quality of public finances is a major challenge for European policy makers. The economic crisis has increased budgetary pressures and accentuated the tension between the need to sustain public spending aimed at raising the EU growth potential and the increased scarcity of public resources. Rising the efficiency and effectiveness of public spending in growth-enhancing areas such as education, R&D and innovation has become, therefore, even more important.

This paper reviews the innovation performance of the different EU Member States and provides estimates of the relative efficiency of their R&D spending. In doing so, it aims at moving the policy discussion from mere volume-based policy targets towards a better assessment of the quality and effects of public R&D spending. The main contribution of this paper is therefore the identification of both (1) a suitable methodology for the evaluation of efficiency levels across Member States and (2) structural and policy determinants which may contribute to raise efficiency levels of R&D spending across countries and over time.

Results indicate that there exist large cross-country differences in terms of measured efficiency, which is an indication that in many Member States there remains a significant potential for further improvement. Currently, there appears to be a divide in efficiency levels between old and new Member States. However, there is some evidence that the new Member States are catching up. The estimated efficiency scores indicate that all EU Member States have improved their efficiency levels over time. There is evidence that the efficiency of R&D spending is higher in countries with a strong knowledge base which, in turn, implies that increases in R&D spending do not necessarily lead to reductions in efficiency levels. Other factors that positively affect efficiency levels include the high-tech specialisation of the economy, the level of investment in education, the employment share in science and technology, and the degree of protection of intellectual property rights. Finally, a R&D tax treatment more oriented towards fiscal incentives rather than direct subsidies appears to have a positive effect on the efficiency level of R&D spending across EU Member States.

This work is based on both a quantitative measurement of efficiency levels and a qualitative analysis of the policy instruments used in the Member States to promote R&D efficiency and effectiveness. Efficiency scores are calculated by means of the Stochastic Frontier Analysis for a set of input and output indicators in order to overcome the limitations associated with each individual indicator.

A complementary survey of national governments highlights some further policy instruments that could contribute to increase the efficiency of R&D and innovation policies, in particular at the national level. The results of the survey argue in favour of adopting a systemic approach to R&D, education and innovation policies, including three main elements: (i) adapting educational programmes and the research infrastructure to the needs of science and industry; (ii) making a sustained commitment to knowledge investment by adopting medium-term funding programmes; and (iii) evaluating existing R&D programmes in order to determine which policy tools are the most effective and in which areas R&D investments offer the highest returns.

More recently, Member States have introduced R&D spending measures specifically targeted to deal with the consequences of the economic crisis. A closer look at these measures reveals that Member States consider direct grants and offers of tax relief as appropriate instruments to counteract the effects of the crisis. It should be clear that such policy measures should be tailored to the specific needs and strengths of every Member State.

Table of Content

1. Economic Rationale and Policy Background

Within the context of the "Lisbon" strategy for growth and jobs the EU Member States have expressed their ambition to increase Europe's overall level of investment in research and development to 3 % of GDP and to raise the share of R&D funded by business. It is no wonder therefore that policy initiatives in this area are at the core of many National Reform Programmes prepared by the Member States as part of Lisbon strategy. The European Commission as well is devoting more and more resources to R&D activities through Community Framework Programmes while the objective of making R&D activities more efficient is at the core of the European Research Area (ERA) initiative.

However, the desire to increase the allocation of public spending for investment in R&D has to be balanced against the scarcity of public resources. Such budgetary pressures explain the increased interest in increasing the efficiency of public spending, which is an important element of the overall framework of the quality of public finances[1]. Efficiency improvements facilitate fiscal consolidation while also helping in raising citizens' welfare. Improving the quality of public finances in different policy areas – such as education, health, public infrastructure, safety, general public services and research and development (R&D) - is therefore a key policy challenge for Europe[2].

This paper presents the results of a first empirical investigation focused on the efficiency and effectiveness of public R&D expenditure. It develops a methodology for the measurement of the efficiency of R&D spending, contains a comparative analysis of the performance of different EU Member States in terms of R&D efficiency and reports on a survey of the policy instruments used to stimulate R&D and innovation. Moreover, the paper examines Member States' responses in the area of R&D spending to the economic crisis. Finally, it suggests some policy actions aimed at increasing the efficiency of R&D and innovation policies.

1.2. Setting appropriate Targets

The issue of efficiency of R&D spending appears particularly relevant from a policy perspective. Within the context of the Lisbon agenda, the R&D-related objectives have been defined in terms of volume only: total R&D expenditures in the EU should reach 3% of GDP with two thirds of R&D investment coming from private sources of funds.

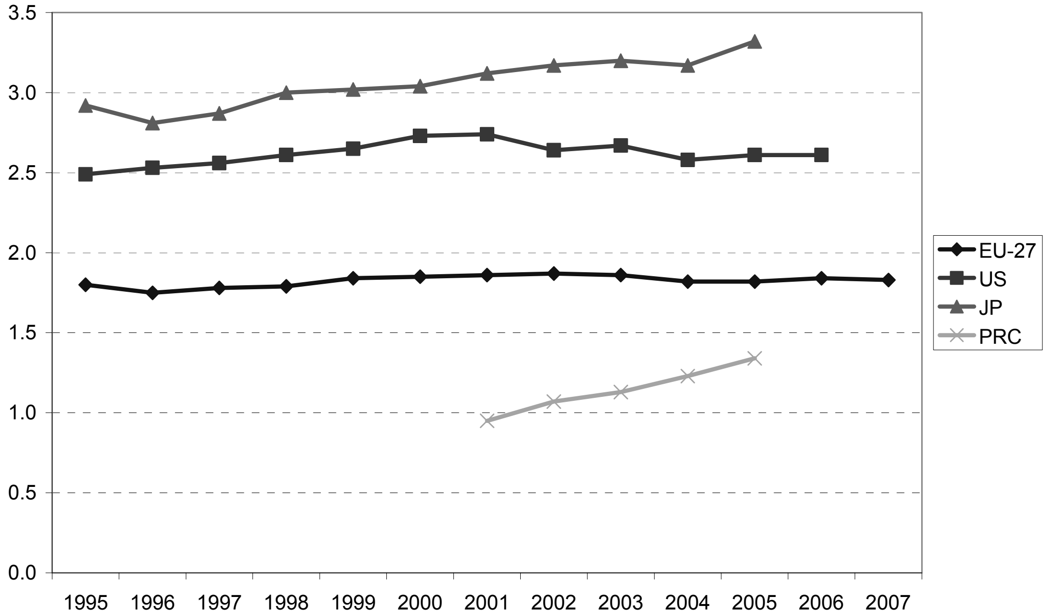
The evolution of R&D intensity over time shows that Europe has not made significant progress in reaching the 3% target (see Figure 1). R&D intensity in the EU has remained relatively stable while fluctuating between 1.8% and 1.9% of GDP. Moreover, given the pro-cyclical nature of private R&D spending, it seems very unlikely that the R&D spending over GDP ratio will increase significantly in the near future. Similarly, the R&D intensity in the US has remained stable at slightly above 2.5% of GDP in recent years. Japan has the highest share of R&D in GDP amongst the major industrial countries (3.32% in 2005). Its R&D intensity has increased in recent years. China, however, has shown the sharpest increase in R&D spending with R&D intensity moving from 0.95% in 2001 to 1.34% of GDP in 2005.

---

1 See Commission Note on the Quality of public finances: A roadmap for deriving a conceptual framework and a set of indicators, February 1st 2008 (ECFIN/C2, REP50439).

2 ECOFIN Council Conclusions, October 2007.

Figure 1: R&D intensity



Source: Eurostat Science and Technology Indicators

Although the objective of attaining a R&D intensity of 3% is still being pursued and the European performance is generally compared at the international level on the basis of this indicator, the appropriateness of this kind of target is being questioned increasingly. Criticism has been fuelled by the fact that the sectoral specialisation of an economy has a clear influence – among other factors - on R&D activity and innovative results (Pavitt, 1982). R&D data do not capture, therefore, the innovative patterns of different sectors – especially mid-tech industries - where figures on R&D spending provide only a partial picture of the overall innovative effort by firms (Conte and Vivarelli, 2005). Accounting for the sectoral specialisation represents therefore a necessary step when assessing a country's relative R&D performance (Van Pottelsberghe, 2008).

This study provides a different approach to the issue of international comparison of R&D indicators by moving from the assessment of volume-based indicators towards the measurement and evaluation of R&D performances based on the efficiency of such spending – namely the evaluation of the different results obtained for a given level of spending across countries. This approach may not only allow a more accurate view on R&D performance, but could also indicate ways to improve efficiency for the sake of reducing the burden of public R&D spending on public finances.

1.3. Structure of this Note

Section 2 presents the analytical framework adopted for the assessment of the efficiency of R&D spending across Member States and its determinants. Section 3 provides a descriptive analysis of R&D input and output indicators as well as alternative estimates of R&D efficiency levels. Section 4 presents the result of an econometric investigation of the determinants of R&D efficiency. Section 5 discusses country specific policies to support R&D on the basis of a survey on the practical experiences of the EU Member States and examines the Member States' responses to the economic crisis in terms of R&D spending. Finally, Section 6 highlights policy interventions aimed at increasing the efficiency of public R&D spending and, more broadly, innovation policies.

2. Analytical Framework

2.1. Economic Background

There are two main economic arguments for governments to take an active role in stimulating investment in R&D[3]. The first reason is that there is a widespread consensus on the recognition of R&D as the main engine of long-run economic growth (Romer, 1990)[4]. In particular, the objective of R&D activity is the generation of new knowledge (invention), which may be then, transformed into commercially-viable innovations (the development stage of the R&D process). Finally, the diffusion process (through adoption by consumers and imitations by firms) induces the long term positive effect of R&D activity on economic growth (Schumpeter, 1934). Public authorities may contribute to enhance a country's R&D system by providing the infrastructure and the institutional framework for supporting innovation activity.

The second reason refers to the important features which make R&D different from other types of profit-motivated investments. For example, R&D is characterised by indivisibilities and economies of scale that create strong incentives for firms to monopolize markets. Moreover, the uncertainty inherent to innovation itself makes R&D activities highly risky from a firm's perspective[5]. This uncertainty, together with asymmetric information on the ultimate nature of the R&D investment, makes it more difficult for firms to obtain external financing[6]. Finally, the partial non-excludability of R&D undermines private incentives to invest in R&D (Jones and Williams, 1998; Mansfield et al., 1977)[7], which in turn explains why there is a role for government policies in promoting R&D and restoring R&D investments to their socially desirable level[8].

The role of governments in supporting R&D activities is, moreover, amplified in times of economic turbulence since the public sector is called on to counterbalance the likely slowdown of private R&D investment, which tends to be of pro-cyclical nature in the short term.

---

3 Indeed, data from the MICREF data base on structural reforms indicate that over the period 2004-2006 nearly 30% of reform measures undertaken by EU Member States were in the field of R&D and innovation.

4 Endogenous growth theory extends the framework depicted by Solow (1956 and 1957) by linking knowledge creation and the accumulation of human capital to economic growth (Romer, 1986) and human capital (Lucas, 1988). For a review of the literature on technological change and growth, see Conte (2006).

5 In particular, the additional "technological uncertainty" embedded in the innovation itself, together with the common "market uncertainty" faced by firms acting in markets, makes R&D activities highly uncertain and risky from a firm's perspective.

6 In more technical terms, the skewness in the distribution of R&D outcomes, due to a mix of high variance of expected returns and a very low-probability associated to the highest payoffs (Scherer and Harhoff, 2000), affects a firm's investment decision (Scherer et al., 2000). In turn, this makes it more difficult to obtain external financing and, to a large extent, requires most firms to fund their R&D activities from internal sources.

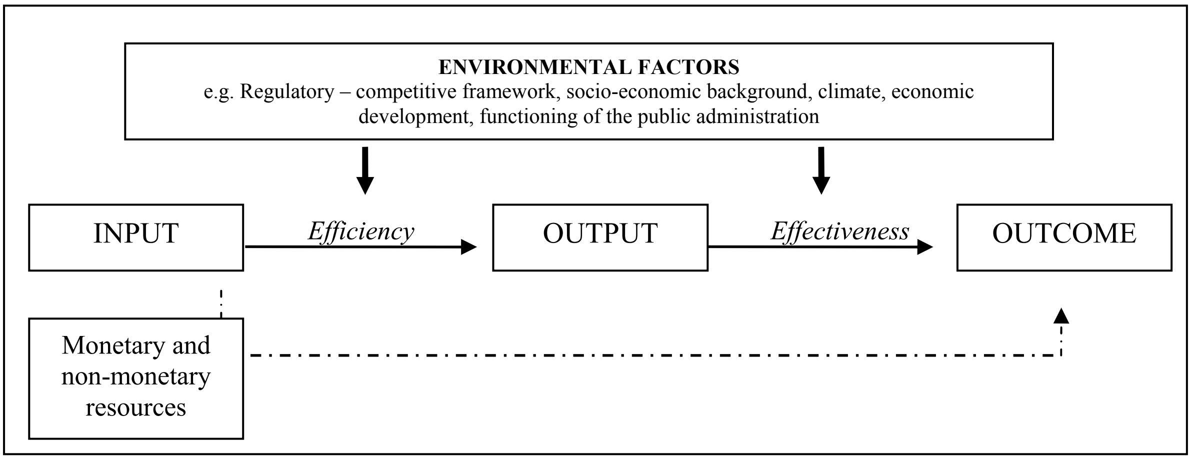
7 A crucial determinant of this outcome is the role played by technological "spillovers" (Mansfield, 1985; Jaffe, 1986; Acs et al., 1994).

8 Market failures in R&D can be addressed either directly (i.e. by targeting them at their source) or by influencing the incentives faced by private actors (Goolsbee, 1998; Hall and Van Reenen, 2000; David et al., 2000; Martin and Scott, 2000). For an overview of policy instruments, see Section 2.2.

2.2. Conceptual Framework

The aim of this section is to provide the conceptual framework which allows addressing the issue of efficiency of public R&D spending within the context of a broader cross-country assessment of innovation systems in Europe. The analysis of efficiency and effectiveness deals with the relationships between inputs, outputs and outcomes (see Figure 2).

Figure 2. Conceptual Framework of Efficiency and Effectiveness



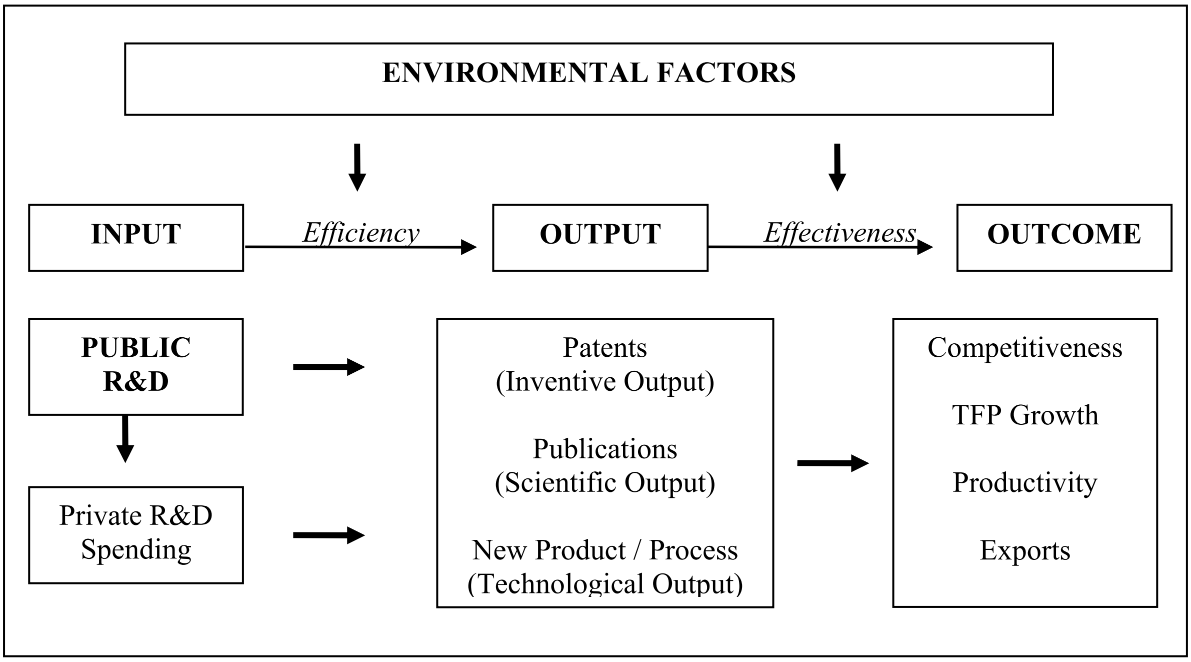
The efficiency concept refers to the concept of production possibility frontier, which indicates the quantity of output which can be efficiently produced for a given input level. The greater the output for a given input, or the lower the input for a given output, the more efficient the activity is. Efficiency levels are, in turn, influenced by environmental factors. They can be time-variant as well as country specific, e.g. associated with the sector composition of the economy.

Effectiveness relates the input or the output to the final objectives to be achieved - the outcome - which is directly influenced by political choice. Indeed, the effectiveness concept refers to the broader assessment of the success in the use of public resources for achieving a given set of political objectives.

This study focuses on a specific spending area, namely public R&D spending[9]. The first step consists, therefore, in the identification of the relevant groups of indicators which will be used for assessing the issue of efficiency and effectiveness. Figure 3 provides an application of the general conceptual framework to the R&D case.

[9] Indeed, the focus on specific spending areas allows a better assessment of the efficiency of public spending (Mandl et al., 2008).

Figure 3. Conceptual Framework of Efficiency and Effectiveness of Public R&D spending



Policy makers are most interested in looking into the effects of public R&D policy. This implies the effects of both (1) direct public spending and (2) other policy instruments aimed at promoting the target of more and more efficient R&D spending.

There are two main targets of public R&D policy. The first objective is to increase the innovative output. This may be proxied by different output measures which capture different aspects of the innovative process (Schumpeter, 1934). In particular, patents represent the output of the inventive process (Ames, 1961), which leads to the generation of new ideas and it is commonly associated with science and basic research. Nevertheless, patents have high heterogeneity with respect to quality, which in turn may cause a comparison bias (Lanjouw and Schankerman, 2004). This is the reason why this survey also considers alternative indicators of innovation such as the number of scientific publications and citations. Publications also contribute to the creation of a scientific knowledge base by formalising and making public advancements in different research fields. Finally, marketable new products and processes represent the output of the innovation process, which translates new ideas into the creation of economic value at a firm level. This stage is generally associated with technology and applied R&D[10].

A second objective of R&D policy is to increase the R&D effort by private players, thus raising a country's R&D investment at no additional cost for taxpayer. The objective of increasing private R&D investment is a necessary condition for reaching the objective of raising the R&D intensity to 3% of GDP as indicated in the Lisbon agenda for growth and jobs . It is therefore an important policy objective to identify measures which will generate additional business investment in R&D activities (Cincera et al., 2008).

Finally, various outcome measures may be defined by the political agenda. The standard approach is to estimate the effects of R&D on different measures of economic outcome either directly (Guellec and van Pottelsberghe, 2004) or through the effect of R&D on innovative output which, in turn, will affect the economic outcome (Crepon et al., 1998).

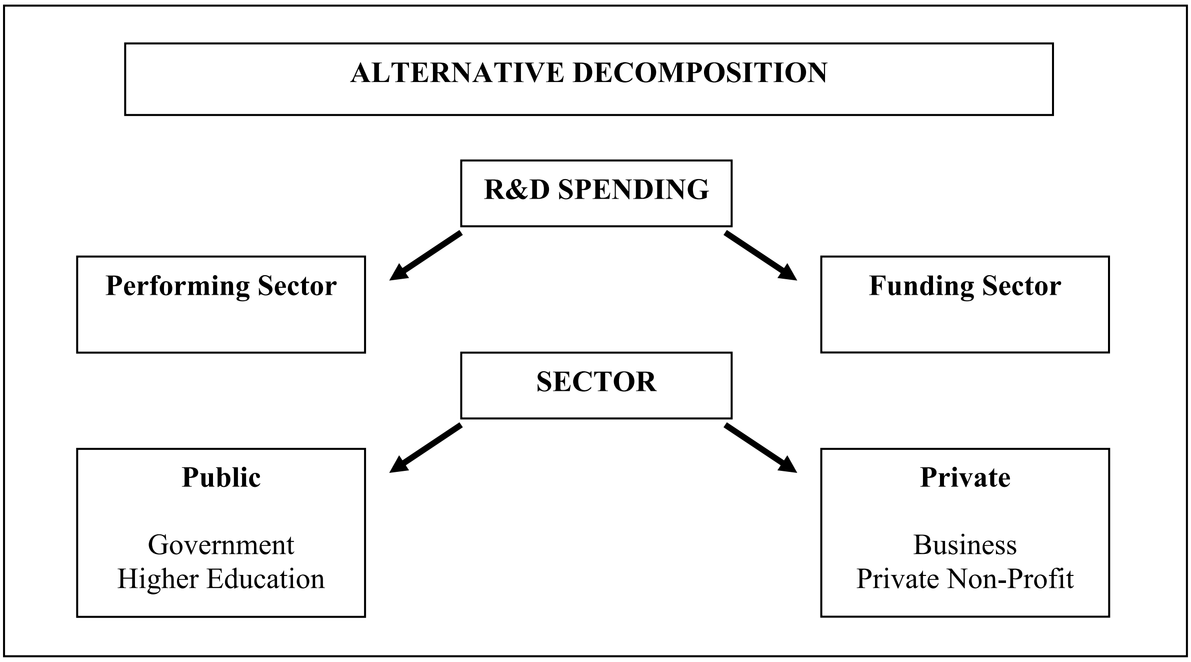
[10] Product and process innovations are included in Figure 3 even though data limitations do not allow investigating the efficiency of R&D spending with respect to these technological output indicators.

The relationship between inputs, outputs, and outcomes is affected by a number of institutional/environmental variables. This study focuses on the efficiency issue – namely on the relationship between inputs and outputs – and it pays attention, therefore, to those control factors which may affect such relationship (see Appendix 2).

2.3. Public Policies in the Field of R&D and Innovation

The final conceptual issue to be addressed concerns the definition of the public R&D indicators. Statistical offices provide R&D data by means of two complementary decompositions. The first one presents R&D data according to sectors of performance, namely those sectors in the economy where R&D activities are actually carried out. The second one is based on the source of R&D funding, namely those sectors which finance R&D investment no matter whether such activity is performed in that specific sector or in other segments of the economy[11]. R&D accounting classifies the overall economy into four broad macro-sectors, namely government, higher education, private business and private non-profit sectors. The public sector is defined as the sum of the government and higher education sectors (European Commission, 2007), and the private sector as the sum of private business and private non-profit sectors[12]. Both the classifications based on sectors of performance and sources of funding represent an important dimension for assessing the output of R&D investment. Indeed, the objective of publicly funded research will differ from that of privately funded research since R&D performed by business is likely to be more market oriented than the R&D of government and higher education institutions. This, in turn, will have implications for the results obtained in the efficiency measurement.

Figure 4. Taxonomy of R&D Spending



---

11 In principle, the estimated total of R&D expenditure according to sector of performance should equal the total according to the sources of funds used to finance R&D. In practice, however, this is not likely to be the case owing to sampling difficulties and reporting differences (Oslo Manual, OECD, 2005).

12 The disaggregation of R&D data according to sources of financing identifies a fifth macro-sector, namely R&D financed by abroad.

Figure 5 refers to the policy instruments which are commonly used to support R&D. A common distinction is often made between direct and indirect channels:

Direct public R&D spending refers to:

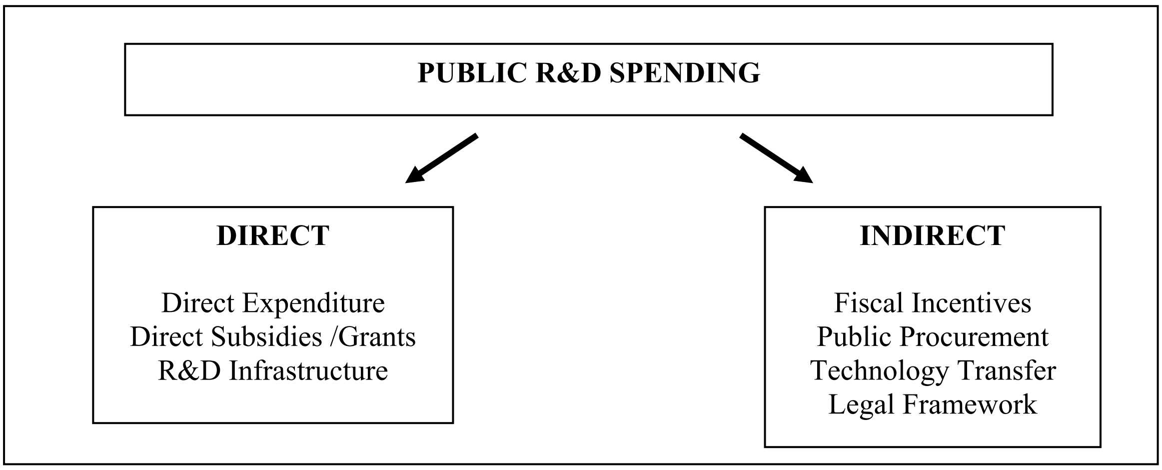
- R&D activities carried out in government / higher education institutions and funded by public sources;
- R&D activities funded by direct subsidies/grants irrespective of the sectors in which they are actually performed;
- Provision of R&D Infrastructure.

The government uses direct intervention when market incentives are weak and potential benefits are likely to have important economy-wide spillovers. Two examples refer to (a) direct support to the creation of R&D infrastructures (e.g. European Technology Platforms - ETPs) and (b) the provision of R&D funding to public-private partnerships (PPPs).

Indirect public R&D spending refers to those measures aimed at reducing the costs of R&D investment carried out by firms or other private institutions. The economic reasoning is to provide a compensation for the spillovers these activities generate to society (see Section 1.1). Main interventions include:

- Fiscal incentives such as R&D tax credits;
- Public procurement;
- Technology transfer initiatives such as R&D collaboration, research joint ventures, spinoffs, science-industry cooperation, mobility of researchers;
- Interventions in the legal and regulatory framework, such as reforms of Intellectual Property Rights (IPRs) and the setting of standards.

Figure 5. Policy Instruments



3. Public R&D Support and Innovation Performance across the Member States

This section provides some descriptive statistics on the main R&D inputs and innovative outputs across EU Member States. Where appropriate, a distinction is made between R&D performed by the public sector (see Section 3.1) and the business sector (see Section 3.2). These input and output indicators are then used for the calculation of efficiency scores (see Section 3.3).

Table 1 indicates the core inputs and outputs indicators used in the empirical analysis and for the calculation of the efficiency scores. The full list of indicators as well as their sources is described in Appendices 1 and 2. On the input side, this study considers both total R&D spending as well as R&D expenditures by sector of performance (see Figure 4). Statistics on R&D personnel are provided along the same disaggregation of R&D spending. On the output side, this note includes four measures of innovative output as proxies of inventive and scientific outputs (see Figure 3)[13].

Table 1. Core R&D-Innovation Indicators

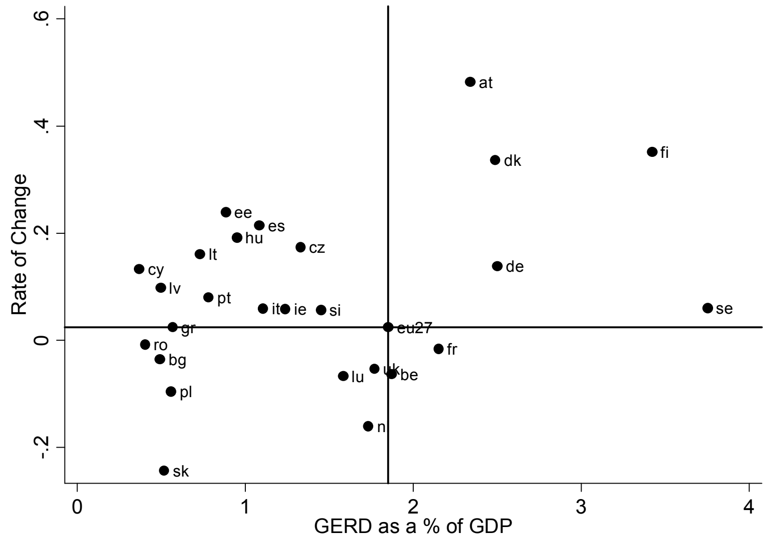
Input	Output	Control
Total R&D	Patents	R&D Personnel
R&D by sector of performance	Triadic Patents	
	Scientific Publications	
	Citations	

A closer look at Gross Expenditure on R&D (GERD) as a % of GDP and its development over time allows distinguishing between four groups of countries (see Figure 6)[14]. Sweden, Finland, Germany, Denmark and Austria are the countries where the level of GERD, measured as a percentage of GDP, is the highest. These five countries perform well both in terms of their static and dynamic position amongst the EU 27 Member States. A second set of countries, namely those located in the upper left quadrant, are defined as catching-up countries in terms of GERD since they start from a low level of GERD as a percentage of GDP but have increased their ratio at a faster rate than the EU average. A third set of countries, namely France, the United Kingdom, Belgium, Luxembourg and the Netherlands have a level of GERD close to the EU average, but they have shown a lower level of GERD over the period 2002-2006 compared to the previous one (1997-2001). Finally, a fourth group of countries located in the lower left quadrant appear rather weak in their overall GERD performance.

13 Measures of technological output, such as new products and processes, have not be included in the analysis due to a limited data coverage over time and across countries. Hollanders and Esser (2007) discuss the issue of innovation efficiency based on these indicators.

14 Since data on some variables for 2007 are still missing, the comparison across countries is performed on the basis of the period 2002-2006 and 1997-2001. The rate of change is expressed in GDP % points.

Figure 6. GERD as a % of GDP



A country's innovation system cannot be described by a single indicator. Table 2 presents some key statistics on R&D and innovation for the EU 27 and its Member States. There is a high degree of variation in terms of both the volume and the type of spending across Member States. This offers a first indication that there can be no single policy strategy that will deliver the desired results in all countries. This is a crucial aspect to be considered in the design of Community level policies since a narrowly defined target for R&D and innovation policies may be counter-productive if applied to countries at different stages of development of their innovation system. A more comprehensive policy approach to innovation may allow a better definition of the instruments in support of a country's own *innovative pathway* and, therefore, provide better results in terms of growth and jobs. Moreover, one needs to consider that the efficiency of public R&D spending depends on a wide range of factors which may go beyond standard boundaries of innovation policies and encompass, among other fields, competition, sector and education policies (see Section 5).

Table 2. Core R&D-Innovation Indicators. Latest available year (2007) (shaded areas refer to the five best performances for each indicator).

Name	R&D as a % of GDP	R&D personnel as a % of Total Employment	Patents per Million of Inhabitants (2005 latest available year)	Triadic Patents per Million of Inhabitants (2005 latest available year)	Scientific Publications per Million of Inhabitants (% terms - 2004 latest available year)	Citations per Scientific Publication (2004 latest available year)
Austria	**2.56**	2.14*	183.11	.12	.56	6.03
Belgium	**1.87**	1.85**	129.07	.98***	.64	6.16
Bulgaria	**.48**	.61*	1.37	---	.12	2.92
Cyprus	**.45**	.71*	17.02	---	.23	3.01
Czech Rep.	**1.54**	1.48	7.27	---	.32	3.82
Germany	**2.53**	1.84**	275.01	.11	.46	7.04
Denmark	**2.55**	2.44**	174.55	.06***	.86	4.38
Estonia	**1.14**	1.44	5.6	---	.31	5.76
Finland	**3.47**	3.22**	267.61	.96***	.83	5.43
France	**2.08**	1.72**	119.17	.02	.45	6
Greece	**.57**	1.41**	6.53	---	.38	3.8
Hungary	**.97**	1.28*	7.78	---	.24	4.5
Ireland	**1.31**	1.5*	64.08	.25	.54	5.26
Italy	**1.14***	1.33*	76.05	.54	.36	5.39
Lithuania	**.82**	1.09*	1.31	.64	.17	4.58
Luxembourg	**1.63**	2.59**	194.91	1.48	.24	3.63
Latvia	**.63**	.92**	5.71	---	.07	2.24
Malta	**.6**	1.04*	21.56	---	.09	4.55
Netherlands	**1.7**	1.4**	173.25	.18	.75	4.09
Poland	**.56***	.83*	3.03	.01	.19	6.91
Portugal	**1.18**	.87**	7.41	---	.29	5.71
Romania	**.53**	.45*	.69	---	.07	3.31
Slovenia	**1.53**	1.41*	32.15	---	.55	4.19
Slovakia	**.46**	.99	5.8	---	.22	2.23
Spain	**1.27**	1.57*	29.27	.02	.38	3.02
Sweden	**3.64**	2.71**	184.77	.22	.96	3.15
UK	**1.76***	---	91.41	.25***	.57	4.8
EU 27	**1.83**	**1.48**	**105.65**	**.04**	**---**	**---**

*2006, **2005, ***2004

Name	R&D as a % of GDP	R&D by the Government – % of GDP	R&D by Higher Education Institution – % of GDP	R&D personnel as a % of Total Employment – Government Sector	Patents by the Government Sector per Million of Inhabitants(2005 latest available year)	R&D by the Business Sector – % of GDP	R&D personnel as a % of Total Employment – Business Sector	Patents by the Business Sector per Million of Inhabitants(2005 latest available year)
Austria	**2.56**	.13	.62	.14*	.12	1.81	1.1*	96.13
Belgium	**1.87**	.16	.41	.1**	.38	1.3	.85*	71.73
Bulgaria	**.48**	.28	.05	.35*	.03***	.15	.09*	.55
Cyprus	**.45**	.12	.19	.2*	---	.1	.18*	10.79
Czech Rep.	**1.54**	.29	.26	.29	.03	.98	.62	4.12
Germany	**2.53**	.35	.41	.25*	.18	1.77	.83**	175.75
Denmark	**2.55**	.18	.7	.18*	.18	1.66	1.38*	81.08
Estonia	**1.14**	.1	.48	.17	---	.54	.41	1.29
Finland	**3.47**	.29	.65	.39*	.08***	2.51	1.57*	126.34
France	**2.08**	.34	.4	.23*	3.69	1.31	.77*	64.67
Greece	**.57**	.12	.29	.18**	.03	.15	.27**	4.15
Hungary	**.97**	.23	.23	.29*	.09	.49	.28*	3.46
Ireland	**1.31**	.09	.35	.06	.24	.88	.67*	22.62
Italy	**1.14***	.21	.34*	.22*	.40	.56	.43*	52.03
Lithuania	**.82**	.17	.41	.2*	---	.23	.1*	.51
Luxembourg	**1.63**	.22	.05	.33**	---	1.36	2.05**	157.01
Latvia	**.63**	.15	.27	.2*	---	.21	.18**	2.21
Malta	**.6**	.02	.19	.02	---	.39	.36*	19.45
Netherlands	**1.7**	.22	.45	.17**	.27	1.03	.76**	93.59
Poland	**.56***	.21*	.17*	.16*	.02	.18*	.11*	1.14
Portugal	**1.18**	.11	.35	.14**	.10	.61	.17**	5.83
Romania	**.53**	.18	.13	.09*	.00	.22	.14*	.49
Slovenia	**1.53**	.36	.24	.32*	---	.94	.55*	13.05
Slovakia	**.46**	.16	.11	.2	---	.18	.15	2.36
Spain	**1.27**	.22	.33	.24*	.25	.71	.52*	15.01
Sweden	**3.64**	.22	.77	.13**	.12	2.65	1.39**	126.55
UK	**1.76***	.18*	.46*	.08*	1.32	1.08*	.5*	40.66
EU 27	**1.83**	**.24**	**.41**	**.19**	**.77**	**1.17**	**.6**	**62.03**

3.1. Public R&D Spending

Data on R&D performed in the government sector provides evidence of cross-country differences in the involvement of the public sector in research activities. It also illustrates the occurrence of different institutional features among the EU 27. This refers, in particular, to the institutional and funding balance between government and higher education sectors, the relative role of public and private institutions within the latter, and the size of the government sector. Firstly, R&D activity is organised in different ways across EU Member States. For instance, in France, Hungary, and Bulgaria most of the public R&D investment occurs in the government sector whereas higher education institutions are responsible for a large share of public R&D spending in Sweden, Austria and Denmark. Secondly, an assessment of public R&D investment in the higher education sector needs to take into account the relative balance between public and private research institutions and universities, as well as differences across countries in the public funding rules of private tertiary education institutions. Finally, differences in (1) the role/activities of government institutions across countries and in (2) the legislation on appropriability of intellectual property rights (IPRs) within public bodies may affect the data on patents by the government sector. The former refers to the relative size of the government sector and the possibility of a wider range of R&D and patenting activities in some countries. The latter refers to the rules on the recognition of ownership of IPRs to individual researchers working in public institutions, and the possible patenting and commercialization of such innovation activities.

We provide some descriptive evidence of public R&D indicators by considering separately government and higher education sectors. In light of the institutional differences described it is not surprising that different patterns emerge across European Member States.

France and Germany are the countries with the highest percentage of government GERD in terms of GDP (Figure 7) but they perform slightly above the EU 27 average in terms of GERD in higher education (Figure 8). On the contrary, Sweden, Austria and Denmark perform well in terms of higher education GERD while they do not appear to be leading in terms of Government GERD. Finland is the only country where GERD in both sectors is significantly above the EU 27 average. Bulgaria and Slovenia have high levels of government GERD while another NMS, that is Hungary, records the highest growth in GDP points among EU 27.

Aggregate growth rates between the two periods under consideration for the EU 27 indicate a substitution from GERD in the government sector towards GERD in the Higher education institutions. This is especially the case for Denmark and Italy, which record the highest decrease of both government GERD, and the highest increase of GERD in Higher Education institutions at the same time among the EU 27.

Figure 7. GERD by the Government as a % of GDP

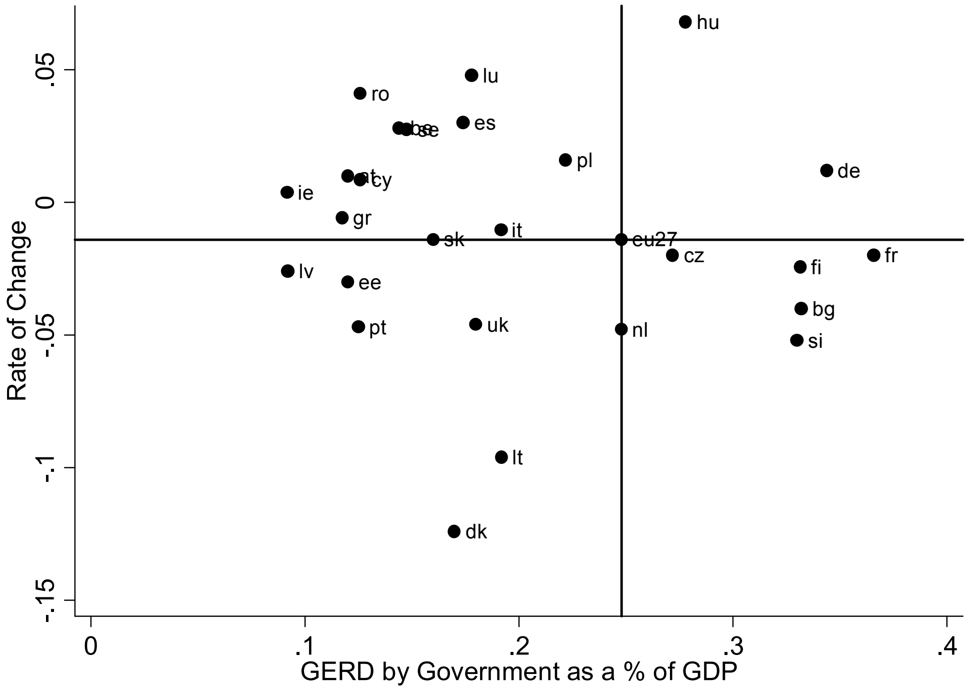
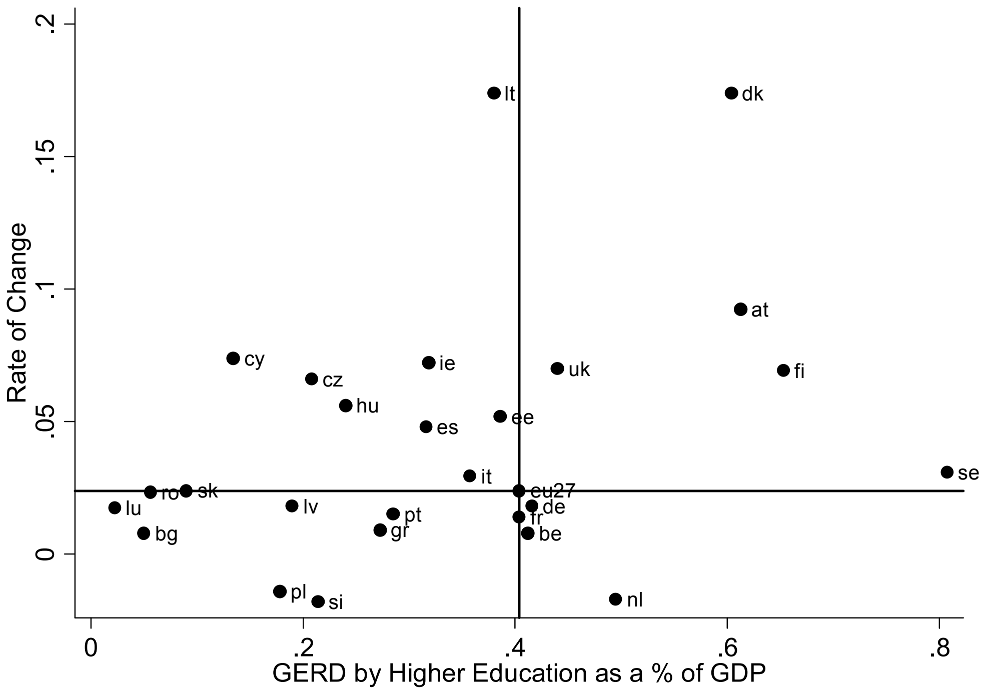


Figure 8. GERD by Higher education Institution as a % of GDP



3.2 Private/business indicators of R&D Spending, Human Resources and Patents

GERD in the business sector represents more than 60% of overall GERD across EU Member States (see Table 1). Aggregated data for the EU 27 show a stable rate of business R&D as a percentage of GDP (growth of 0.002 GDP percentage points between the two periods) and a slight increase in R&D personnel as a percentage of total employment in the business sector (0.024 GDP percentage points) (see Figures 9 and 10). Overall GERD performance depends on the level of GERD in the business sector. Indeed, the five best performing countries in terms of business GERD, namely Sweden, Finland, Germany, Denmark and Austria, are also the countries with the highest level of overall GERD. Beyond this group, three other country groups clearly emerge from Figure 13. A group of countries with stable R&D performance in the private sector includes Luxembourg, France, Belgium, the United Kingdom, the Netherlands and Ireland. Moreover, it is possible to identify a group of countries, most of them New Member States, which are catching-up in terms of private R&D expenditure, as well as a group of countries where there is no signal of stronger investment of the private sector in R&D activity.

Figure 9. GERD by the Business Sector – % of GDP

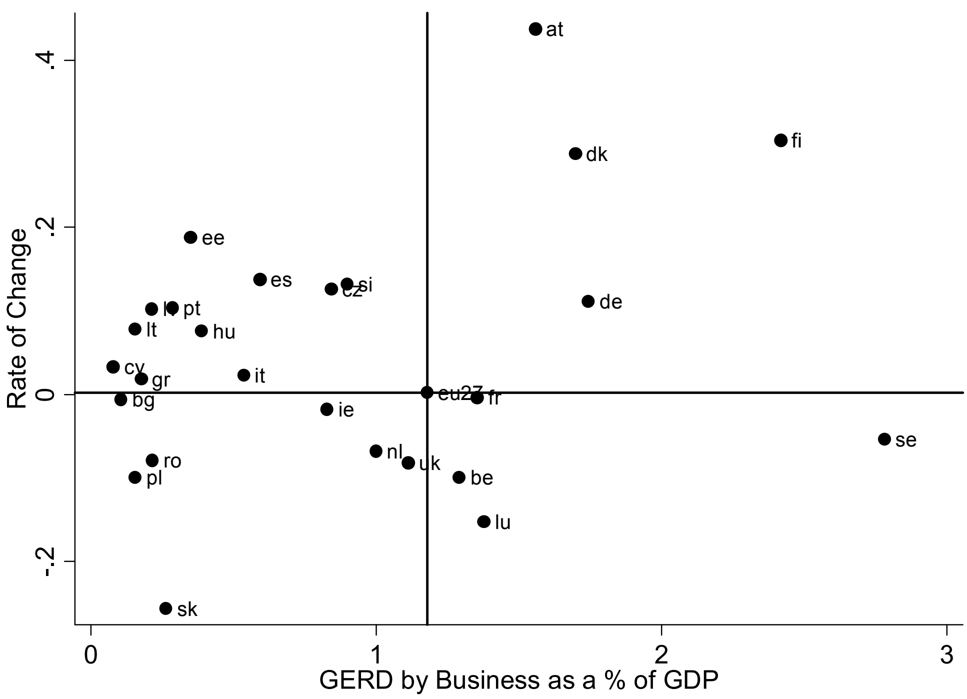
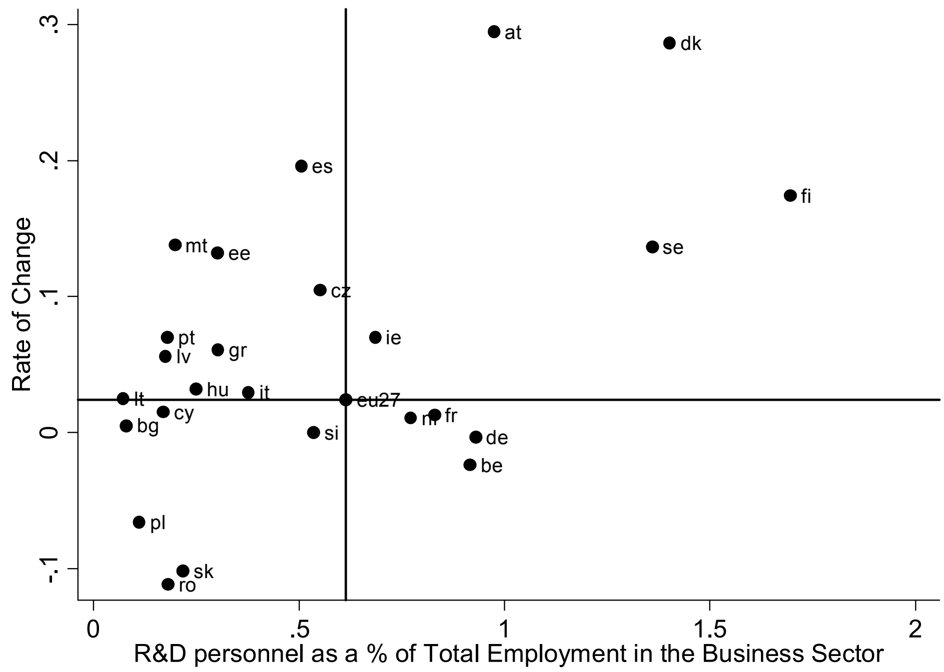


Figure 10. R&D personnel as a % of Total Employment – Business Sector



Enhancing private R&D investments represents a fundamental policy initiative for meeting the targets set out in the Lisbon strategy for growth and jobs. In recent years a number of Member States witnessed a significant shift in the policy mix from direct subsidies to fiscal incentives (Figure 11). The acceleration of the shift towards more tax incentives after 2000 did not happen at the expense of direct subsidies. Instead, countries have chosen to focus on strengthening of the whole portfolio of policy instruments by maintaining or even increasing their level of direct funding (e.g., Portugal, Spain, the United Kingdom) while keeping generous R&D tax incentives. Some countries with high R&D intensities and a favourable business innovation climate (such as Finland, Sweden or Germany) have both low R&D tax incentives and low direct subsidies for R&D.

Figure 11. Summary of analytical findings on direct subsidies versus tax incentives for R&D, 1991-2006 (Source: Warda, 2006)

Analytical Category	1991	2000	2006
Strong direct funding and unfavourable tax treatment	UK, IT, SE, DE	CZ, IT, PL	IT
Little direct funding and unfavourable tax treatment	BE, DK, EL, FI, HU, IE, NL, PT, JP	BE, DE, EL, FI, SE, UK	DE, EL, FI, SE
Little direct funding and favourable tax treatment	AT	AT, DK, ES, FR, HU, IE, NL PT, JP, US	AT, BE, DK, FR, HU, IE, NL, PT, JP
Strong direct funding and favourable tax treatment	ES, FR, US	No countries	CZ, ES, PL, UK, US

3.3. Evidence on Efficiency Levels across Member States

This section provides information on five patent-based indicators and two scientific-based indicators across European Member States (see Table 3). Descriptive evidence on these indicators will provide the basis for the empirical exercise on the determinants of efficiency of public R&D spending which will be carried out through means of both parametric and non-parametric techniques in a later stage of this analysis.

The first efficiency indicator suggested is the ratio of the total number of patents over the overall expenditure in R&D. There is no evidence of decreasing returns to scale in this indicator since among the most efficient countries there are both large and small economies (see Table 3).

The second and third efficiency indicators present the ratio of patents over publicly performed and publicly funded R&D, respectively. For the purpose of these efficiency calculations both the government and higher education sectors are considered to be part of the public sector. A similar country ranking emerges between the taxonomy based on performers and funding of public R&D (Figures 13 and 14). The Netherlands, Germany, Malta, Italy, Austria and Belgium are amongst the best performing countries according to the three indicators considered thus far.

The fourth and fifth efficiency indicators rescale patents by population size and GERD by GDP in order to provide a further check to both the size of the economy and the GDP level across countries[15]. Results differ to some extent from the earlier efficiency indicators in terms of both most efficient economies and relative distribution of countries. However, Germany and the Netherlands appear among the most efficient countries in all patent-based efficiency indicators.

The sixth column of Table 3 presents an overall efficiency calculation based on DEA technique for the R&D-patent relationship. In particular, "Patents per Million of Inhabitants" and "Triadic Patents per Million of Inhabitants" are used as joint output measures while government R&D, higher education R&D and business R&D are adopted as input indicators. This country-specific DEA score may be thought as an additional step toward a more comprehensive assessment of a country's relative position in terms of the relationship between different innovative inputs and outputs.

Finally, Table 3 provides two additional ratios based on the relationship between R&D spending as a % of GDP, scientific publications and citations per capita.

---

[15] This is a common procedure of normalising patent and R&D data since GERD is influenced by the economic structure of each country (EC, 2007). Indeed, it allows controlling for a different level of GDP per capita across countries.

Table 3. Normalized Ratios (averages over the period 2002-2006; EU 27 = 100 where applicable)*.

Name	Patents by GERD	Patents by Public-performed GERD	Patents by Public-funded GERD	Patents per Million of Inhabitants by GERD as a % of GDP	Triadic Patents per Million of Inhabitants by GERD as a % of GDP	DEA Efficiency Levels	Publications per Million of Inhabitants by GERD as a % of GDP	Citations per Scientific Publication by GERD as a % of GDP
Austria	90	97	103	127	113	.82	33	35
Belgium	90	92	100	121	170	.82	51	48
Bulgaria	59	51	59	7	-	.82	37	89
Cyprus	38	51	44	31	247	.74	76	98
Czech Rep.	31	27	28	12	10	.82	31	36
Germany	141	135	134	188	212	.82	27	35
Denmark	72	73	75	123	98	.84	51	41
Estonia	34	51	38	12	-	.73	41	56
Finland	83	81	81	124	113	.80	36	24
France	79	78	81	101	100	.82	32	38
Greece	24	38	28	19	8	.76	100	98
Hungary	66	73	66	21	29	.91	37	68
Ireland	48	51	50	82	126	.99	62	59
Italy	107	127	109	119	129	.82	47	69
Lithuania	21	32	22	6	108	.82	18	85
Luxembourg	72	57	72	216	380	.86	31	40
Latvia	62	78	69	14	33	.76	22	41
Malta	110	143	113	59	379	.38	22	100
Netherlands	148	162	156	205	266	.80	66	60
Poland	31	35	31	9	4	.77	51	87
Portugal	24	35	22	14	24	.79	36	52
Romania	69	65	69	5	6	.00	20	62
Slovenia	90	81	88	49	35	.77	70	96
Slovakia	59	57	56	17	8	.76	54	30
Spain	45	51	47	40	20	.83	45	55
Sweden	62	62	63	98	70	.87	39	26
Utd. Kingdom	66	70	78	88	71	1	48	54
EU 27	**100**	**100**	**100**	**100**	**100**	**---**	**---**	**---**

*Shaded areas refer to the five highest ratios for each indicator.

Figure 12. Total Number of Patents by GERD - Real Terms[16]

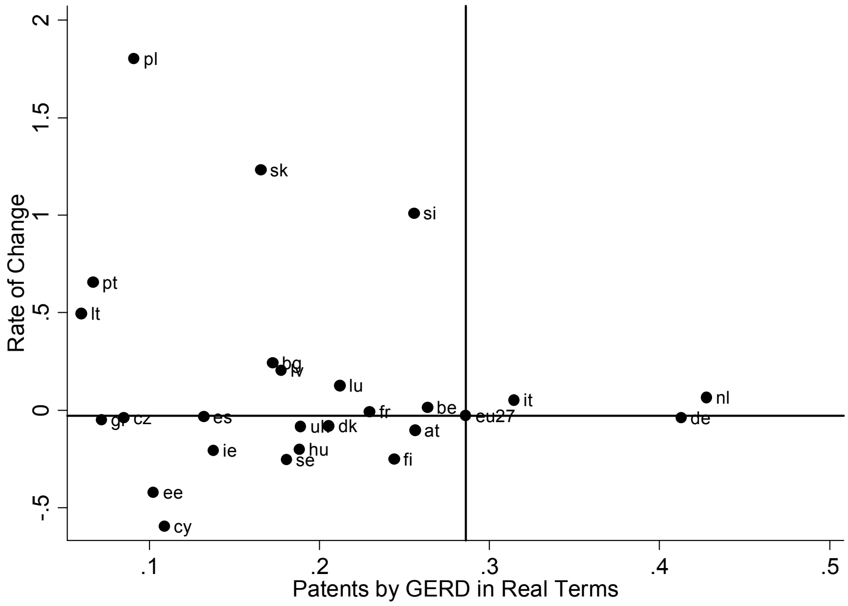
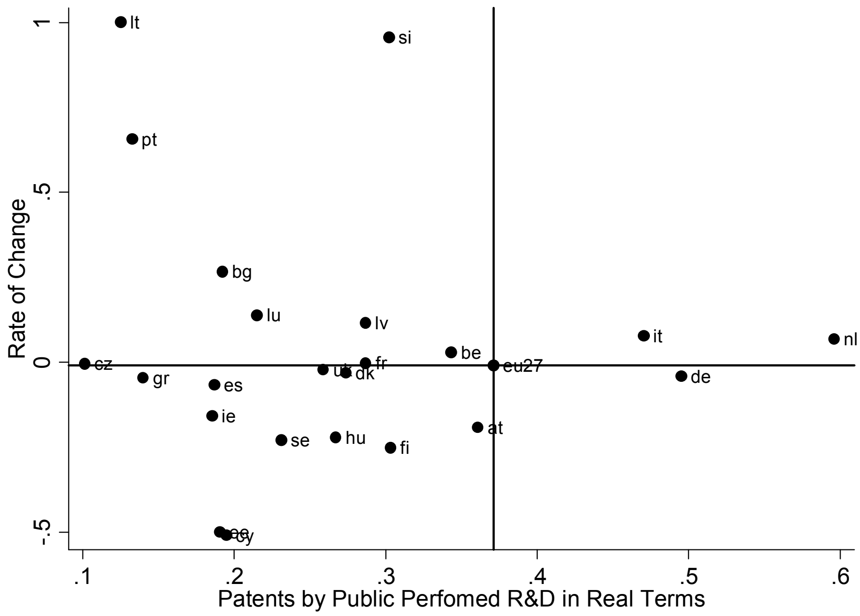


Figure 13. Total Number of Patents by Public Performed R&D - Real Terms[17]



16 Romania has been excluded from Figure 10 for the sake of graphic readability. The growth figure for Romania amounts to 7.22.

17 Romania, Poland and Slovakia have been excluded from Figure 11 for the sake of graphic readability.

Figure 14. Total Number of Patents by Public Funded R&D - Real Terms[18]

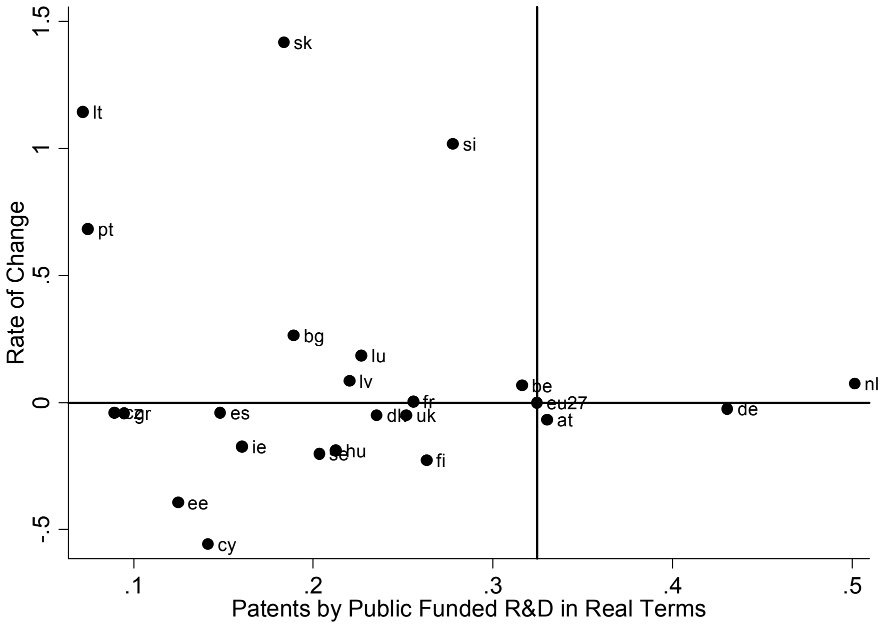
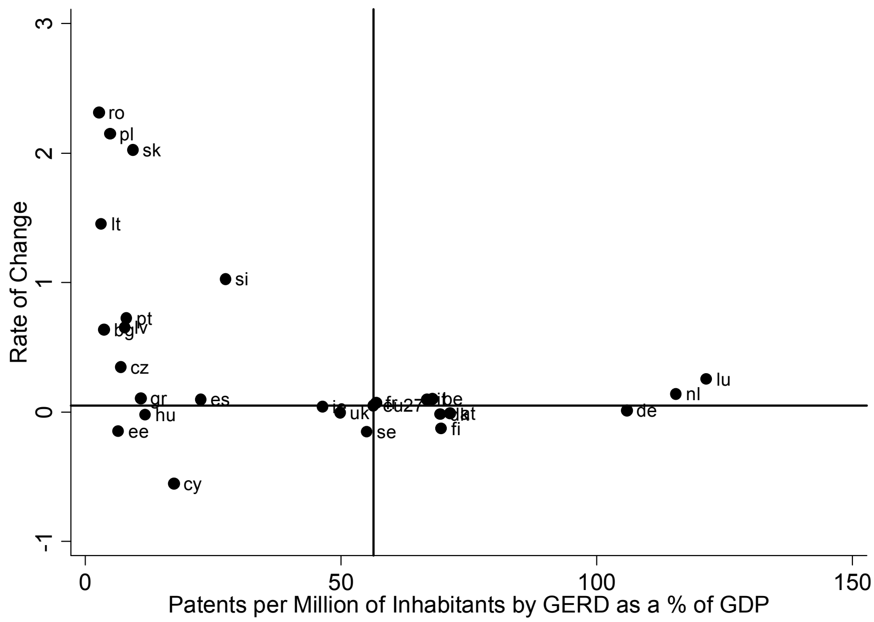


Figure 15. Patents per Million of Inhabitants by GERD as a % of GDP



18 Romania and Poland have been excluded from Figure 12 for the sake of graphic readability.

3.4. Efficiency Scores

Moving beyond the relatively simple efficiency ratios presented in the previous section, this section provides estimates of efficiency scores across countries by means of a parametric regression approach - the Stochastic Frontier Analysis (SFA).

In particular, SFA identifies a theoretical efficiency frontier in the relationship between a set of innovative inputs (i.e. different R&D items) and outputs indicators (i.e. patents, publications). In doing so, it computes the relative distance of each observation from the frontier by assigning an efficiency score to each country in each year. In turn, this allows mapping efficiency levels across countries and over time. Moreover, SFA allows controlling for several additional country factors which cannot be included into the DEA analysis. In turn, this makes SFA scores more precise and more robust for the purpose of policy evaluation (Appendix 3 provides more details on the econometric method adopted in this note).

Table 4 summarises the results for each output indicator considered. In particular, the analysis focuses on the efficiency of R&D spending in the generation of inventive output (patents) and scientific output (publications, citations). The results of the background regressions used for the calculation of the efficiency scores are reported at the bottom of Table 4.

Some sensitivity checks have been performed by running similar estimations with a different lag structure. However, results appear very similar and, therefore, this paper presents efficiency scores based on simultaneous estimations (that is, without a lag structure).

Table 4. Efficiency Scores (2005) and Background Equations

EFFICIENCY SCORES						
Country	Patents by Million of Inhabitants	Variation (1995/2000 -2001/2005)		Country	Business Patents by Million of Inhabitants	Variation (1995/2000 -2001/2005)
Sweden	1.00	0.06		United States	1.00	0.05
Switzerland	0.94	0.10		Japan	1.00	0.06
Austria	0.92	0.09		Sweden	0.99	0.07
Finland	0.91	0.10		United Kingdom	0.99	0.07
United States	0.90	0.10		Finland	0.99	0.07
Estonia	0.90	0.07		Belgium	0.99	0.07
Luxembourg	0.90	0.07		France	0.98	0.07
Japan	0.89	0.11		Denmark	0.98	0.08
France	0.88	0.11		Estonia	0.98	0.05
United Kingdom	0.85	0.13		Switzerland	0.98	0.10
Denmark	0.85	0.13		Austria	0.98	0.08
Belgium	0.83	0.13		Norway	0.98	0.10
Malta	0.81	.		Netherlands	0.96	0.10
Germany	0.81	0.14		Germany	0.96	0.10
Italy	0.80	0.14		Italy	0.95	0.11
Norway	0.77	0.17		Luxembourg	0.93	0.08
Netherlands	0.73	0.16		Hungary	0.92	0.15
Hungary	0.70	0.17		Ireland	0.91	0.16
Greece	0.68	0.19		Malta	0.91	.
Spain	0.66	0.17		Cyprus	0.88	0.11
Ireland	0.66	0.17		Spain	0.88	0.19
Bulgaria	0.57	0.18		Bulgaria	0.82	0.23
Portugal	0.52	0.18		Slovakia	0.80	0.24
Cyprus	0.50	0.12		Czech Republic	0.79	0.25
Slovenia	0.46	0.17		Greece	0.78	0.26
Czech Republic	0.46	0.17		Portugal	0.76	0.27
Lithuania	0.43	0.17		Lithuania	0.71	0.24
Slovakia	0.42	0.17		Slovenia	0.71	0.29
Poland	0.29	0.13		Latvia	0.68	0.27
Latvia	0.28	0.12		Turkey	0.66	0.30
Turkey	0.27	0.12		Poland	0.57	0.31
Romania	0.20	0.07		Romania	0.50	0.23
Overall Gross Expenditure in R&D (GERD) as a % of GDP	0.41***					
Business R&D (BERD) as a % of GDP					0.40**	
Country Dummy Variables	V				V	

EFFICIENCY SCORES								
Country	Publications by Million of Inhabitants		Country	Publications by Million of Inhabitants (scores computed on R&D Funding Taxonomy)		Country	Citations by Million of Inhabitants
Switzerland	1.00		United Kingdom	1.00		Sweden	1.000
Denmark	0.86		Sweden	0.88		Denmark	0.998
United Kingdom	0.82		Switzerland	0.87		United Kingdom	0.995
Norway	0.76		Netherlands	0.87		Netherlands	0.993
Finland	0.76		Italy	0.85		Belgium	0.993
Sweden	0.76		Slovenia	0.84		Finland	0.992
Netherlands	0.75		Austria	0.79		Austria	0.991
Belgium	0.71		Finland	0.78		Ireland	0.989
Slovenia	0.69		Norway	0.77		Germany	0.988
United States	0.65		Ireland	0.70		France	0.986
Ireland	0.62		Belgium	0.68		Italy	0.985
Austria	0.57		France	0.63		Spain	0.985
Germany	0.56		Portugal	0.58		Slovenia	0.982
France	0.55		Spain	0.53		Luxembourg	0.982
Spain	0.49		Czech Republic	0.49		Estonia	0.982
Italy	0.46		Slovakia	0.45		Hungary	0.982
Czech Republic	0.43		Poland	0.40		Portugal	0.981
Japan	0.39		Estonia	0.38		Czech Republic	0.981
Hungary	0.38		Luxembourg	0.31		Slovakia	0.981
Slovakia	0.38		Cyprus	0.28		Cyprus	0.980
Estonia	0.36		Bulgaria	0.25		Poland	0.980
Luxembourg	0.35		Malta	0.23		Malta	0.979
Portugal	0.34		Lithuania	0.22		Bulgaria	0.979
Cyprus	0.31		Latvia	0.17		Latvia	0.979
Poland	0.30		Romania	0.16		Lithuania	0.979
Bulgaria	0.24		Turkey	.		Romania	0.979
Lithuania	0.19		Greece	.		Japan	.
Malta	0.18		Japan	.		Norway	.
Latvia	0.18		Germany	.		Turkey	.
Turkey	0.15		Denmark	.		United States	.
Romania	0.15		Hungary	.		Switzerland	.
Greece	.		United States	.		Greece	.
Business R&D (BERD) as a % of GDP	0.02			0.16			0.000
Government R&D (GOVERD) as a % of GDP	-0.01			-0.04			0.9804**
Higher Education R&D (HERD) as a % of GDP	0.99***			4.14**			0.607*

Table 4 indicates that Sweden, Austria and Finland are the most efficient EU Member States in terms of the effect of overall R&D spending on patenting activity. These countries appear to perform better than the US, Japan and other major EU Member States[19]. Moreover, there appears to be a clear divide in efficiency levels between old and new Member States with the notable exception of Estonia.

Figure 16 shows that higher levels of expenditure do not come at a cost of less efficiency. On the contrary, countries with the highest levels of R&D expenditure are amongst the most efficient. This seems to indicate a broadly positive relationship between efficiency levels and R&D expenditure and points to the existence of positive externalities in R&D activities. Moreover, countries with high level of R&D spending on GDP are also those countries where institutional characteristics, industry-science linkages and other environmental factors enhance R&D investment. In turn, this result seems to call for a broader approach to R&D policy – especially in new Member States – where *catching-up* in R&D spending has to be complemented by additional measures supporting the efficiency of R&D itself.

All countries in the sample show an improvement in their efficiency levels over time (see Table 4). The increasing globalisation of R&D activities may provide a possible explanation for this observation, as it provides the incentive to gradually adopt best practices and, thus, raise efficiency levels over time[20].

Figure 16. Average Efficiency levels (2001-2006) and overall R&D expenditure as a % of GDP (2001-2006).

19 Indeed, the direct comparison of EU and US patent data is not straightforward due to the so-called "home bias" effect, namely evidence that, proportionate to their inventive activity, domestic applicants tend to file more patents in their home country than non-resident applicants.

20 European Commission, Science, Technology and Competitiveness Key Figures Report 2008/2009.

Although new EU Member States appear to be lagging behind in terms of R&D efficiency, there is evidence that they are catching up with the 'old' Member States (see Table 4). On average, efficiency levels in most new Member States are rising faster than in the other Member States (the average of the EU27 efficiency variation being equal to 0.13).

In contrast with the previous result on aggregate R&D efficiency, the United States and Japan are leading all EU Member States when looking at the efficiency of the business sector in transforming R&D investments into patents. However, this result has to be interpreted with caution given the difficult comparisons and the measurement biases related to patent data. Among EU Member States, Sweden, the United Kingdom, Finland and Belgium appear the countries where private R&D is most efficient in generating patenting activity.

The distinction made between the efficiency of public and private R&D spending is important since there appears to be a clear division of labour in the R&D process between public and private actors. Indeed, organisations that undertake innovation activities have different objectives. Public R&D aims at enhancing the research part of the process (the "R" component of R&D) by providing scientific output and increasing a country's knowledge base. Business R&D, on the contrary, is more focused on the development stage of the R&D process (the "D") and on the commercial exploitation of these results through means of patents. For the EU27 as a whole, the share of patents assigned to business actors increased gradually from 76% in 1990 to almost 80% in 2004.

R&D – measured either in terms of sector of performance or sector of funding - by Higher Education institutions appears to be the major determinant of scientific production as measured by publications. Overall public R&D expenditure – namely government and higher education R&D - shows a significant effect on scientific output measured by citation while private business R&D does not appear to have a significant effect. Again, this result seems to point to the different objectives pursued by private and public R&D activities. Denmark and the United Kingdom appear among the most efficient in terms of both scientific publications and citations[21].

[21] Results differ somehow if we consider efficiency scores computed on R&D funding sectors rather than R&D performing sectors. The difference between the two taxonomies refers to the relative role played by each sector, namely whether it is financing or actually performing R&D. However, several missing observations hamper a full international comparison based on R&D funding data. Results based on this taxonomy should be better interpreted as a robustness check of previous efficiency scores.

4. Determinants of Efficiency of Public R&D Support across Member States

The aim of the following section is to provide some quantitative explanations of different efficiency scores across countries by looking at a set of control variables. In particular, these indicators refer to some country-specific factors (such as population, GDP, sector specialization), some R&D-related variables (such as public and foreign R&D stocks, Human Resources in S&T as a % of Total Employment, % of basic R&D) and some additional controls (such as education spending and IPR protection). Appendix 1 describes the adopted indicators and their source.

The lack of available information on control variables - for some countries and over time - limits substantially the possibility to perform in a single step a fully complete assessment of the joint effect of the different determinants of efficiency scores. This note presents, therefore, some evidence based on (1) standard correlation techniques and (2) parametric regressions only for a selected number of explanatory variables[22]. It is important to bear in mind that the former do not provide any information on the causality of the relationship investigated. Nevertheless, the correlation coefficients appear to suggest an important role of some of the control variables under investigation (see Section 3). This set of evidence is, then, used as a basis for the regression techniques described in Section 4.2.

4.1 Correlation between Efficiency Levels and Control Variables

Each control variable appears related to efficiency levels across countries in the expected way (see Table 5).

- There is no general evidence that the size of a country affects efficiency levels. On the contrary, GDP level appears to be positively related to efficiency.
- Evidence of lower efficiency rates in new Member States is confirmed.
- A better Intellectual Property Right (IPR) system seems to be related to higher efficiency levels. This result is hardly surprising given that patents themselves represent the most adopted tool to protect IPRs.
- Both the Stock of Public R&D investment and the percentage of Human Resources in Science and Technology are positively correlated to efficiency levels. Again, these results appear to confirm the importance of economies of scale and positive externalities in R&D activities and their enhancing effect on a country's efficiency level. The Stock of Foreign R&D is positively correlated to efficiency level. This result suggests the importance of international spillovers of R&D activity and the importance of setting up policies which support international cooperation as well as mobility of R&D resources (e.g. European Research Area, Joint Programming of Research).

[22] In particular, data availability hampers the analysis of other potential determinants of R&D efficiency such as, for instance, firm size and market structure.

Table 5. Correlation between Efficiency Scores and Control Indicators

	CORRELATION WITH EFFICIENCY TERM MEASURED ON				
	Patents by Million of Inhabitants	Business Patents by Million of Inhabitants	Publications by Million of Inhabitants	Publications by Million of Inhabitants (R&D funding)	Citations by Million of Inhabitants
LOG Population	-0.02	-0.07	0.13	0.28*	0.23*
LOG GDP	0.34*	0.20*	0.51*	0.66*	0.58*
New Member States - Dummy	-0.49*	-0.34*	-0.60*	-0.68*	-0.72*
GERD as a % of GDP	0.68*	0.55*	0.72*	0.72*	0.81*
Index of Patent Protection (Intrapolation) - Park (2008)	0.75*	0.82*	0.61*	0.60*	0.67*
Public R&D Stock	0.32*	0.26*	0.17*	0.46*	0.31*
Foreign R&D Stock	0.23*	0.32*	0.11	0.25*	0.31*
Human Resources in S&T as a % of Total Employment	0.59*	0.65*	0.71*	0.53*	0.69*
% of High Tech Manufacturing in Total manufacturing	0.67*	0.58*	0.73*	0.74*	0.66*
% of Basic R&D on Total R&D	-0.11	-0.03	-0.43*	-0.35*	-0.31*
Public Tertiary Education Spending as a % of GDP	0.35*	0.33*	0.66*	0.53*	0.70*
Tax Subsidy (1 – B index)	-0.02	0.04	-0.24*	0.2	-0.23*
Business R&D funded by the Gov as a % of GDP	0.34*	0.29*	0.53*	0.46*	0.43*

* Correlation significant at 5% level.

- A country's sector composition appears related to its efficiency level. In particular, the more high-tech oriented, the more efficiently an economy will use resources devoted to R&D activities. This result might be explained in part (1) by the existence of economies of scale which vary across sectors and (2) by the specific technological characteristics of sectors, i.e. sectoral system of innovation (Malerba, 2002), which may hamper the full efficient exploitation of R&D potential[23]. This result may suggest a better targeted approach to R&D investment by selecting sectors at the technological frontier and where the benefits of R&D investment may be maximised (e.g. Lead Markets).
- Tertiary Education appears as a relevant public "infrastructure" for enhancing the efficiency of R&D investments. Indeed, this type of public spending is positively correlated to efficiency levels of R&D activities across countries.
- By looking at the instruments to increase efficiency of private R&D activities, there is mixed evidence on the relationship between the choice of a specific policy tool and efficiency levels[24]. A more robust check is performed in the next section where regression techniques are adopted to investigate the determinants of efficiency levels across countries.

4.2 Regression Analysis

This section discusses the results on the determinants of SFA efficiency scores based on standard regression techniques. As already mentioned, the main bottleneck in this analysis refers to the availability of data on control variables. This strongly hampers the possibility of running estimates by simultaneously taking into account all the determinants discussed in the previous section. To deal with this problem, this note adopts the following econometric strategy: regression coefficients are computed by means of a fixed effect model where each control indicator is used as the explanatory variable of SFA efficiency scores. The choice of a fixed effect model allows to eliminate all country-specific time-invariant factors and, thus, exploiting the advantage of relying on panel data techniques (see Table 6)[25].

---

23 Indeed, in order to maximise the efficiency of R&D investment, it is important to target innovation expenditure in R&D-intensive sectors while supporting capital investment in low-tech industries (Ortega-Argilés *et al.*, 2009).

24 The B-index indicates the relative generosity of R&D tax treatment in different countries (Warda, 2006). However, the amount of data on R&D tax treatment is still limited across the EU MSs.

25 Moreover, an additional check has been performed on these results. In particular, the coefficients obtained by regressing R&D on patents have been compared across countries which have been grouped according to the different control variables. Overall, this indirect test allows to verify whether there is an effect of the adopted control indicators on the efficiency of R&D spending. This exercise has not been replicated for publications / citations as the number of data available are insufficient for this test.

Table 6. Regression Coefficients – Pairwise Fixed Effect Estimations

	PAIRWISE EFFECT ON THE EFFICIENCY TERM				
	Patents by Million of Inhabitants	Business Patents by Million of Inhabitants	Publications by Million of Inhabitants	Publications by Million of Inhabitants (R&D funding)	Citations by Million of Inhabitants
LOG Population	1.87***	2.57***	.65***	.44***	.06***
LOG GDP	-.010	-.07***	.06***	.13***	.01***
GERD as a % of GDP	.084***	.03	.06**	.05**	.01***
Index of Patent Protection (Intrapolation) - Park (2008)	.19***	.29***	.08***	.06***	.01***
Public R&D Stock	1.44***	-2.30	1.01***	5.53***	6.72***
Foreign R&D Stock	3.19***	4.08***	1.51***	1.17***	5.94***
Human Resources in S&T as a % of Total Employment	.02***	.02***	.01***	.01***	.01***
% of High Tech Manufacturing in Total manufacturing	1.34***	1.02**	.24	-.05	.05***
% of Basic R&D on Total R&D	1.14***	1.66***	.11	.16**	.01*
Public Tertiary Education Spending as a % of GDP	.06*	.04	.01	.03	-.00
Tax Subsidy (1 – B index)	.95***	1.13***	.12***	.08**	.00
Business R&D funded by the Gov as a % of GDP	-1.47***	-1.32***	.01	.01	-.02**

*** Coefficient significant at 1% level.

** Coefficient significant at 5% level.

* Coefficient significant at 10% level.

Although based on a different method, the results derived from the regression analysis are largely consistent with those based on simple correlations:

- This note finds evidence of the effect of a better Intellectual Property Right (IPR) system on efficiency levels across countries and over time.
- Moreover, both the Stock of Public R&D and Foreign R&D investments appear to positively affect efficiency levels. In particular, the impact of the latter is stronger in the case of patenting efficiency (the stock of public R&D is not significant in the case of business patents) while the former appears on average more important when looking at publications/citations.
- The percentage of Human Resources in Science and Technology as well as a country's relative sector specialization towards high-tech sectors appears to increase efficiency of R&D spending (sector specialization does not appear, however, significant in the case of publications).
- Moreover, our findings confirm the effect of R&D spending on efficiency levels. This result indicates that R&D investments are indeed characterised by non-decreasing returns to scale. Even after controlling for (time-invariant) country specific effects, higher spending seems to enhance efficiency across countries and over time.
- Contrary to the results based on simple correlation techniques, regression-based analyses show R&D tax subsidies to be effective in raising a country's R&D efficiency.

The results presented above provide first insights into the determinants of efficiency of R&D spending across EU Member States. More in particular, they could be used to help assess (1) the different levels of efficiency across countries; (2) the evolution of efficiency levels over time; and (3) the possible determinants of such efficiency performance.

The next section complements the analysis provided so far by presenting the results based on a set of qualitative information collected from Member States on their national R&D system and, thus, offering additional insights on the instruments to raise the efficiency of public R&D spending in Europe.

5. Country Specific R&D Policies

As a complement to the quantitative analysis of R&D efficiency presented in previous sections, this section contains a review of the effects of public R&D policies as well as a qualitative analysis of Member States' strategies and policy instruments used in support of R&D activities. The analysis is mainly based on country-specific information provided directly by the Member States in early 2009 as feedback to a questionnaire prepared by the Commission. This information is complemented by relevant findings from the research literature on R&D and innovation policies. The section concludes with an examination of R&D spending measures taken by Member States in response to the current economic crisis.

5.1. The Effects of Public R&D Policies

Afonso et al. (2005) survey different studies that analyse the performance and efficiency of the public sector in its different functions. However, most of these studies deal with the efficiency of public spending on education and health (Afonso & St. Aubyn, 2006). While there is a wide agreement on the importance of public investment in R&D, there is no consensus on how and how much governments should spend on R&D. The relationship between public investment in R&D, innovation and economic growth is difficult to capture and there is little empirical literature on the measurement of R&D efficiency. Moreover, some studies have reached inconclusive results on the capacity of public R&D to promote innovative outputs and economic growth (Bilbao-Osorio and Rodriguez-Pose, 2004; Bassanini and Scarpetta, 2000), while others have shown a positive impact (Guellec and van Pottelsberghe de la Potterie, 2001).

The "Knowledge Production Function" (Griliches, 1979) represents the most common analytical framework for assessing the effect of R&D on innovative output (e.g. patents) and economic outcomes (e.g. productivity growth). Based on an estimation of the knowledge production function, Verspagen (1995) finds a significant effect of R&D on productivity growth in high-tech sectors while no significant relationship emerges for medium-low tech sectors.

Most of these studies are carried out at the sector/micro level by means of parametric methods (OECD, 2007a) since this setting allows to deal better with the issue of heterogeneity. In this context, it is possible to verify the effect of environmental variables as well as policy indicators on the efficiency of R&D investment on output and outcomes (Crepon et al., 1998). In turn, such micro evidence appears to provide useful information for defining a macro-economic policy strategy (OECD, 2008).

At the macro-economic level, an overview of the relationship between public R&D and different performance major indicators is provided by the European Commission's "Key Figures on Science, Technology and Innovation" (2007). However, there is limited evidence on the determinants of different levels of efficiency of R&D spending at the macro level. Among the few studies dealing with this topic, Lee and Park (2005) investigate different efficiency levels by adopting a two-input (R&D expenditure, average number of researchers) and three-output (technology balance of receipts, number of scientific and technical journal articles published and number of triadic patent families) framework using data for 27 countries. Wang and Huang (2007) investigate the relative efficiency of R&D activities across 30 countries. They treat R&D capital stocks and labour stock as input measure and patents and academic publication as output measures. Tobit regressions are used in a second stage to assess the effects of environmental variables on R&D efficiency. The adopted control variables include the rate of enrolment in tertiary education, the index of English proficiency, and the PC density. The first two indicators appear to increase the efficiency of R&D while the PC density does not show any significant result.

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 both patenting activity and business R&D intensity. The authors show the effects of real interest rates, the development of the financial markets, the strength of intellectual property rights, the degree of regulation and competition as well as the international openness of an economy (restrictions on inward FDIs) on the output indicators. They find that the share of high-tech manufacturing industries as well as the share of scientists and engineers in total employment are positively related to the level of R&D investment and outputs.

Coe & Helpman (1995) estimate the impact of domestic and foreign R&D stock on TFP in 22 EU and non-EU countries for the period 1971-1990. The authors find evidence of different elasticities of both R&D/TFP across countries and domestic and foreign R&D. In particular, the estimated elasticities of TFP with respect to domestic R&D capital stocks show a marginal rate of social return of 123% for the larger OECD economies and 85% for the remaining countries.

A different approach is proposed by Zabala-Iturriagagoitia et al. (2007), who use 2002/2003 data drawn from the European Innovation Scoreboard (EIS). They assess the performance of regional innovation systems by means of several indicators, such as 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). All these variables contribute to explain differences of regional GDP per capita.

All of these studies aggregate both public and private R&D expenditure, as the specific effect of public R&D expenditure on productivity growth is more difficult to be assessed. However, the study from Guellec and van Pottelsberghe de la Potterie (2004) makes a distinction between public/private R&D expenditure and highlights the importance of public R&D investment for economic growth. In particular, this study differentiates three sources of R&D: (1) R&D performed by government and universities, (2) R&D performed by businesses and (3) foreign knowledge spillovers. Distinguishing these three R&D sources allows the definition of more precise policy recommendations. The study underlines the need for governments to carry out a broad and coherent innovation policy approach due to the occurrence of strong interactions between the various channels and sources of technology.

Section 2.1 mentioned an additional target of R&D policy, namely the increase of privately-financed R&D investment. David et al. (2000) provide a review of the econometric studies over the period 1965-2000 on the effects of publicly-financed R&D expenditure on private R&D investment by summarising results obtained at different levels of aggregation. Although findings appear rather ambivalent, studies at the meso- and macro levels tend towards the hypothesis of complementarity instead of crowding out between publicly- and privately-financed R&D expenditure.

On the one hand, Goolsbee (1998) provides some evidence of crowding out suggesting that government spending may lead to reduction of private spending by increasing the demand of R&D (through the wage of R&D personnel) and hence its price[26]. On the other hand, the cross-country study by Guellec and van Pottelsberghe (2003) and the country-specific analysis of Falk and Leo

[26] This implies that even if the aggregate amount of R&D is higher due to government funding, the real amount of R&D (adjusted for the higher cost of research) will be lower. This channel of crowding out - through prices - is complementary to the standard crowding out effect through substitution between public and private R&D.

(2006) suggest a complementarity between public and private R&D funding. In a recent study, Cincera et al. (2008) based on a sample of 32 countries over the 1980-2005 period also conclude that publicly and privately financed R&D activities are complementary.

Macroeconomic and financial factors are important for understanding the evolution of business R&D expenditure. In particular, investments in R&D are fostered by a stability oriented macroeconomic framework, by the availability of external as well as internal finance (Jaumotte and Pain, 2005b) and by the absence of capital market imperfections (Hall and van Reenen, 2000). Another set of important determinants of business R&D investment refers more to reseach policies and scientific institutions, such as the level of R&D performed in the non-business sector, the extent of direct government subsidies for private sector R&D, the strenght of intellectual property rights, the country's industrial structure, and the human resources available for science and technology (Jaumotte and Pain, 2005a).

Finally, some additional research on the determinants of efficiency of public spending more generally underlines the role played by further framework conditions, such as the size of government expenditure, the level of education of the population, the competence of the civil servants, per capita GDP, the strength of the IPR systems, trade openness, transparency in public policy, civil liberty and the existence of political rights (Afonso et al., 2005, Herrera and Pang, 2005 and Jaumotte and Pain, 2005b).

5.2. Survey of the Member States' R&D Policies

The questionnaire which was sent to the Member States focused on three main areas which appear to be best suited to set the scene for the evaluation of R&D policies: institutional factors and governance, market and framework conditions, and industry/science linkages. This section is organised along the same structure. Table 8 provides a more detailed systematic summary of the outcome of the Member States' survey.

The Commission received completed questionnaires from 25 Member States.[27] Three Member States did not reply. The reference dates for questions with a time dimension were 2001 and 2006. The amount of detail given in the responses received varied substantially from one Member State to the other. This has to be taken into consideration when interpreting the results. Nevertheless, the analysis of the answers provided, in connection with the efficiency scores presented before, suggests some interesting conclusions.

5.2.1. R&D Policy Governance

As innovation has been found to be an important driver of economic growth, R&D policies in most countries are aimed at improving innovative performance (see e.g. OECD, 2007b). This subsection describes the main characteristics of R&D policies in the EU Member States, which may be used to further explore the relation between policy instruments used and the efficiency and effectiveness of R&D spending.

The responsibility to decide how public R&D funds are used is split among various bodies in a large majority[28] of Member States. Research priorities are usually set at the central/national level and most of the basic research is funded by federal institutions. The closer R&D approaches commercially-viable applied research, the greater is the involvement

27 Feedback has been received from Austria, Belgium, Bulgaria, Cyprus, the Czech Republic, Germany, Spain, Finland, France, Greece, Hungary, Ireland, Italy, Lithuania, Luxemburg, Latvia, Malta, the Netherlands, Poland, Portugal, Romania, Sweden, Slovenia, Slovakia and the United Kingdom.

28 For more detailed results, please refer to Table 8.

of regional authorities, research institutes and industry in decisions on R&D funding. Nevertheless, the Ministry of Finance often retains a coordinating role, which can be associated with its budgetary responsibilities (e.g. finance ministries often have veto rights to stop individual R&D investment programmes).

Nearly all Member States have set long term priorities for innovation. While in 2001 only around half of the Member States (14) had agreed on long term innovation priorities, by 2006 nearly all of them (23) had set such long term priorities as part of a multi-annual strategy for R&D and innovation. Such policy strategies generally aim at increasing not only the quantity but also the quality of R&D. The term "quality" is commonly understood to refer to the efficiency and effectiveness of R&D. Beyond the 3% of GDP target for overall R&D investment, which was set as part of the Lisbon Strategy for Growth and Jobs, the policy objectives most frequently mentioned are to increase public R&D spending[29], to enhance R&D infrastructure, to improve educational measures, to foster innovation diffusion and adoption through more effective science-industry cooperation, to ease access to finance for companies engaging in R&D and to improve the IPR system.

In 2006 all Member States to a certain extent relied on medium-term funding programmes. As shown in Table 8, such programmes did not yet exist in a large number of Member States in 2001. They offer an important value added to companies, because they reduce to some extent the uncertainty facing firms considering long-term investments in R&D (Guellec and Pottelsberghe, 2000). In addition, some Member States use ad-hoc measures to support R&D, although most of the funds used for such measures are included in their medium-term funding programmes as well.

Most Member States rely on R&D funding mechanisms to distribute the funds available. R&D funds are generally not granted directly to the beneficiaries by the authorities in charge for R&D policy design. Most Member States have established (independent) funds or agencies which handle the distribution of R&D funding amongst research organisations. For example, the Slovak Research and Development Agency was set up in 2005 as an instrument for the distribution of public finances for research and development in all fields of science in Slovakia; the Austrian Research Promotion Agency was established in 2004 and serves as a one-stop-shop for applied industrial research; and the Finnish Funding Agency for Technology and Innovation "Tekes" provides funding and technical support for selected R&D projects of companies, research institutes and universities.

Nearly all Member States carried out evaluations of their R&D programmes and projects in 2006. 18 Member States indicate that they had evaluation schemes in place already in 2001, whereas in 2006 23 out of 25 Member States used such schemes. Most Member States conduct both ex-ante and ex-post evaluations. Already during the tender stage for new programmes and projects Member States usually assess the potential benefits of certain measures. These tender appraisals are viewed by many Member States as ex-ante evaluations. Ex-post evaluations of R&D projects or programmes are conducted in many Member States, but often on a rather irregular basis. Most Member States which conduct ex-post evaluations do this every few years. The ex-post evaluations often aim at assessing the impact on R&D performance overall, rather than the outcome of a specific programme or project. However, only a few Member States, including Finland, Austria, Germany, Sweden, Slovakia and Spain, have made ex-ante and ex-post evaluation a fixed element of all their R&D programmes and projects.

---

29 Surprisingly the objective to increase private R&D spending was not mentioned explicitly by the Member States as a long term priority.

5.2.2. R&D Framework Conditions

Certain characteristics of the economy hamper private R&D activity, others nurture it. This section aims to identify the structural characteristics of national economies, which are favourable for R&D.

A majority of the Member States regards the sectoral structure of the economy and the size structure of firms as key determinants of the amount of R&D spending. Most Member States which consider the structure of the economy as a decisive factor for R&D activity argue that companies in the high-tech sector (such as ICT, pharma, chemicals) engage more in research.

However, only a few Member States see a connection between the structural characteristics of the economy and the efficiency of R&D spending. Nevertheless, our empirical analysis of the determinants of the efficiency scores (see sections 3 and 4) provides some evidence indicating that the efficiency and effectiveness of R&D spending is higher in the high-tech sector. The link between economic structure and R&D effectiveness is also confirmed by Ortega-Argilés et al. (2009), who investigate the effectiveness of corporate R&D investments in different sectors using sectoral and firm level data.

Regarding the influence of the size distribution of firms, Member States in their replies frequently mention the larger volume of private R&D expenditure of large firms in comparison with the total private R&D expenditure of SMEs. While ten Member States perceive that sectoral specialisation influences the efficiency of R&D spending, only six see an influence of the size distribution of firms in this respect.

The interaction between market structure, firm size and innovation was explored extensively in the economic literature (for a closer look, refer to: Cohen et al., 1987; Levin et al., 1987; Comanor, 1967; Nelson, 1959; Fellner, 1951; Rothwell, 1989; Link and Bozeman, 1991; Mansfield, 1981). Diverging research results show that the relationship between the size of firms and their R&D spending might not be so straightforward. Conducting R&D brings along different challenges for differently sized companies. For smaller companies the main obstacles seem to be financing constraints, whereas larger companies do not always take into account the full return on their investment in research activities (Fellner, 1951; Comanor, 1967). Moreover, the size of firms and the sectoral structure of the economy cannot be examined separately. It has been found that in different sectors, differently sized companies execute research. For instance in the electronics and chemicals sectors innovating firms tend to be relatively large, whereas in the mechanical and instrument engineering sectors small firms show higher innovative activity (Acs and Audretsch, 1987; Pavitt, 1984).

Regarding the instruments for the promotion of business R&D, Member States attach special importance to grants and direct R&D subsidies, to policies for the promotion of R&D cooperation and to fiscal incentives. The rather intensive use of direct grants and subsidies is to a certain extent due to the fact that they serve as basic (and regular) means of finance for R&D institutes in some Member States. Table 8 provides more detail on these and other policy instruments.

Academic research confirms that fiscal incentives and direct funding are best suited for the stimulation of business-funded R&D, whereas government and university performed research suffer from a crowding-out effect (see e.g. Guellec and Pottelsberghe, 2000; Aerts and Czarnitzki, 2004). Thus, if raising business R&D is the objective, the literature suggests that fiscal incentives and direct funding seem to be appropriate measures. Nevertheless, worth mentioning in this respect seems the case of Finland. Although Finland also classifies fiscal incentives as an important instrument for the promotion of business R&D, it claims that the educational system is the true foundation of its excellent R&D performance. Statistics show that Finland's public expenditure on education is one of the highest in the EU (Eurostat, 2005: FI: 6.3% of GDP compared to the EU-27 average of 5.0% of GDP). Examining the efficiency scores calculated for Finland in section 3, the conclusion that education is a main driving force of R&D is tempting. Indeed, the application of the Stochastic Frontier Analysis in section 4 confirms the positive relationship between education spending and R&D efficiency.

Out of the 25 Member States who replied, 18 claimed they benefit a lot from R&D from abroad. The majority of them view foreign direct investment (FDI) as an increasingly important transmission channel. Eurostat statistics show an increase over time in the share of the Member States' overall Gross Expenditure in R&D (GERD) stemming from abroad. In the EU-27 on average 9%[30] of GERD was financed from abroad in 2005, whereas in 2000 this share was only 7.3% (see Table 7). The calculations in section 4 confirm a significant relationship between the foreign R&D stock and the efficiency score.

Table 7. Share of GERD financed from abroad in % (Source: Eurostat Science and Technology Indicators)

	EU27	BE	BG	CZ	DK	DE	EE	IE	GR	ES	FR	IT	CY	LV	LT	LU	HU	MT	NL	AT	PL	PT	RO	SI	SK	FI	SE	UK
2000	7.3	12.2	5.3	3.1	n.a.	2.1	12.7	8.9	n.a.	4.9	7.2	n.a.	9.4	29.1	6.7	1.6	10.6	n.a.	11.6	19.9	1.8	5.2	4.9	6.2	2.3	2.7	n.a.	16.0
2005	9.0	12.4	7.6	4.0	10.1	3.7	17.1	8.6	19.0	5.7	7.5	8.0	10.9	18.5	10.5	3.6	10.7	25.5	n.a.	17.7	5.7	4.7	5.3	7.3	6.0	6.3	7.7	19.3

The internationalisation of R&D activity is reflected in a growing role of foreign affiliates in host countries' R&D. This increase in R&D activity in the host countries is not always regarded as entirely positive. At times it has raised concerns about a possible dependency and vulnerability of the local R&D base. Moreover, an increasing number of patents is owned by a firm's headquarters rather than by someone in the inventor's country of residence. As a result, payments for technologies developed elsewhere (licences, patents, etc.) are far higher in some countries than domestic R&D expenditures. This fact points at the importance for policy makers to account for spillover effects when designing R&D policy (OECD, 2006a).

Half of the Member States point to the mobility of researchers as an important channel through which foreign R&D has an influence on them. The European research framework programmes and multilateral research cooperation are also regarded as important factors.

5.2.3. Industry-Science Linkages

The translation of inventions into innovation is a crucial link to gain economic value out of research activity. To better establish this link, Member States take measures to improve the work of publicly (co-)financed research institutions, steer the formation of human capital, and better respect the needs of the industry.

18 out of 24 Member States who replied to the relevant question declared that they execute evaluations of their public research institutes on a regular basis in 2006, 11 executed evaluations already in 2001. Most Member States which perform such evaluations do this every few years rather than every year. As benchmarks, in most cases internationally used indicators like publications, patents or the number of Ph.D. students are used. Public research institutes usually serve as instruments for basic research. They also respond to

[30] Eurostat Science and Technology Indicators [Download: 21.4.2009]

demands from industry. Only a few Member States use indicators measuring the adoption of scientific R&D by industry, such as new products, processes or materials resulting from R&D, to shed light on the application of research results in practice. The evaluation of research has been increasingly covered by the academic literature. Especially when it comes to basic research, evaluation appears to be necessary but difficult. A convergence of evaluation practices is observed and there is a trend towards the use of "internationalised peer reviews" (OECD, 2006b).

16 out of 25 Member States mentioned that there is a lack of qualified human capital in certain fields of science. When addressing this question though, some Member States focused their answers on the lack of qualified personnel for the industry. Most of them claim to experience a general lack of researchers. Among those Member States pointing at deficiencies in specific fields, a dominance of shortcomings in the field of technical sciences, especially engineering is observable. Therefore, it seems appropriate to address the lack of human resources in these fields specifically.

Only a few Member States provided information about new educational programmes. When such new programmes are set up, they are commonly of general nature, aiming for example on a general increase in the number of Ph.D. students.

Brain drain is currently an issue in some European Member States. Twelve out of 25 Member States that answered the questionnaire claimed that brain drain is an issue for them. It is worth to notice that 8 of these 12 are new Member States. These Member States claim low salaries and poor research infrastructures as reasons for the brain drain out of their territories. It is interesting as well to look at the brain drain taking place in the opposite direction, namely human capital moving to Europe. A study commissioned by the Commission in 2003 found that paperwork barriers constitute a serious obstacle not only for skilled workers and researchers moving within Europe, but also for foreign personnel coming to Europe from third countries (MERIT, 2003). Many initiatives are already taken in the context of the European Research Area to remove such obstacles.

Table 8. Summary of the results of the questionnaire

Institutional Factors/ Governance		
	Major Patterns	**Additional Information**
Distribution of competences/responsibilities regarding R&D funding	Decision making competence regarding the funding of public R&D activities is split up among various bodies => 22/25 MS Competence is centralised => 3/25 MS	In most MS the Ministry of Finance (MoF) has a coordinating role concerning R&D funding connected to its budgetary competence. Also in most MS who indicate that the competence is concentrated in one body different from the MoF, the MoF has influence on the amount of R&D spending. 3 MS point out that R&D responsibilities are allocated at separate federal levels.

Long term innovation priorities	Long term innovation priorities in place => 2001: 14/25 MS 2006: 23/25 MS One MS pointed out that long term priorities were established after 2006.	Most MS have established multi-annual R&D strategy plans. Policy objectives generally aim at increasing the quantity but also the quality of R&D. The most frequent objectives are to increase public R&D funds, to enhance R&D infrastructure, to improve educational measures, to foster innovation diffusion and adoption (increasing science-industry cooperation), to ease access to finance for companies engaging in R&D and to improve the IPR system.
Medium-term funding programmes or ad-hoc measures	Medium-term funding programmes in place => 2001: 16/24 MS 2006: 24/24 MS Ad-hoc measures used => 2001: 8/24 MS 2006: 9/24 MS 1 MS did not answer this question.	Today all MS rely on medium-term funding programmes. Some of them state that they additionally apply ad-hoc measures, although most of these MS describe these ad-hoc measures as being funded within medium-term frameworks.
Existence/ properties of R&D funding mechanisms	Specific R&D funding mechanisms applied => 2001: 20/25 MS 2006: 22/25 MS One MS pointed out that a funding mechanism was established after 2006.	Only in a few MS R&D funding to the private sector is entirely granted directly by the various bodies in charge of basic R&D policy decision making. Most MS have established (independent) funds/agencies which grant R&D funds upon successful application. MS did not provide information regarding the efficiency of the structures in place.
Evaluation of programmes/ projects	Evaluation of R&D programmes and projects => 2001: 18/25 MS 2006: 23/25 MS	Most MS conduct both ex-ante and ex-post evaluations. Whereas ex-ante evaluations are usually integrated in the set-up procedure of a new programme or project (e.g. appraisal of tenders), ex-post evaluations are executed irregularly in many MS. The latter often assess the change in the global R&D situation in the MS, rather than the success of a single programme or project.

Market and Framework Conditions		
	Major Patterns	**Additional Information**
What affects (a) the amount of private R&D spending (b) the efficiency of R&D spending? => (I) the sectoral specialisation (II) the size distribution of firms	Following causal relationships were indicated as existing: (I) => (a) by 18 MS (II) => (a) by 18 MS (I) => (b) by 10 MS (II) => (b) by 6 MS 2 MS out of 25 gave no information on this question.	The majority of MS who see a link between the firm size and the amount of R&D spending claim that larger companies invest relatively more in research than smaller companies. MS name the ICT, pharma and chemicals sectors as the most research intensive sectors. A few new MS indicated that many large companies in their country are in foreign ownership, one MS suggested that company ownership might influence R&D spending.
Main instruments to promote business R&D and their importance	Among the MS who provided rankings of the R&D instruments, a clear preference for three instruments is revealed: 1. Grants and direct R&D subsidies 2. Policies to promote R&D cooperation 3. Fiscal incentives 8 MS out of 26 did not provide a ranking.	Apart from the three top instruments the importance of the education system and the financing conditions still seem to be regarded as rather high for the promotion of business R&D, less importance is attributed to public procurement, labour market conditions, standards and regulations and intellectual property rights. Some MS indicate that grants and direct subsidies are their most extensively used instrument, because they serve as basic (and regular) means of finance for R&D institutions.
Benefits from R&D from abroad; channels	18/25 MS claim to benefit a lot from R&D carried out abroad.	The majority of the MS who answered this question mention FDI as the main influencing channel; about half of them mention the mobility of researchers as an important factor. These two factors are closely followed by the European research framework programmes and multilateral research cooperation respectively, which are also regarded as very important channels.

Industry/Science Linkages		
	Major Patterns	**Additional Information**
Evaluation of public research institutes; benchmarks	Regular evaluation of public research institutes => 2001: 11/24 MS 2006: 18/24 MS One MS did not answer this question.	Most MS which evaluate their research institutes don't do this every year, but rather every few years. As benchmarks, mostly indicators like publications, patents or the number of Ph.D. students are used; on occasion indicators measuring the adoption of R&D like the application of results in practice, resulting new products, processes or materials are used as well.
Lack of researchers in a specific field of science	16 MS claim to lack researchers in a specific field.	Most answers pointed on a general lack of researchers, whereas some MS highlighted special deficiencies in the field of technical sciences, especially ICT and engineering.
New educational programmes in which fields of science	Only few MS gave information about new educational programmes.	The majority of the programmes indicated are of a general nature, aiming e.g. at a general increase in the number of Ph.D. students.
Brain drain an issue	12 MS indicated that brain drain is an issue for them.	Few MS claim low remuneration of researchers and poor research infrastructures as reasons for brain drain. One MS indicated that most high-educated people return after some years resembling brain circulation.

5.3. R&D Policies in the Crisis – Efficiency and Beyond

Over the recent months many Member States have deployed stimulus packages to counteract the negative effects of the economic downturn on R&D and innovation. Nevertheless, sharp reductions in venture capital spending and patent filings point to decreasing R&D and innovation activity in the private sector.[31] This should not be surprising as investment in innovation by the private sector tends to be pro-cyclical. In the current crisis, this is exacerbated by particularly tight credit constraints, which prevent firms which try to increase their R&D activities (with the view to having an advantage over competitors in the prospective upswing) from doing so.

When facing a sharp decline of economic activity, the objective of increasing the efficiency of R&D spending is to a certain extent subordinated to the more immediate need to stimulate economic growth. Nevertheless, Member States have tried to design the measures in support

31 See also OECD (2009)

of the economic recovery in such a way that they not only produce short-term gains but also help build a stronger economy for the future.[32] An increase of public R&D funding during economic crisis therefore appears to be justified in order to compensate the decline in private R&D spending and maintain a sound knowledge base.

Innovation activity is the foundation of future competitiveness and growth. The European Economic Recovery Plan[33] recommends that Member States "increase planned investments in education and R&D (consistent with their national R&D targets) to stimulate growth and productivity. They should also consider ways to increase private sector R&D investments, for example, by providing fiscal incentives, grants and/or subsidies." In response, many Member States have already stepped up their public R&D spending in order to overcome the crisis and improve the competitiveness of their economies. Table 9 provides a list of crisis related measures taken by EU Member States which entail an increase in R&D spending. Most measures described below have been reported by the Member States to the Commission as measures taken in response to the current crisis; additional information has been retrieved from the ERAWATCH Research Inventory, the OECD, Member States' Stability and Convergence Programmes and Member States' National Reform Programmes. The given list of measures is not necessarily exhaustive.

Table 9. Crisis-related changes of the Member States' public R&D spending

MS	**Type of Crisis-related Measure**	**Description of Measure**
AT	direct funding	In Austria 404 million Euros are made available additionally for R&D for the years 2009 and 2010 from the federal budget altogether. 100 millions thereof have been foreseen explicitly to counteract the crisis (two thirds of this amount is earmarked for business-related research, one third for universities).
BE	tax relief	Belgium extended the partial exemption from payment of the withholding tax on salaries of researchers. After the harmonisation of the exemption rate at its maximum of 65% in July 2008, this maximum rate has been increased to 75% as of 2009.
BG	direct funding	Bulgaria announced in the 2009 State budget Law to increase the volume of the funding through the National Fund for Scientific Research by 50% in 2009 compared to 2008, up to a total of 100 million Lev. These funds are mainly targeted to applied research projects. However, the budgetary allocation hasn't been implemented yet.
CY	direct funding	In Cyprus the budgetary allocation for the "Research and Promotion Foundation´s Framework Programme for Research, Innovation and Technological Development" for the three years from 2008 to 2010 will be 120 million Euros (co-financed by EU structural funds) compared with just 10 million Euros in 2006.
CZ	direct funding	The Czech Republic increased the public expenses on research and development by 8% in the 2009 budget and intends to apply this rule in the coming years. 600 million Czech Crowns are allocated as investment incentives for projects of technology centres, which will be spent in the following years.

[32] See Conclusions of the Brussels European Council 19/20 March 2009
[33] Communication from the Commission and the European Council COM(2008)800

DE	direct funding and tax relief	Germany increases its general spending on R&D by nearly 1 billion Euros in 2009 compared to 2008. Additional resources will come from the "Central Innovation Programme for SMEs", 0.45 billion in 2009 and 2010 respectively, to support individual R&D operations. Specifically for R&D activities on hybrid-propulsion, fuel cell and saving technologies additional 0.5 billion for 2009 and 2010 (total for two years) are made available in the form of loans to the automotive sector. Furthermore, a special depreciation facility for SMEs has been introduced. During 2009 and 2010, in addition to the degressive depreciation, the federal government will increase the business asset thresholds and profit thresholds relevant in this regard. The budgetary impact of the latter measure will amount to 605 millions Euros for 2009 and 2010.
DK		Denmark did not directly react to the crisis with increased public R&D expenditure. However, public R&D expenditure is planned to increase from 0.89% of GDP in 2008 to 0.94% in 2009 and 1% in 2010, as already announced ahead of the current crisis.
EE		Estonia did not increase public R&D expenditure in reaction to the crisis.
ES	tax relief / direct funding	The planned elimination of the R&D tax credit on the corporate income tax has been suspended. Moreover, the tax credit has been expanded as of 2008. The credit may now be applied also to companies with more than 25% of their research activity in another EU or European Economic Area country. Non military R&D budget amounts increase in 2009 by 10,2% with respect to 2008.
FI	direct funding	Finland introduced additional business subsidies focusing on R&D for 2009. 561 million Euros have been foreseen within the budget, for a total of 5.6 billion Euros off-budget guarantees have been arranged.
FR	tax relief	France substantially increased the R&D tax credit as of 2008. Additionally, as of 1 January 2009 any outstanding R&D tax credits not offset against corporate tax will be immediately refunded upon request.
GR		Greece did not increase public R&D expenditure in reaction to the crisis.
HU	direct funding	Hungary wants to maintain employment in the field of R&D, not only to prevent temporary unemployment but also to avoid brain drain. It is foreseen to achieve this by giving financial support to public research centres and SMEs which could amount to about 6 Million Euros.
IE	tax relief	Ireland introduced a 25% tax credit for equipment related to R&D as of 2009.
IT		Italy did not increase public R&D expenditure in reaction to the crisis. However, the extension of tax credit to research carried out in Italy commissioned by foreign entities as of 2009 has been proposed.
LT		Lithuania did not increase public R&D expenditure in reaction to the crisis. However, corporate income tax exemptions for investment into R&D have been introduced as of 2008. The measure has already been announced before the economic crisis.
LU		Luxemburg did not increase public R&D expenditure in reaction to the crisis.
LV		Latvia did not increase public R&D expenditure in reaction to the crisis. An increase in government R&D funding, envisaged in the budget of 2009, has been postponed.
MT	direct funding	Malta directs 20 million Euros to business related R&D activities in the period 2009-2013.
NL	tax relief / direct funding	In the Netherlands the Research and Development Promotion Act (WBSO) principally is intensified in phases, increasing from 39 million Euros in 2009 to 115 million Euros in 2011. Recently, the WBSO has been stepped up, and 150 million Euros are made available additionally in 2009 and 2010 respectively. Under this Act, a contribution is paid towards the wage costs of employees directly involved in R&D in the form of a reduction of payroll tax and social security contributions and an increase in the tax deductions available to self-employed persons.

		Two additional measures foreseen for 2009 and 2010 are expected to be adopted soon: 180 million Euros will be made available to support the employment of researchers in the private sector, and 100 million Euros will be allocated to support research projects in areas where the Netherlands have a strong position, such as nanoelectronics and automotive.
PL		Poland did not increase public R&D expenditure in reaction to the crisis.
PT	tax relief	Portugal increased the R&D tax credit to a maximum rate of 82.5% of total expenses in R&D as from 2009.
RO		Romania did not increase public R&D expenditure in reaction to the crisis.
SE	direct funding	In Sweden a new research and innovation bill was presented in October 2008 which covers the period 2009-2012 and in terms of additional resources, includes the largest allocation ever. It amounts to 5 billion Swedish Kronas and is more than twice as large as the former bill.
SI	direct finding	For the period 2009-2011 Slovenia is providing additional subsidies to businesses for investment in R&D and new technologies. In the latest supplementary budget for 2009, in comparison to the implemented budget 2008, additional 75.4 million Euros (representing additional 0.21% of GDP) were dedicated to R&D, and additional 163.3 million Euros (representing 1.04% of GDP) to science and technology.
SK	direct funding / tax relief	Slovakia grants financial support for research and development activities carried out by the business sector in the form of state subsidies and corporate income tax allowances, amounting to an overall volume of about 100 million Euros in 2009 and 2010.
UK	direct funding	The United Kingdom brings forward parts of the funds intended for the financial year 2010-11 to provide fiscal stimulus. In this way 442 million Pounds will be available earlier for projects to improve infrastructure for further education, improve facilities at higher education institutions, and to bringing forward development of scientific research facilities and improvements to university research infrastructure.

Around two thirds of the Member States appear to have increased their public R&D spending in response to the current economic crisis. Examining the measures taken, it can be seen that around two thirds of them constitute direct funding (subsidies, grants) whereas the remaining measures offer tax relief (credits, exemptions). Member States tend to resort to the same policy instruments which have been used to stimulate R&D and innovation in a non-crisis situation. In the slight majority of cases, the additional measures had an expiration date already at the time of adoption, implying the termination of the stimulus as soon as the private sector steps up its R&D investments again.

In the best case, the money spent should lead to a stabilisation of the economies in the short term, and additionally spur a sustainable (mid- to long-term) increase of R&D spending in the private sector. This would support the endeavour to improving the competitiveness of the European economies, increasing potential output and therewith secure sustainable growth. In order to make this plan work, due attention needs to be paid to ensuring that the additional funds made available are spent efficiently. In this respect, a close collaboration between the public and private sector seems useful, not only to gain information about the right timing and necessary volume of support, but also to identify special needs and opportunities within the business sector. Furthermore, as the stimulation of market activity is essential for lifting innovative activity to a higher level, public measures should be directed to the demand and the supply side simultaneously.

6. Policy Conclusions

In order for the European Union to emerge stronger from the current crisis it could among other things increase the level of R&D spending and take steps to raise its efficiency and effectiveness. As changes in business R&D tend to be pro-cyclical, public investments in R&D should move counter-cyclically in order to safeguard the innovation potential of the European economy. Public support of R&D and innovation is even more important, as the crisis has made it more difficult for companies to finance their investments in R&D and innovation. While there has been a slight increase in the level of public R&D spending, greater progress appears to have been made in increasing the efficiency of such spending, particularly by the new Member States. Nevertheless, the potential for further increases in efficiency remains substantial.

Countries with higher R&D spending as a percentage of GDP are also the countries with higher efficiency levels. The creation of a knowledge base, in terms of both national investment and absorptive capacity from abroad (the latter being measured by foreign R&D stock) appears to be important for raising efficiency levels. Since countries with higher R&D spending also have better institutions for supporting R&D and other innovative activities, this outcome seems to suggest that a more systemic approach to R&D policy is needed in order to make the national innovation system more efficient. Indeed, several factors appear related to higher efficiency levels. In particular, IPR protection, education policies, the high-tech specialisation of the economy, and the share of human resource in S&T over total employment are all positively correlated to efficiency levels across countries and over time.

The Member State survey on national R&D systems and on market and framework conditions for R&D highlighted the importance of having a long-term perspective when promoting R&D. Such a perspective not only helps to ensure a continued focus by the public sector on its long-term policy objectives, but it also offers the private sector the possibility to plan well ahead. Regular evaluations are another prerequisite for maintaining and raising the efficiency and effectiveness of R&D measures. The increased importance of R&D from abroad points to the possible benefits of an internationalisation of R&D policy, which would allow capturing possible spillover effects. Finally, Member States indicated that there is a need to better adapt educational programmes to the needs of industry.

The overview of the R&D policy measures which have recently been introduced by the Member States in reaction to the current crisis reveals that Member States consider direct grants and offers of tax relief as the preferred instruments to counteract the negative effects of recent economic crisis. Member States perceive these measures to be effective in attaining their policy objectives.

The results obtained suggest some policy actions that could contribute to increasing the efficiency of R&D and innovation policies. First of all, investment in a sound knowledge base seems to be a prerequisite for innovation. Especially medium-term funding programmes could serve as means for sustained support for private and public research. To ensure that funds are directed to those areas where R&D investments offer the highest returns, existing R&D funding programmes need to be regularly evaluated. Moreover, currently existing mismatches between the qualification of the work force and respective industry demands need to be addressed by better adjusting educational programmes and research infrastructure to the needs of science and industry. Finally, policy interventions should be tailored to the specific needs and strengths of each of the Member States. These suggestions could provide input for a more systemic approach to R&D, education and innovation policies.

Appendix 1. Dataset Structure and Variables Definition

For the purpose of this study, a panel dataset at the country level has been constructed, which contains the most relevant indicators in the area of R&D and innovation for which sufficient data are available.

The final dataset contains information on 32 EU and non-EU countries over the period 1990-2006. The maximum size of the available sample consists of 544 observations (32 countries for 17 years). In fact, the actual number of observations varies across variables and, especially, across countries. The panel dataset is, therefore, unbalanced.

Data are entirely drawn from the "Eurostat - Science and Technology Indicators", which contains information on all EU Member States as well as other major world economies. Monetary indicators (GDP and R&D expenditure data) have been rescaled in real terms using the GDP Deflator Index available from DG ECFIN's Annual Macro Economic Database AMECO to make time series data comparable over time. Data on scientific output (publications, citations) is obtained from the ISI Web of Knowledge dataset.

A more detailed description of the variables is provided below:

PUBLIC R&D SPENDING

- *Total R&D expenditures* (GERD). **Source: Eurostat (S&T Indicators)**
- *Public R&D* (GOVERD and HERD). **Source: Eurostat (S&T Indicators)**
- *Direct Public Funding of Private R&D* (Grants, subsidies and Public Procurements) (BERD-BYGOV). **Source: Eurostat (S&T Indicators)**

OUTPUT MEASURES

- *Additional Business R&D expenditures* (BERD). **Source: Eurostat (S&T Indicators)**
- *Patents Applications to EPO (PAT) according to the inventor's country of residence.* **Source: Eurostat (S&T Indicators)**
- *Triadic Patents Applications to EPO* (TRIPAT). Source: **Eurostat (S&T Indicators)**
- *Total number of citations to patent applications* (CIT). **Source: ISI Web of Knowledge**
- *Total number of scientific publications* (PUB). It corresponds to the number of papers (in all scientific fields) published in a 5-year interval period. **Source: ISI Web of Knowledge**
- *Total number / average citations to scientific papers in a 5-year interval period* (CITP). Each five-year period is self-contained. Only citations within a time period to articles within that time period are counted. For example, the period 2000 - 2004 counts papers for each full year (2000 through 2004) and cumulates citations to these papers from all citing items from 2000 through 2004. **Source: ISI Web of Knowledge**

CONTROL VARIABLES (See Appendix 2)

Appendix 2. Control Variables: Definition and Data Source

This study discusses 5 possible groups of variables - obtained from different data sources - which may affect the efficiency and effectiveness of public R&D spending.

R&D CONTROL VARIABLES

- *R&D Personnel.* This variable allows to control for the effects of crowding out of private R&D investment by public R&D sources (see Section 2.3) which are associated with the fact that additional public R&D funding puts upward pressures on the wages of the R&D personnel (Cincera *et al.*, 2008). **Source: Eurostat (S&T Indicators)** .
- *Basic R&D as % of total R&D expenditures.* On the importance of basic R&D, see Nelson (1961). **Source: Eurostat (S&T Indicators)**

FRAMEWORK CONDITIONS

There are a number of institutional and structural variables which may contribute to a more efficient public expenditure in R&D. However, for most of these variables data comparability across countries is still very poor.

- *Size of the Government.* **Source: Fraser Institute - Economic Freedom World Index**
- *Strength of Intellectual Property Rights.* IPRs affect innovative activities by changing the appropriability conditions and, therefore, the incentives for undertaking innovative investment. In turn, this implies a constant trade-off for policy makers which have to balance the need for more innovation-enhancing appropriability conditions without hampering innovation diffusion and user-generated innovation. **Source: Park and Ginarte's Index of Patent Protection (Park, 2008)**
- *Access to Sound Money.* **Source: Fraser Institute - Economic Freedom of the World Index**
- *Public Tertiary Education Spending as a % of GDP.* **Source: Eurostat (Indicators on Education Finance)**
- *Human Resources in S&T as a % of Total Employment.* **Source: Eurostat (S&T Indicators)**

TECHNOLOGY-PUSH FACTORS

This analysis uses *stock measures of domestic, public and foreign R&D* as an indicator of a country's knowledge base. Indeed, although pure economic forces affect the direction of technological change, these effects take place *"within the changing limits and constraints of a body of scientific knowledge growing at uneven rates among its component subdisciplines"* (Rosenberg, 1976, p. 270). A common way to proxy this body of knowledge is then to use aggregate stock measures of R&D which allows also to proxy the spillovers effect due to R&D spending in the economy[34].

[34] A large piece of literature has documented the spillovers effect at the industry level (Bernstein and Nadiri, 1988 and 1989; Wolff and Nadiri, 1993; Sterlacchini, 1994), at the regional level (Jaffe et al., 1993;

- *Technological Opportunity (Knowledge Spillovers).* This is proxied by the following variables:
    - *Domestic R&D capital stock.* The domestic business R&D capital stock has been computed using the perpetual inventory method (OECD, 2001) from total intramural business R&D expenditures, in constant 2000 GDP prices and US PPPs and assuming a 15% depreciation rate. **Source: Eurostat (S&T Indicators)**
    - *Public R&D stock.* The public R&D capital stock corresponds to the R&D performed in Higher Education Institutions (e.g. universities) and in the Government sector (e.g. public research labs). It is computed using the perpetual inventory method from total intramural public R&D expenditures, in constant 2000 GDP prices and US PPPs again with a 15% depreciation rate. **Source: Eurostat (S&T Indicators)**
    - *Foreign R&D capital stock and Technological proximities P_{ij}.* The foreign R&D capital stock is constructed as a weighted sum of the domestic business R&D capital stocks of the other countries under analysis. The weights are the bilateral technological proximity P_{ij} between countries i and j. This measure is similar to the one used by Jaffe (1986), Capron and Cincera (1998) and Guellec and van Pottelsberghe (2004). **Source: Eurostat (S&T Indicators)**
- *Public-Private R&D collaborations (Science-industry links).* Business funding of non-business R&D. **Source: Eurostat (S&T Indicators)**
- *% of Foreign Ownership in Domestic Patents*. **Source: Eurostat (S&T Indicators)**
- *Foreign Control of Enterprises*. **Source: Eurostat (Structural Business Statistics)**

INDUSTRIAL DYNAMICS

This study controls for both the *sectoral composition of the economy* and for some *structural business characteristics,* such as the number of start-ups and the distribution of firms according to their size in the economy. However, a very limited number of observations for this second group of indicators does not allow us to use this information in the econometric analysis.

- *Number of new start-ups.* **Source: Eurostat (Structural Business Statistics)**
- *Sector Composition of the Economy. %* of High Tech Manufacturing in Total manufacturing. **Source: Eurostat (Structural Business Statistics)**
- *Firm's size.* **Source: Eurostat (Structural Business Statistics)**

Audretsch and Feldman, 1996) and between different firms (Acs et al., 1994b; Audretsch and Vivarelli, 1996; D'Aspremont and Jacquemin, 1988; Capron and Cincera (1998), Los and Verspagen, 2000, Cincera and van Pottelsberghe, 2001 and Cassiman and Veugelers, 2002).

POLICY VARIABLES

Policy variables may influence the creation of a country's knowledge base as well as the incentives affecting the marginal cost and returns of R&D investment. EU Member States have different mixes of direct and indirect funding of R&D activities. However, data on the different channels of public R&D expenditure are only partially available across EU Member States.

Indicators of direct public R&D spending are included in this study as input measures. Policies affecting the returns to R&D investment are proxied by the IPRs indicator. Finally, we include measures aiming at reducing the marginal cost of R&D investment carried out by businesses. In this area, data limitations appear especially severe. The only (limited) available measure is the index of R&D tax credits, namely the B-Index (Warda, 2006)[35].

Finally, this paper includes broader policy measures such as *public procurement* and the share of *government budget appropriations for civil R&D* to control for other policy-relevant differences across countries which may affect the degree of efficiency of public R&D spending.

- *Index of R&D tax credits* (B-Index). **Source: OECD, Warda (2006)**
- *GBOARD in % of GDP.* **Source: Eurostat (S&T Indicators)**
- *GBOARD in % of Total Government Expenditure.* **Source: Eurostat (S&T Indicators)**

[35] The B-index (OECD, 2006) is defined as the ratio of the after-tax cost per unit of R&D expenditures to one minus the corporate income tax. The index takes the value 1 if all R&D expenditures are fully deductible in the current year; less than 1 when they are more than fully deductible; and greater than 1 in case the R&D expenditures are not fully deductible. An increasing index thus indicates that the tax treatment is becoming less generous. The B-index is calculated with 90 per cent current expenditures and 10 per cent capital expenditures for all countries. The B-index does not discriminate between different definitions of innovation and R&D expenditures, which may, however, seriously affect the overall scope and impact of the fiscal incentives.

Appendix 3. Methodology

This study adopts a standard background model for the estimation of countries' efficiency scores as indicated by the following general specification of the R&D equation:

$$\ln(OUT)_{ct} = \alpha + \sum_{i=1}^{s} \beta_i \ln(R\,\&\,D)_{ct} + \sum_{j=1}^{c} \beta_j CD + (v_{ct} + te_{ct})$$

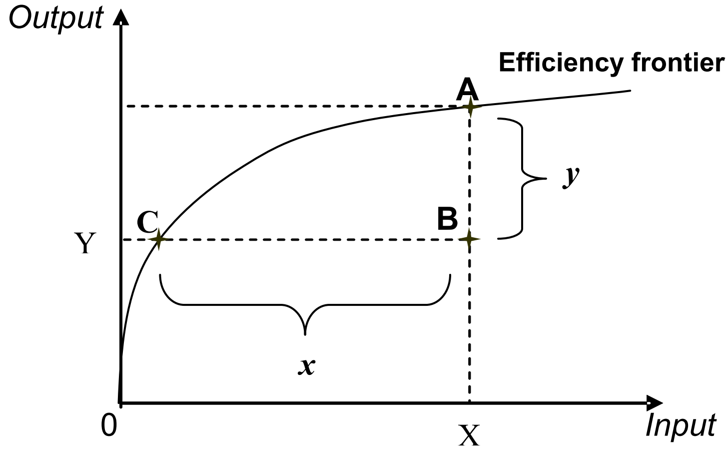
where OUT represents the output measures under investigation. For instance, in the patent equation this note uses PAT{ct} which represents the number of Patents Applications to the European Patent Office (EPO) by country of applicant (c) and year (t). R&D{ct} indicates the amount of R&D expenditure by sector of performance (s) as indicated in the standard EUROSTAT disaggregation. Alternatively, a disaggregation of R&D spending by sector of funding has been used in the analysis. This equation is augmented by a set of country dummies (CD). These are very important since they allow capturing any time-invariant effect related to each country (i.e. institutional features, sector composition, population size and any other variables which may be assumed to be constant in the short term). Finally, the structure of the error term follows the characteristics described above, namely it is divided into the standard white-noise error term v_{ct} and the technical (in)efficiency component (te). The latter is modelled as a time-invariant component, thus allowing comparisons both cross-country and over time.

Several approaches for measuring the efficiency of governmental expenditures have been proposed in the literature after the seminal work in the area of efficiency measurement proposed by Farrell (1957). Beyond standard parametric regressions, studies dealing with efficiency of government spending have used three main categories of methods, namely composite indicators, non-parametric methods and parametric methods.

For the purpose of this study, methods based on composite indicators are not well suited since we are interested in assessing the efficiency of a specific policy, namely public R&D spending. Therefore two methods which have been widely used in this stream of literature, namely a non-parametric method - Data Envelopment Analysis (DEA) - and a parametric regression approach - the Stochastic Frontier Analysis (SFA) have been considered for this analysis.

Both of these methods use the production possibility function (see Figure 17) as a benchmark. The production possibility function illustrates efficient combinations of inputs and outputs (A and C in Figure 17). The main difference between the parametric and the non-parametric approach is that the former requires the ex-ante definition of the functional form of the efficiency frontier whereas the non-parametric approach constructs an efficiency frontier using the sample data.

Figure 17: The efficiency frontier



The **DEA** allows the estimation of efficiency frontiers and efficiency losses. This method is a linear programming based technique which is able to convert multiple inputs and outputs into a single comprehensive measure of productive efficiency or productivity for the particular decision making units (DMUs). More precisely, following this non-parametric approach an envelope is constructed around the observed combinations of inputs and outputs, which provides a benchmark by which the efficiency performance can be evaluated. The obtained technical efficiency scores of public R&D spending are then explained by exogenous factors or framework conditions varying across countries and within countries (in a panel structure) in a second stage.

On the contrary, the **SFA** allows the simultaneous estimation of the R&D equation and the efficiency terms. It assumes a specific functional form for the relationship between input and output. The error term, which reflects the unmeasured determinants of the dependent variable Y_i, is divided into two components: first, the random error term ε and second, a positive error term that captures inefficiency ν. This last element of the residual provides an indication of the true level of inefficiency.

The choice of the appropriate method is dependent on the specific research question and the data structure on which the analysis is based. Figure 18 provides a comparison of strengths and weaknesses of these two methods.

Figure 18. Methods for assessing the efficiency and effectiveness of public R&D spending

STRENGHTS	WEAKNESSES
DATA ENVELOPMENT ANALYSIS (DEA)	
No need to specify a functional relationship between inputs and outputs	Heavy reliance on the accuracy of the data
Allows to deal with the simultaneous occurrence of multiple inputs and outputs	Efficiency scores attributed to inputs while other factors may also contribute
Not subject to specification errors	Frontier depends on the set of countries considered

STOCHASTIC FRONTIER ANALYSIS (SFA)	
Error term with 2 components: conventional ε + deviation from frontier ν (relative inefficiency)	Assumes functional form for the production function
Allows for hypothesis testing, confidence interval Allow to explain inefficiency	Assumes distributional form of the technical efficiency term

Given the purpose of the current exercise, there are several advantages to using SFA over using the DEA method.

In particular, DEA implies a heavy reliance on the accuracy of the data. On the contrary, the strength of the SFA is that it is based on a regression type of analysis which, in turn, allows a more robust approach to data analysis[36]. In addition, DEA is not able to split a country's relative position into a pure technical (in)efficiency component and the usual statistical error, the latter being dependent of (random) factors unrelated with the true degree of efficiency of a country. On the contrary, SFA allows such disaggregation by simultaneously estimating the main equation and the efficiency term[37].

Moreover, the use of panel data - beyond the strong advantage of allowing the control for unobservable country-specific attributes and then to extract more reliable parameter estimates - has important implications when using SFA. First, panel data allow overcoming the major limitation of this technique, namely the need of strong assumptions over the distributional form of the technical efficiency term. Second, with panel data, adding more observations from the same country generates more information about each country so that inefficiency can be estimated consistently as the number of observations over time increases. Third, the inefficiency term and the explanatory variables are unlikely to be independent. Indeed, it is quite likely that if a country knows its level of technical inefficiency this will affect its choice of input (R&D) levels. By controlling for a country's characteristics, we are able to deal more effectively with such endogeneity problem.

An additional point refers to the identification of the inefficiency term. Indeed, we can estimate a country's efficiency score by making the assumption that the inefficiency component is (1) constant over time or (2) time-varying. There is a strong argument in favour of the latter in this context, since the policy purpose of this note is exactly to set the background for the evaluation of policy instrument in changing a country's relative position.

[36] Moreover, while DEA provide one-point estimates, SFA allows for confidence intervals and hypothesis testing of the estimates. In turn, this allows a better analysis of the robustness of the results.

[37] Such procedure allows to estimate an (in)efficiency score which is conditional to the set of regressors included in the analysis and, therefore, more reliable when compared to the (biased) unconditional DEA efficiency scores.

List of References

Acs, Zoltan J. & Audretsch, David B. 1987. Innovation, Market Structure and Firm Size. The Review of Economics and Statistics, Vol. 69 (No. 4), pp. 567-574

Acs, Zoltan J., Audretsch, David B., & Feldman, Maryann P. 1994a. R&D Spillovers and Innovative Activity. Managerial and Decision Economics, Vol. 15(2), pp. 131–138.

Acs, Zoltan J., Audretsch, David B., & Feldman, Maryann P. 1994b. R&D Spillovers and Recipient Firm Size. Review of Economics and Statistics, Vol. 4(2), pp. 336–340.

Aerts, Kris; Czarnitzki, Dirk. 2004. Using Innovation Survey Data to Evaluate R&D Policy: The Case of Belgium. ZEW Discussion Paper, No. 04-55

Afonso, Antonio, & St. Aubyn, Miguel. 2006. Cross-Country Efficiency of Secondary Education Provision: A Semi-Parametric Analysis with Non-Discretionary Inputs. Economic Modelling, Vol. 23(3), pp. 476–491.

Afonso, António, Schuknecht, Ludger, & Tanzi, Vito. 2005. Public Sector Efficiency: An International Comparison. Public Choice, Vol. 123(3), 321–347.

Ames, Edward. 1961. Research, Invention, Development and Innovation. American Economic Review, Vol. 51(3), pp. 370–381.

Audretsch, David B., & Feldman, Maryann P. 1996. R&D Spillovers and the Geography of Innovation and Production. American Economic Review, Vol. 86(3), pp. 630–640.

Audretsch, David B., & Vivarelli, Marco. 1996. Firms Size and R&D Spillovers: Evidence from Italy. Small Business Economics, Vol. 8(3), pp. 249–258.

Bassanini, Andrea, Scarpetta, Stefano, & Visco, Ignazio. 2000. Knowledge, Technology and Economic Growth: Recent Evidence from OECD Countries. OECD Economics Department Working Paper No. 259.

Bernstein, Jeffrey I., & Nadiri, M. Ishaq. 1988. Interindustry R&D Spillovers, Rates of Return, and Production in High-Tech Industries. American Economic Review, Vol. 78(2), pp. 429–434.

Bernstein, Jeffrey I., & Nadiri, M. Ishaq. 1989. Research and Development and Intra-industry Spillovers: An Empirical Application of Dynamic Duality. Review of Economic Studies, Vol. 56(2), pp. 249–267.

Bilbao-Osorio, Beñat, & Rodríguez-Pose, Andrés. 2004. From R&D to Innovation and Economic Growth in the EU. Growth and Change, Vol. 35(4), pp. 434–455.

Capron, Henri, & Cincera, Michele. 1998. Assessing the R&D Determinants and Productivity of World-wide Manufacturing firms, Annales d'Economie et de Statistiques, 49/50, pp. 565-587.

Cassiman, Bruno, & Veugelers, Reinhilde. 2002. R&D Cooperation and Spillovers: Some Empirical Evidence from Belgium. American Economic Review, Vol. 92(4), pp. 1169–1184.

Cincera, Michele, Czarnitzki, D., & Thorwarth, S. 2008. Efficiency of public spending in support of R&D activities: An international comparison, Final report of a study commissioned by the European Commission (DG ECFIN).

Coe, David T., & Helpman, Elhanan. 1995. International R&D Spillovers. European Economic Review, Vol. 39(5), pp. 859–1073.

Cohen, Wesley M.; Levin, Richard C. & Mowery, David C. 1987. Firm Size and R&D Intensity: A Re-Examination. The Journal of Industrial Economics, Vol. 35 (4), pp. 543-565

Comanor, William S. 1967. Market Structure, Product Differentiation and Industrial Research. The Quarterly Journal of Economics, Vol. 81, pp. 639-657

Conte, Andrea. 2006. The Evolution of the Literature on Technological Change over time: A Survey. Max Planck Institute of Economics, Discussion Paper No. 107.

Conte, A. & Vivarelli, M., 2005. "One or Many Knowledge Production Functions? Mapping Innovative Activity Using Microdata, IZA - Institute for the Study of Labor, Working Paper No. 1878

Crepon, Bruno, Duguet, Emmanuel, & Mairesse, Jacques. 1998. Research, Innovation and Productivity: An Econometric Analysis at the Firm Level. Economics of Innovation and New Technology, Vol. 7(3), pp. 115–156.

D'Aspremont, Claude, & Jacquemin, Alexis. 1988. Cooperative and Noncooperative R&D in Duopoly with Spillovers. American Economic Review, Vol. 78(5), pp. 1133– 1137.

David, Paul A., Hall, Bronwyn H., & Toole, Andrew A. 2000. Is Public R&D a Complement or Substitute for Private R&D? A Review of the Econometric Evidence. Research Policy, Vol. 29(4-5), pp. 497–529.

European Commission. 2007. Key Figures 2007. Towards a European Research Area. Science, Technology and Innovation.

Falk, Rahel, & Leo, Hannes. 2006. What Can Be Achieved By Special R&D Funds When There is No Special Leaning Towards R&D Intensive Industries? WIFO Working Paper No. 273.

Farrell, M. J. 1957. The Measurement of Productive Efficiency. Journal of the Royal Statistical Society, Vol. 120(3), pp. 253–290.

Fellner, William. 1951. The Influence of Market Structure on Technological Progress. The Quarterly Journal of Economics, Vol. 65 (No. 4), pp. 556-577

Goolsbee, Austan. 1998. Does Government R&D Policy Mainly Benefit Scientists and Engineers? American Economic Review, Vol. 88(2), pp. 298–302.

Griliches, Zvi. 1979. Issues in Assessing the Contribution of Research and Development to Productivity Growth. Bell Journal of Economics, Vol. 10(1), pp. 92–116.

Guellec, D.; Van Pottelsberghe, B. 2000. The Impact of Public R&D Expenditure on Business R&D. OECD Science, Technology and Industry Working Papers, Vol. 2000/4

Guellec, Dominique, & de la Potterie, Bruno Van Pottelsberghe. 2004. From R&D to Productivity Growth: Do the Institutional Settings and the Source of Funds of R&D Matter? Oxford Bulletin of Economics and Statistics, Vol. 66(3), pp. 353–378.

Guellec, Dominique, & Van Pottelsberghe De La Potterie, Bruno. 2001. The Effectiveness of Public Policies in R&D. Revue D'Economie Industrielle, Vol. 94(1), pp. 49–68.

Guellec, Dominique, & Van Pottelsberghe De La Potterie, Bruno. 2003. The Impact of Public R&D Expenditure on Business R&D. Economics of Innovation and New Technology, Vol. 12(3), pp. 225–243.

Hall, Bronwyn H., & Reenen, John Van. 2000. How Effective are Fiscal Incentives for R&D? A Review of the Evidence. Research Policy, Vol. 29(4-5), pp. 449–469.

Herrera, Santiago, & Pang, Gaobo. 2005. Efficiency of Public Spending in Developing Countries : An Efficiency Frontier Approach. World Bank Policy Research Working Paper No. 3645.

Jaffe, Adam B. 1986. Technological Opportunity and Spillovers of R&D: Evidence from Firms'Patents, Profits, and Market Value. American Economic Review, Vol. 76(5), pp. 984–1001.

Jaffe, Adam B., Trajtenberg, Manuel, & Henderson, Rebecca. 1993. Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. Quarterly Journal of Economics, Vol. 108(3), pp. 577–598.

Jaumotte, F., & Pain, N. 2005a. From Ideas to Development: The Determinants of R&D and Patenting. OECD Economics Department Working Paper No. 457.

Jaumotte, F., & Pain, N. 2005b. An Overview of Public Policies to Support Innovation. OECD Economics Department Working Paper No. 456.

Jones, Charles I., & Williams, John C. 1998. Measuring the Social Return to R&D. Quarterly Journal of Economics, Vol. 113(4), pp. 1119–1135.

Lee, Hak-Yeon, & Park, Yong-Tae. 2005. An International Comparison of R&D Efficiency: DEA Approach. Asian Journal of Technology Innovation, Vol. 13(2), pp. 207–222.

Lee, Tom, & Wilde, Louis L. 1980. Market Structure and Innovation: A Reformulation. Quarterly Journal of Economics, Vol. 94(2), pp. 429–436.

Levin, Richard C.; Klevorick, Alvin K.; Nelson, Richard R. and Winter, Sidney G.; Link, Albert N. & Bozeman, Barry. 1991. Innovative Behavior in Small-Sized Firms. Small Business Economics, Vol. 3 (No. 3), pp. 179-184

Los, Bart, & Verspagen, Bart. 2000. R&D Spillovers and Productivity: Evidence from U.S. Manufacturing Microdata. Empirical Economics, Vol. 25(1), pp. 127–148.

Lucas, Robert E. Jr. 1988. On The Mechanics Of Economic Development. Journal of Monetary Economics, Vol. 22(1), pp. 3–42.

Malerba, 2002, Sectoral Systems of Innovation and Production, *Research Policy, Vol. 31*, pp. 247-264.

Mandl, U.; Dierx, A. & Ilzkovitz, F. 2008. The Effectiveness and Efficiency of Public Spending, European Economy, Economic Paper No. 301

Mansfield, Edwin, Rapoport, John, Romeo, Anthony, Wagner, Samuel, & Beardsley, George. 1977. Social and Private Rates of Return from Industrial Innovations. Quarterly Journal of Economics, Vol. 91(2), pp. 221–240.

Mansfield, Edwin. 1981. Composition of R&D Expenditures: Relationship to Size of Firm, Concentration and Innovative Output. The Review of Economics and Statistics, Vol. 63 (No. 4), pp. 610-615

Mansfield, Edwin. 1985. How Rapidly Does New Industrial Technology Leak Out? Journal of Industrial Economics, Vol. 34(2), pp. 217–223.

Marshall, Alfred. 1920. Principles of Economics. 8th edn. London: Macmillan and Co. Ltd. (1st edition: 1890).

Martin, Stephen, & Scott, John T. 2000. The Nature of Innovation Market Failure and the Design of Public Support for Private Innovation. Research Policy, Vol. 29(4-5), pp. 437–447.

MERIT, 2003. The Brain-Drain - Emigration Flows for Qualified Scientists.

Nelson, Richard R. 1959. The Simple Economics of Basic Scientific Research. The Journal of Political Economy, Vol. 67 (No. 3), pp. 297-306

OECD. 2006a. STI Outlook 2006 - Internationalisation of R&D. DSTI/STP(2006)21

OECD. 2006b. Evaluation of Publicly Funded Research: Recent Trends and Perspectives. DSTI/STP(2006)24

OECD. 2007a. Assessing The Socio-Economic Impacts of Public R&D.

OECD. 2007b. Innovation and Growth – Rationale for an Innovation Strategy.

OECD. 2008. Science, Technology and Industry Outlook.

OECD. 2009. First Interim Report on the OECD's Strategic Response to the Financial and Economic Crisis. C(2009)26

Ortega-Argilés, Raquel; Piva, Mariacristina; Potters, Lesley; Vivarelli, Marco. 2009. Is Corporate R&D Investment in High-Tech Sectors More Effective?, Discussion Paper No. 3945, Institute for the Study of Labor (IZA), Bonn

Park, Walter G. 1995. International R&D Spillovers and OECD Economic Growth. Economic Inquiry, Vol. 33(4), pp. 571–91.

Park, Walter G. 2008. International Patent Protection: 1960-2005. Research Policy, Vol. 37(4), pp. 761–766.

Pavitt, Keith. 1982. R&D, Patenting and Innovative Activities: A Statistical Exploration. Research Policy, Vol. 11(1), pp. 33–51.

Pavitt, Keith. 1984. Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory. Research Policy, Vol. 13 (No. 6), pp. 343-373

Romer, Paul M. 1986. Increasing Returns and Long-Run Growth. Journal of Political Economy, Vol. 94(5), pp. 1002–1037.

Romer, Paul M. 1990. Endogenous Technological Change. Journal of Political Economy, Vol. 98(5), pp. S71–S102.

Rosenberg, Nathan. 1976. Perspectives on Technology. Cambridge: Cambridge University Press.

Rothwell, Roy. 1989. Small Firms, Innovation and Industrial Change. Small Business Economics, Vol. 1 (No. 1), pp. 51-64.

Scherer, Frederic M., & Harhoff, Dietmar. 2000. Technology Policy for a World of Skew-Distributed Outcomes. Research Policy, Vol. 29(4-5), pp. 559–566.

Scherer, Frederic M., Harhoff, Dietmar, & Kukies, Jorg. 2000. Uncertainty and the Size Distribution of Rewards from Innovation. Journal of Evolutionary Economics, Vol. 10(1-2), pp. 175 –200.

Schumpeter, Joseph. 1934. The Theory of Economic Development. Cambridge (Mass.): Harvard University Press, 1st edn. 1912.

Solow, Robert M. 1956. A Contribution to the Theory of Economic Growth. Quarterly Journal of Economics, Vol. 70(1), pp. 65–94.

Solow, Robert M. 1957. Technical Change and the Aggregate Production Function. Review of Economics and Statistics, Vol. 39(3), pp. 312–320.

Sterlacchini, Alessandro. 1994. Technological Opportunities, Intra-Industry Spillovers and Firm R&D Intensity. Economics of Innovation and New Technology, Vol. 3, pp. 123–137.

Van Pottelsberghe, Bruno. 2008. Europe's R&D: Missing the Wrong Targets? Bruegel Policy Brief, Issue 2008/03, February 2008

Verspagen, Bart. 1995. R&D and Productivity: A Broad Cross-Section Cross-Country Look. Journal of Productivity Analysis, Vol. 6(2), pp. 117–135.

Wang, Eric C., & Huang, Weichiao. 2007. Relative Efficiency of R&D Activities: A Cross-Country Study Accounting for Environmental Factors in the DEA Approach. Research Policy, Vol. 36(2), pp. 260–273.

Warda, Jacek. 2006. Tax Treatment of Business Investments in Intellectual Assets: An International Comparison. OECD Science, Technology and Industry Working Paper Series, No. 4.

Wolff, Edward N., & Nadiri, M. 1993. Spillover Effects, Linkage Structure, and Research and Development. Structural Change and Economic Dynamics, Vol. 4(N. 2), pp. 315–331.

Zabala-Iturriagagoitia, Jon M., Voigt, Peter, Gutiérrez-Gracia, Antonio, & Jiménez-Sáez, Fernando. 2007. Regional Innovation Systems: How to Assess Performance. Regional Studies, Vol. 41(5), pp. 661–672.