



DYNREG



CITIZENS AND GOVERNANCE IN A
KNOWLEDGE-BASED SOCIETY

**DYNAMIC REGIONS IN A KNOWLEDGE-DRIVEN GLOBAL ECONOMY:
LESSONS AND IMPLICATIONS FOR THE EUROPEAN UNION – DYNREG**

Final Conference

Brussels, 27 November 2008

**The relations between public subsidies, business R&D
and innovativeness: A quantitative meta - analysis**

Patricia van Hemert

VU Center for Entrepreneurship, VU University Amsterdam, the Netherlands

Peter Nijkamp

Department of Spatial Economics, VU University Amsterdam, the Netherlands

The relations between public subsidies, business R&D and innovativeness

A quantitative meta-analysis

Patricia van Hemert*
VU University Amsterdam
VU Center for Entrepreneurship
De Boelelaan 1085
1081 HV Amsterdam
pthemert@feweb.vu.nl

Peter Nijkamp
VU University Amsterdam
Department of Spatial Economics
De Boelelaan 1105
1081 HV Amsterdam
pniijkamp@feweb.vu.nl

* Corresponding author

Abstract

The rate of innovation is the result of profit-maximizing choices of economic agents, rather than merely an exogenous technological phenomenon with productivity levels and growth rates converging over time. Due to this, permanent differences in productivity levels and growth rates are possible, and, more importantly, productivity levels and growth rates can be influenced by public or private agents. Investments in private and public R&D are nowadays believed to make up the heart of a modern knowledge society. Education, training, learning and research are activities that are the responsibility of many stakeholders. According to much empirical research, most societies tend to underinvest in research and development (R&D). The aim of the paper is to find further evidence for the influence of R&D expenditures on innovation performance in 27 EU countries. We do this by applying rough set analysis, which is used in the light of the incomplete knowledge, the management of inconsistent pieces of information and the manipulations of various levels of representation of data that the analysis of data of the European Innovation Scoreboard (EIS) is often concerned with. Rough set analysis, primarily used to explore qualitative data, proves a promising tool in order to explore the quantitative data of the EIS and identify broad underlying relations between variables used. Our findings, then, show an important relation between public R&D expenditures and countries with lower innovation performance, but we also find support for the strong positive relation between business R&D expenditures and countries with higher levels of innovation performance. Besides, there seems a considerable influence of education on innovation, which may very well be related to the growing service sectors in Europe.

Key words: innovation, R&D expenditures, knowledge economy, services sector, rough set analysis, MCA

1. Introduction

The largest part of worldwide growth and development over the past ten years has been associated with an acceleration in the diffusion of technological change and world wide access to codified knowledge. The growth externalities of knowledge appear connected to the rapid post war growth of the OECD countries. First, there was a technological and consumption catching up of the European countries and Japan. Subsequently, the newly industrializing South East Asian economies started catching up. And in the late 1990s, there was the world integration of the large emerging economies such as Brazil, Russia, India and China (the BRICs). In many industrial sectors ranging from chemicals to motor vehicles, semiconductors and electronic consumer goods, technological improvements appear to proceed along clear agreed-upon criteria and a continuous ability to evaluate progress. The more recent mode of technological progress is associated more with knowledge service activities with as extreme examples the continuous attempts at ICT-based efficiency improvements in e.g. the financial and insurance sectors, the wholesale and retail sectors, health, education, government services, business management and administration. This form of technological progress seems more based on flexibility. Learning from previous experiences or from other sectors is difficult and sometimes even misleading. Evaluation is difficult because of changing external environments: over time, among sectors, across locations. This has given rise to the idea that not the impact of the transfer of industrial technologies on economic development should be at the centre of the debate nowadays, but rather the broader organizational, economic and social embedding of such technologies in a development environment and the way they unleash or block particular specific development and growth opportunities.

Knowledge-based economies can be defined as economies that have a high share of knowledge-intensive jobs; where information sectors are a prerequisite to the functioning of the economy; and intangible capital is dominant of physical capital (Foray, 2004). Research and development (R&D) plays a crucial role in the technological development and economic competitiveness of a country (Rosenberg and Birdzell, 1990; Fagerberg, 1994; Tijssen, 2002). Generally, industry-funded R&D is considered most significant for innovation, with government-funded R&D making a smaller contribution. Public R&D has, more than private R&D, however, benefits accruing to society like skill development, generation of new knowledge, new scientific instruments, methodologies, creation of new products, companies, and improved processes (Salter and Martin, 2001). There are many challenges in assessing R&D impacts related to causality, attribution, internationality, evaluation of time scale and definition of appropriate indicators. Also, although many micro-econometric and macro-econometric analyses exist of spillovers and social rate of return measuring the positive effects of R&D investments on productivity gains and analysing systemic effects in the economy, overall these studies say little about the innovation process or non-economic impacts of public R&D. The focus of the present paper will be on the role of R&D expenditures on innovation performance in the 27 EU member states. The causality problem will hereby be central, i.e. what is the relationship between research inputs, outputs, outcomes and impacts of innovation performance? The problem of definition of appropriate indicators will consequently also be discussed. Aim of this paper is to gain insight into the levels of influence of different forms of R&D expenditure on innovation performance in the EU-27 by means of a quantitative rough set analysis and MCA-modelling, hereby finding support for the hypothesis that public R&D expenditures have a different effect in terms of innovation generation than private R&D expenditures.

A rough set analysis of a specific set of indicators of the European Innovation Scoreboard (EIS, 2007) will be applied for our explanatory empirical work. After a concise overview of the most important findings in the recent innovation literature, the methodology used in this paper will be further analysed by means of a description the European Innovation Scoreboard (EIS, 2007) and its most relevant input

and output factors. A special focus will in this respect be on R&D expenditures in both a public and private setting. On the basis of this theoretical part, several testable hypotheses will be formulated with regards to R&D expenditures and innovation and economic development. The conclusion will reflect upon the findings of our qualitative empirical study and will suggest policy and research directions.

2. R&D, innovation and economic growth

It is widely accepted that technology and technological advances are a key component of innovation and economic growth (see for example Grossman and Helpman, 1994). The relationship between R&D investment, technological potential, innovation and growth is receiving increasing attention from researchers and policy makers, because it seems to show the path towards economic growth in any given region. R&D investment increases the possibility of achieving a higher standard of technology in firms and regions, which would allow them to introduce new and superior products and/or processes, resulting in higher levels of income and growth (Bilbao-Osorio and Rodriguez-Pose, 2004). Equally, Romer (1990) and Lichtenberg (1992) have shown the relationship between investment in technology and R&D expenditures and increases in productivity and growth. There is less of a consensus, however, regarding the capacity of different countries to profit from technology and investments in R&D. The increasing evidence of the persistence of regional disparities in the EU has provided the bases for a growing number of studies on the factors that cause this lack of convergence.

The boom of the high-tech sector in the last decade is perceived to be large due to government R&D and innovation policies (Trajtenberg, 2002). In the literature, however, especially in innovation-augmented growth accounting studies, industry-funded R&D expenditure is usually found to be most significant for innovation. Public-sector R&D is often directed at making improvements in areas not directly related to growth, such as defence and medical research, which could diffuse and slow down impact on output growth (see OECD, 1998). These considerations suggest that any quantitative analysis of growth must take R&D activity into account as an additional form of investment and differentiate between various types of R&D expenditures. Government support of R&D is supported by the idea that some form of market failure exists that leads the private sector to under invest in R&D (Arrow, 1962). Underinvestment in R&D occurs because the social benefits from new technologies are difficult to appropriate by the private firms bearing the costs of their discovery, and because imperfect capital markets may inhibit firms from investing in socially valuable R&D projects (Griliches, 1998; Romer, 1990). For measuring the impact of R&D, a distinction between private and public sector R&D expenditure, in the form of industry, higher education or government, is therefore necessary.

When looking at EU countries, overall expenditure on R&D as a share of GDP has risen since the mid-1990s (see Table 1), mainly reflecting increases in R&D activity in the business sector and higher education that accounts for the majority of expenditure in this area in most EU member countries. With 3.73 and 3.45 % of GDP in 2006, respectively, Sweden and Finland invest most in technology. They are also among the 'traditional' EU member states with the highest growth rates in 2006, together with Ireland and Luxembourg. Between 1998 and 2006 the 'size' of the public sector decreased slightly in approximately half of the EU member states. Changes in military R&D budgets are often considered to have a considerable influence on the share of publicly financed R&D, although defence and space R&D is often thought to be less economically productive than government supported R&D that supports consumer-oriented industries, such as health care or pollution abatement. It seems plausible that there is some spillover effect of defence research to consumer-oriented industries, but the sensitivity of the information may hamper spillover. Variations in severity of state security in countries may lead to further country differences. With regards to the 9/11 attacks, the participation of countries in military activities may also cause differences in expenditures. Real GDP growth rates show that economic growth

experienced a decrease in 2001 after which rates started to rise again, hereby generally increasing 1998 growth rates. Further, in Table 1, in particular, there appears to be a general rise in R&D expenditures on higher education, apart from the Netherlands and Poland. These countries also experienced a decline in business R&D together with Belgium, France, Romania, Slovakia and the UK.

Table 1 Research and development expenditures by sector as a share of total spending in EU member states, 1998, 2002 and 2006 (% of GDP)

	A Business		B Government		C Higher education		A+B+C		Real GDP growth rate (% change previous year)		
	1998	2006	1998	2006	1998	2006	1998	2006	1998	2002	2006
Austria	1.12	1.66	0.11	0.13	0.52	0.65	1.77	2.49	3.6	1.6	3.4
Belgium	1.32	1.24	0.11	0.16	0.4	0.41	1.86	1.83	1.7	1.5	2.8
Bulgaria	0.11	0.12	0.43	0.31	0.03	0.05	0.57	0.48	4.0	4.5	6.3
Cyprus	0.03	0.09	0.12	0.12	0.05	0.18	0.22	0.42	5.0	2.1	4.0
Czech Republic	0.74	1.02	0.29	0.27	0.11	0.25	1.15	1.54	-0.8	1.9	6.8
Denmark	1.32	1.62	0.29	0.16	0.41	0.63	2.04	2.43	2.2	0.5	3.9
Estonia	0.11	0.51	0.14	0.15	0.32	0.46	0.57	1.14	5.4	8.0	11.2
Finland	1.92	2.46	0.36	0.32	0.56	0.65	2.86	3.45	5.2	1.6	4.9
France	1.33	1.32	0.4	0.36	0.38	0.38	2.14	2.09	3.5	1.0	2.2
Germany	1.54	1.77	0.33	0.35	0.4	0.41	2.27	2.53	2.0	0.0	2.9
Greece	0.12(a)	0.17	0.11(a)	0.12	0.23(a)	0.27	0.45(a)	0.57	3.4	3.9	4.2
Hungary	0.26	0.48	0.18	0.25	0.17	0.24	0.68	1	4.8	4.4	3.9
Ireland	0.89	0.89	0.11	0.09	0.26	0.34	1.24	1.32	8.0	6.6	5.7
Italy	0.51	0.54	0.21	0.19	0.33	0.33(b)	1.05	1.09(b)	1.4	0.5	1.8
Latvia	0.08	0.35	0.13	0.11	0.19	0.24	0.4	0.7	4.7	6.5	12.2
Lithuania	0.01	0.22	0.32	0.18	0.21	0.4	0.55	0.81	7.5	6.9	7.7
Luxembourg	:	1.25	:	0.19	:	0.04	:	1.47	6.5	4.1	6.1
Malta	:	0.34	:	0.03	:	0.18	:	0.54	:	2.6	3.4
Netherlands	1.03	0.96	0.34	0.24	0.51	0.49(c)	1.9	1.67	3.9	0.1	3.0
Poland	0.28	0.18	0.21	0.21	0.18	0.17	0.67	0.56	5.0	1.4	6.2
Portugal	0.15	0.35	0.17	0.12(b)	0.26	0.29(b)	0.65	0.83	4.9	0.8	1.3
Romania	0.38	0.22	0.09	0.15	0.02	0.08	0.49	0.45	:	5.1	7.9
Slovakia	0.51	0.21	0.19	0.16	0.07	0.12	0.78	0.49	4.4	4.8	8.5
Slovenia	0.71	0.96	0.41	0.39	0.23	0.24	1.36	1.59	3.6	3.7	5.7
Spain	0.46	0.67	0.15	0.2	0.27	0.33	0.87	1.2	4.5	2.7	3.9
Sweden	2.6(a)	2.79	0.12(a)	0.17	0.74(a)	0.76	3.55	3.73	3.8	2.4	4.1
United Kingdom	1.17	1.1	0.24	0.18	0.35	0.46	1.79	1.78	3.4	2.1	2.9

Source: Eurostat

(a) 1997 instead of 1998

(b) 2005 instead of 2006

(c) 2003

(:) Not available

When looking at the expenditures on R&D in Europe in 2006 in more detail, Table 2 shows that business-financed R&D has the prevailing impact on output in most EU countries. Overall, though, the share of total government expenditure in GERD was still in the range of 40-50 per cent in the EU. Most countries, it appears from Tables 1 and 2, still fall short of the R&D expenditure target set forth by the Lisbon Strategy for Growth and Jobs (2000), which requires an annual R&D expenditure of at least 3 percent of GDP of which a minimum of two-thirds should be generated by the business community. In 2006, only Finland and Sweden were able to meet the target, followed at a distance by Germany,

Austria, and Denmark. High-growth countries like Sweden and Finland traditionally outspend other EU member states on R&D expenditures performed by industry. In contrast, their government R&D expenditures are generally lower than most member state countries. Interestingly, their higher education expenditures are again amongst the highest in Europe. This implies that for high overall growth, not only high R&D expenditures and lower public R&D expenditures seems important, but also high expenditures on higher education. This may be related to a growing economic importance of services in Europe. Apparently, the relative economic contribution of knowledge-intensive services has been increasing over time, while that of manufacturing has been declining (Arundel et al., 2007).

Table 2 Main science and technology indicators

	Gross domestic expenditures on R&D 2006						Total researchers 2006
	Million current PPP€	% of GERD financed by		% performed by			All sectors
		Industry	Government	Industry	Higher Education	Government	
Austria	257 294.5	45.6	36	1.66	0.65	0.13	44 127(c)
Belgium	316 622.0	59.7(a)	24.7(a)	1.24	0.41	0.16	48 757(a)
Bulgaria	25 238.2	27.8(a)	63.9(a)	0.12	0.05	0.31	11 920(a)
Cyprus	14 630.9	16.8(a)	67(a)	0.09	0.18	0.12	1 424(a)
Czech Republic	113 458.5	56.9	39	1.02	0.25	0.27	39 676
Denmark	220 069.4	59.5(a)	27.6(a)	1.62	0.63	0.16	43 460(a)
Estonia	13 233.6	38.1	44.6	0.51	0.46	0.15	6 411
Finland	16 7041.0	66.6	25.1	2.46	0.65	0.32	53 273
France	180 7462.0	52.2(a)	38.4(a)	1.32	0.38	0.36	252 994(a)
Germany	2 322 200.0	67.6(a)	28.4(a)	1.77	0.41	0.35	411 784(a)
Greece	213 985.0	31.1(a)	46.8(a)	0.17	0.27	0.12	33 396(a)
Hungary	90 045.1	43.3	44.8	0.48	0.24	0.25	32 786
Ireland	174 705.0	59.3	30.1	0.89	0.34	0.09	18 589
Italy	1 479 981.1	39.7(a)	50.7(a)	0.54	0.33(a)	0.19	125 534(a)
Latvia	16 046.7	32.7	58.2	0.35	0.24	0.11	7 200
Lithuania	23 721.4	26.2	53.6	0.22	0.4	0.18	11 918(a)
Luxembourg	33 853.6	26.2	16.6(a)	1.25	0.04	0.19	2 443(a)
Malta	5 075.1	52.1	34.4	0.34	0.18	0.03	977
Netherlands	534 324.0	51.1(b)	36.2(b)	0.96	0.49(d)	0.24	49 831(a)
Poland	272 130.7	33.1	57.5	0.18	0.17	0.21	96 374
Portugal	155 322.6	36.3	55.2(a)	0.35	0.29(a)	0.12(a)	37 769(a)
Romania	97 718.4	30.4	64.1	0.22	0.08	0.15	30 122
Slovakia	44 571.4	35	55.6	0.21	0.12	0.16	18 816
Slovenia	30 453.9	59.3	34.4	0.96	0.24	0.39	8 213
Spain	980 954.0	47.1	42.5	0.67	0.33	0.2	193 024
Sweden	313 327.0	65.7	23.5(a)	2.79	0.76	0.17	82 496(a)
United Kingdom	1 912 656.0	45.2	31.9	1.1	0.46	0.18	:

Source: Eurostat

(a) 2005 instead of 2006

(b) 2003

(c) 2004

(:) Not available

While these statistics provide interesting cross-country insights, they give little guidance on the economic effect and desirable level of R&D. Given that the apparent returns to R&D to individual firms is

so large, why is not more R&D undertaken so that the return is driven down to its competitive level? Presumably, this is the result of the large degree of risk and uncertainty in the innovation process, as well as asymmetries in information between capital markets and R&D spenders. Private firms are unable to fully exploit the benefits of the scientific results of R&D investment since they cannot entirely protect their inventions from use by others. Competition in markets for high-tech products is fierce and near perfect. And gains from R&D are quickly transferred to consumers through lower product prices, leaving a smaller profit for firms. The amount of resources that are devoted to R&D can be influenced by government intervention. Due to spillover effects new ideas may not be fully beneficial to the innovators themselves. As a result, the private sector may engage in less R&D than what could be socially optimal. Government involvement in R&D, both through direct provisions and funding, but also through indirect measures such as tax incentives and protection of intellectual property rights to encourage private-sector R&D can therefore be justified (see for example, Nadiri, 1993 and Cameron, 1998).

This observation prompts a discussion on the role of governments. No country in history has succeeded in attaining a high level of economic prosperity without some form of government. The precise allocation of government spending depends on culture, political preferences and people's tastes, and leads to very different outcomes in each country (see Nijkamp and Poot, 2004). But applied research has shown that public expenditures for research and education are a critical factor of economic growth. Government intervention can have both a 'size' effect, as well as specific effects stemming from the financing and composition of public expenditures. At a conclusive level, the productive effects of public spending are likely to exceed the social costs of raising funds. Government expenditure and the required taxes may also reach levels where the negative effects on efficiency and growth start dominating. These negative effects may be more evident where the financing relies heavily on more 'distortionary' taxes (i.e., direct taxes) and where public expenditures focus on 'unproductive' activities. Expenditures on schooling, infrastructure and R&D are usually classified as directly 'productive' (see Barro, 1991). In this paper, we hope to gain more insight into the effect of public and private expenditures on innovation output, in particular human capital output which seems increasingly important for the European knowledge economy. We will start in the next paragraph by introducing our methodology.

3. Rough set analysis

3.1 Introduction

In the light of the above sketch, we now aim to clarify the relevance of different R&D expenditures for the innovation process in the EU-27, by addressing the following questions: 1) Have the R&D investments carried out by different sectors – private, public, and higher education – different impacts on innovation output in the form of employment in high-tech services and medium and high-tech manufacturing?, Which forms of expenditures influence differences in employment?, What is the role of the different factors in the overall innovation performance?; and 2) What may be the implications of this for innovation policies and future research? We apply here rough set analysis, which is a fairly recent classification method originating from the artificial intelligence literature, dealing with conditional statements of an 'if-then' nature (see Pawlak, 1991; Slowinski, 1993; Polkowski and Skowron, 1998). This analysis aims to identify under which conditions certain features (or attributes) are necessary to 'explain' the existence of a feature of the response variable (essentially, the endogenous variable). In general terms, a rough set is a set for which the classification of a group of certain objects is not entirely certain, as this depends on the classification boundaries of the objects. In our case, there

are different forms of expenditure (direct or indirect) on innovation, but we do not know exactly which particular expenditure is more effective and creates higher output. Of course, we have to assume that there is a finite set of objects to be classified (and that, as a result, other objects are excluded). Usually, rough set data analysis is used to perform a classification analysis on 'soft' categorical data distinguished according to various groupings derived from a data matrix or information table. However, in this case we have used 'hard' data derived from the EIS (2007); a database that focuses strongly on matters like knowledge creation and factors like public and business R&D expenditures. In the next section, we explain the characteristics of rough set analysis in more detail, as well as its apparent usefulness for exploring and categorizing data of the EIS. We will conclude this paragraph by outlining the specific framework and data used for our rough set analysis.

3.2 The European Innovation Scoreboard as a data source for rough set analysis

The EIS was developed at the request of the Lisbon European Council in 2000. The idea behind its creation is that innovation is a priority in all member states, and of the European Commission, but the framework conditions, cultural preferences and political priorities are often very diverse in the different member state countries. The European Commission has therefore been keen to develop a common and political framework for innovation policy in Europe (European Commission, 1996). The EIS is developed as a statistical report belonging to the all-encompassing *Trend Chart on Innovation in Europe*. The EIS focuses on high-tech innovation and provides indicators for tracking the EU's progress towards the Lisbon goal of becoming the most competitive and dynamic knowledge-based economy in the world within the next decade. The EIS complements the Enterprise Policy Scoreboard and other benchmarking exercises of the European Commission. Since the 2000 pilot report, seven full versions of the EIS have been published. Current and past versions of the EIS have continuously tried to improve measurement of innovation performance by countries, sectors and regions, reflecting changing perceptions and understanding of the innovation process. The list and number of indicators has undergone major changes over time (EIS, 2007). Also, although the EIS recognizes the growing role of services innovation, current statistics are still biased towards measuring technological innovation. Further, the EIS provides a composite index, the Summary Innovation Index, which summarizes innovation performance by aggregating the various indicators for each country in one single number. While this is useful in their ability to integrate large amounts of information, results strongly depend on the choice of indicators and weighting schemes and can lead to misleading information (see Freudenberg, 2003; Grupp and Moguee, 2004). For example, the SII transforms each indicator on a relative basis, i.e. each indicator is measured relative to the best and worst performing country, and, as a result, some of the indicators are highly skewed, e.g. patent applications.

The methodology that is used for the EIS has changed considerably over the years of its existence, which supports the representation of innovation as a complex phenomenon where firms can use different models of innovation. EIS broadly focuses on three innovation models. Science-based innovation, which has been used by certain industries and large firms for a long time, lies at the basis of the EIS. Here, innovation and technological progress is driven by firms by their new scientific discoveries. Secondly, the model of user innovation in which consumers and end users are considered to develop the innovations, is considered important. More recently, the model of open innovation has emerged as an important new trend: companies can no longer rely on their own research but must instead combine own ideas and research with external research, e.g. by buying licenses and other external knowledge. However, at the moment, many of the current EIS indicators are better suited to capture science-based innovation. Comparing innovation performance across member states is essential, because it helps uncover the different framework conditions, cultural preferences and political priorities of the EU

countries. One needs to take into account that countries differ in their state of economic development, in their industrial specialization patterns and in their need for innovation driving their current and future well-being. Not all countries would benefit from the heavy investment in innovation as some of the innovation leaders; other strategies for improving economic well-being may be more realistic for those countries. It is therefore important that differences in the industrial structure between countries would be taken better into account. Also, on an analytical level, comparability issues easily arise within the EU due to differences between member states in methodologies or sampling methods for collecting their data. Some of the EIS indicators are subject to national contexts (e.g. what constitutes tertiary education) which makes cross country comparisons difficult.

The EIS database has accumulated considerable quantities of information about innovation indicators. Relationships and patterns within these data could provide new knowledge about innovation performance (Zhong and Skowron, 2001; Cios et al. 1998). Analysis of EIS data, however, is often concerned with incomplete knowledge, with management of inconsistent pieces of information and with manipulation of various levels of representation of data. Rough set analysis may therefore be a useful alternative tool for analyzing the data of the EIS. Rough set theory, namely, provides a formal tool for the classification of a set of objects, in this case EU countries, into predefined homogenous groups. It is a fairly new intelligent technique that is being used for the extraction of rules from databases in the form of readable if-then rules. Such rules have a potential to reveal new patterns in the data material. Existing intelligent techniques of data analysis are mainly based on quite strong assumptions (some knowledge about dependencies, probability distributions, large number of experiments), that are unable to derive conclusions from incomplete knowledge or cannot manage inconsistent pieces of information (Ella Hassanien et al., 2007). The main advantage of rough set theory is that it does not need any preliminary or additional information about data (like probability in statistics, basic probability in Dempster-Shafer theory, grade of membership, or the value of possibility in fuzzy set theory). Another advantage is that inconsistencies in the database are not corrected; instead, produced classification rules are categorized into certain and possible (Slowinski, 1992).

In this paper, the rough set approach is used to provide a set of rules able to discriminate between highly innovative, innovative and hardly innovative EU countries in order to predict what input and output factors influence innovation performance at different levels of innovation performance. In the literature, innovation is often related to the concept of productivity. Most econometric studies based on aggregate or industry level data report a large, positive and significant effect of R&D on productivity (see, for instance, Guellec and Van Pottelsberghe, 2001, for recent estimates on a panel of OECD countries). Increasing R&D intensity is therefore also a focus point of the Lisbon strategy and the Barcelona target, and many countries have taken steps to increase their innovation efforts. In a recent study on innovation efficiency by Hollanders and Celikel Esser (2007), the idea is supported that higher productivity is achieved when more innovation outputs are produced with the same amount of inputs or when the same output is produced with less input. As a result, they believe it worthwhile to examine differences in innovation efficiency by assuming that efficiency can be defined as the ratio of outputs over inputs, even though innovation is not a linear process where inputs automatically transfer into outputs. In our study, we take a similar approach insofar that we investigate efficiencies between innovation inputs and outputs of the different countries of the EIS, while at the same time we evaluate how EU countries are classified on the basis of innovation input and output of the EIS and how this can predict innovation performance.

3.3 Practical application of the data in the rough set analysis

The rough set scheme consists of two stages here: preprocessing and processing (Ella Hassanien et al., 2008). The preprocessing stage includes tasks such as data cleaning, completeness, correctness, attribute creation, attribute selection and discretization. Processing includes the generation of preliminary knowledge, such as the computation of object reducts from data, derivation of rules from reducts, and classification processes. These stages lead towards the final goal of generating rules from information or decision system of the innovation database (see also Pawlak, 1982, 1991; and Komorowski et al., 1999). In rough set theory, the data is collected in a table, called a decision table. Rows of a decision table correspond to objects, and columns correspond to features. In the data set, we assume that a set of examples with a class label to indicate the class to which each example belongs are given. The class label is called a decision feature, the rest of the features are conditional. An important task of the rough set analysis is the discovery of classification rules from the data provided in the decision tables, with rules representing dependencies in the dataset, and representing extracted knowledge which can be used when classifying new objects not in the original information system. In this case, the discovery of relevant subsets of innovation characteristics is our main goal, together with a representation of all important relationships between the structure of a country and its level of innovativeness.

The scoreboard calculates overall innovation performance on the basis of 25 indicators covering five dimensions of innovation. For our first rough set analyses, we have used a selection of input and output indicators, and for our second analysis we have focused especially on the dimensions of the scoreboard (see Table 3). This set of rough set analyses focus on the relation between innovation input indicators in the field of expenditures and the innovation output indicators employment in high-tech services and medium-tech and high-tech manufacturing. R&D expenditures, in principle, say nothing about the output side of the innovation process (Kleinknecht et al., 2001). By analysing its relation towards employment, however, we hope to get some further insight into the working of R&D on innovation output. As R&D is only one out of several inputs, we have also included indicators as S&E graduates, population with tertiary education ICT expenditures on a firm level and innovation on a firm level in the model. The decision for especially the latter set of indicators is based on our choice for human capital output factors, which, in turn, stems from the idea that in Europe, nowadays, the production and diffusion of knowledge are central, and closely connected to the development of human capital through education, skills and on-the-job training. As a factor of production, then, the stock of human capital has been estimated to be up to three times as large as the stock of physical capital in an economy (Davies et al., 1989). Of course, these indicators give only insight into a specific sub section of innovation performance. In order to also form a picture of the overall innovation performance, and to find out whether the results of the different analyses show similarities, we also estimate overall innovation performance by showing the relation of the five dimensions of the scoreboard (see Table 3) towards overall innovation performance presented in the form of the Summary Innovation Index (SII), which is a composite indicator of the 25 measures calculated per country.

Table 3 Overview of European Innovation Scoreboard dimensions and indicators used for our rough set analysis

European Innovation Scoreboard (2007)	1st RSA	2nd RSA
INPUT – Innovation Drivers		*
S&E graduates (per 1000 population aged 25-64)	*	
Population with tertiary education (per 100 population aged 25-64)	*	
Broadband penetration rate (number of broadband lines per 100 population)		
Participation in life-long learning (per 100 population aged 25-64)		
Youth education attainment level (% aged 20-24 with at least upper secondary education)		
INPUT-Knowledge Creation		*
Public R&D expenditures (% of GDP)	*	
Business R&D expenditures (% of GDP)	*	

Share of medium-high-tech and high-tech R&D (% of manufacturing R&D expenditure)		
Share of enterprises receiving public funding for innovation (Community Innovation Survey)		
INPUT – Innovation & Entrepreneurship		*
SMEs innovating in-house (% of SMEs)		
Innovative SMEs co-operating with others (% of SMEs)		
Innovation expenditures (% of turnover)	*	
Early stage venture capital (% of GDP)		
ICT expenditures (% of GDP)	*	
SMEs using organizational innovation (% of SMEs)		
OUTPUT – Applications		*
Employment in high-tech services (% of total workforce)	*	
Exports of high technology products as a share of total exports		
Sales of new-to-market products (% of turnover)		
Sales of new-to-firm products (% of turnover)		
Employment in medium-high and high-tech manufacturing (% of total workforce)	*	
OUTPUT – Intellectual Property		*
EPO patents per million population		
USPTO patents per million population		
Triad patents per million population		
Community trademarks per million population		
Community industrial designs per million population		

As a result, this rough set analysis may be interpreted as a quantitative exploratory correlation analysis for small samples. It is similar to qualitative methods in its pursuit to evaluate the importance of attributes for a classification of objects, reduce all superfluous objects and attributes, discover the most significant relationships between the condition attributes and object's assignment to decision classes, and represent these relationships in the form of decision rules (Slowinski and Stefanowski, 1993). Rough set analysis basically places objects into equivalence classes using available attributes that act as equivalence relationships for the objects considered. Objects in the same equivalence class are indiscernible (indistinguishable). A class that contains only indispensable equivalence relationships (attributes) is called a core. An attribute is indispensable if the classification of the objects becomes less precise when the attribute is left out. The values of the attributes of all objects may be subdivided into condition (background) and decision (response) attributes. In the following sub sections, rough set analysis will be put into practice. The reliability of the explanatory model used in a rough set context, then, can be judged by means of the so-called quality of classification. In the next paragraph, first, we conduct a rough set analysis on a specific sub set of innovation indicators, followed by an analysis of the innovation dimensions.

4. A meta-analysis of innovation output and performance

4.1 Rough set analysis of expenditures and employment

We will now present the results of applying the rough set methodology to the level of employment in the high-tech services and in medium-high/ high-tech manufacturing of 21 EU member states (Austria, Cyprus, Finland, Latvia, Slovenia and the United Kingdom were omitted due to missing data). Employment in the high-tech services and in medium-high/ high-tech manufacturing are innovation output indicators of the EIS and as such have been used as decision attributes to explain the value of the innovation input indicators that we have used for our condition attributes. Using the computer software programme ROSE, we find that there are 7 and 14 rules respectively for the level of employment in the high-tech services and in medium-high/ high-tech manufacturing and these are

concerned with the categories: (3) high, (2) medium and (1) low development, calculated per attribute based on an EU level (note: the categorization may be different for other regions or countries outside the EU). The condition attributes (essentially in economic term, the explanatory variables) that are selected for our empirical study are, viz.: A1) Public R&D expenditures; A2) Business R&D expenditures; A3) Innovation expenditures on a firm level; A4) ICT expenditures on a firm level; A5) Population with tertiary education; A6) S&E graduates.

Table 4 shows the influence of the condition attributes on the level of employment in the high-tech services. It is important to note here that there are some straightforward quality assessments based on the characteristics of the information table. In this case, both the accuracy and the quality of the rough set approximation equal 1, meaning that the reliability of the classification for the dependent variable and the overall quality are at their maximum. Not all condition variables, however, belong to the core. Only public R&D expenditures and tertiary education are assigned to the core with a quality of 0.476, meaning that these two condition attributes explain 47.6 % of the level of employment in the high-tech services. With regard to the EU countries that have been screened, it can be concluded that Romania's and Slovakia's low employment in high-tech services is caused by low public and business R&D expenditures and innovation expenditures. The coverage of this decision rule is 100%, which means that for both countries the rule is 100% true. Rule 2 and rule 5 also have a high coverage rate with respectively 69.23% and 66.67%, so in these countries the level of public and business R&D expenditure and, in the case of rule 5, tertiary education have a considerable influence (either negative or positive) on the level of employment in high-tech services.

Table 4 Rules based on the Rough Set Analysis

Conditions	Strength of rules	Number of countries*	Generalization
Rule 1. A1=1, A2=1, A3=2 / D=1	100%	2 (Romania, Slovakia)	IF public R&D expenditures = 0-0.33; business R&D expenditures = 0-0.80; and innovation expenditures = 0-1.14 THEN employment in high tech services = 0.1.82
Rule 2. A1=2, A2=1 / D=2	69.23%	9 (Bulgaria, Estonia, Greece, Hungary, Italy, Lithuania, Poland, Portugal, Spain)	IF public R&D expenditures = 0.34-0.66; business R&D expenditures = 0-0.80; innovation expenditures = 2.33-3.50; population with tertiary education = 13.33-26.66; and S&E graduates = 0-8.32 THEN employment in high tech services = 1.83-3.66
Rule 3. A6=1 / D=2	30.77%	4 (Czech Republic, Hungary, Luxembourg, Malta)	
Rule 4. A3=3, A5=2 / D=2	15.38%	2 (Germany, Greece)	
Rule 5. A2=2, A5=3 / D=3	66.67%	4 (Belgium, Denmark, Ireland, Netherlands)	
Rule 6. A2=3 / D=3	16.67%	1 (Sweden)	
Rule 7. A1=3, A6=3 / D=3	16.67%	1 (France)	
Rule 7. A1=3, A6=3 / D=3	16.67%	1 (France)	
Accuracy of classification	1.0000		
Quality of classification	1.0000		
Core set	A1 (public R&D expenditures), A5 (population with tertiary education)		
Quality of core	0.4762		
Strength of rules	Rule 1 (100%), including Romania and Slovakia Rule 2 (69.23%), including Bulgaria, Estonia, Greece, Hungary, Italy, Lithuania, Poland, Portugal, Spain Rule 5 (66.67%), including Belgium, Denmark, Ireland, Netherlands		

*N: 21

The individual country results are shown in more detail in Table 5. Romania and Slovakia have the lowest employment in high tech services, which seems in both cases caused by a combination of low public R&D expenditures, low business R&D expenditures, and medium innovation expenditures on a firm level. In Bulgaria, Czech Republic, Estonia, Germany, Greece, Hungary, Italy, Lithuania, Luxembourg, Malta, Poland, Portugal and Spain, employment in high-tech services is medium level, so between 1.83 and 3.66 % of total workforce. Especially medium public R&D expenditures and low business R&D expenditures seem to be of influence on the medium employment level. For Germany and Greece a high level of innovation expenditures is causing a medium level of employment in high tech services. Innovation expenditures in the firm, for example in the form of process innovations, could affect employment. For employment in high-tech services this will probably be a positive effect, since experts will be necessary in the area of, for example, information technology. On the long term, though, the effect may become negative, because less people will be necessary for the same job, especially if innovation expenditures on a firm level remain an exception rather than the rule in most firms. This may explain why Germany, which is at the top level of the medium employment group, and Greece, which is at the bottom of this same group, have similar scores, although Greece also has medium public R&D expenditures and low business R&D expenditures. Belgium, Denmark, France, Ireland, the Netherlands and Sweden, finally, are the countries with high employment in high-tech services. At least a medium level of business R&D, but with high business R&D as ideal level, and a high level of population with tertiary education seem of importance for gaining such a high level of employment in high-tech services. In this stadium, public R&D expenditures seem of less influence, although it positively affects employment in France together with S&E graduates. This may be caused by the large role of the public sector in general in France in comparison to the other countries with high employment, but this needs further researching.

Table 5 Summary of rough set results with decision variable: employment in high-tech services

	Public R&D expenditures	Business R&D expenditures	Innovation expenditures	ICT expenditures	Population with tertiary education	S&E graduates	Employment in high tech services
Belgium		0			+		+
Bulgaria	0	-					0
Czech Republic						-	0
Denmark		0			+		+
Estonia	0	-					0
France	+					+	+
Germany			+		0		0
Greece	0	-	+		0		0
Hungary	0	0				-	0
Ireland		0			+		+
Italy	0	0					0
Lithuania	0	-					0
Luxembourg						-	0
Malta						-	0
Netherlands		0			+		+
Poland	0	-					0
Portugal	0	-					0
Romania	-	-	0				-
Slovakia	-	-	0				-
Spain	0	-					0
Sweden		+					+

- (low development); 0 (medium development); + (high development)

In Table 6, the level of employment in medium-high and high-tech manufacturing is used as decision attribute. Here, the accuracy varies between 0.714 and 1, while the quality of the rough set approximation is 0.9048, meaning that the reliability of the classification for the dependent variable and the overall quality are not at all times at their maximum. The 21 cases are not totally distinguishable. Further, in this case, public R&D expenditures, innovation expenditures and tertiary education are assigned to the core with a quality of 0.524, meaning that these three condition attributes explain 52.4 % of the level of employment in the high-tech services. When looking at the outcomes of this rough set estimation in Table 6, for employment in medium-tech and high-tech manufacturing, the outcomes of the rough set analysis seem far less conclusive. Public and business R&D expenditures again seem of relative importance for employment in medium-tech/high-tech manufacturing, as well as innovation expenditures by companies. Education seems of less importance here, and may even have a negative influence. In medium-tech/high-tech manufacturing, especially new EU member states do relatively well. This implies that other factors are more important here that have not been addressed, like e.g. 'cheap workforce'. High coverage rules for employment in the medium-tech and high-tech manufacturing are rules 7, 9 and 12 and focus especially on expenditures on innovation and public R&D, tertiary education and S&E graduates.

Table 6 Rules based on the Rough Set Analysis

Conditions	Strength of rules	Number of countries*	Generalization
Rule 1. A4=2, A5=3, A6=3 / D=1	16.67%	1 (Lithuania)	IF public R&D expenditures = 0-0.33, 0.34-0.66 or 0.67-1; business R&D expenditures = 0-0.8 or 0.9-1.9; innovation expenditures = 1.15-2.32 or 2.33-3.5; ICT expenditures = 5.9-7.9 or 8-10; tertiary education = 26.67-40; and S&E graduates = 16.67-25 THEN employment in manufacturing = 0-4.14
Rule 2. A1=1, A2=2 / D=1	16.67%	1 (Luxembourg)	
Rule 3. A1=3, A3=2, A5=3 / D=1	16.67%	1 (Netherlands)	
Rule 4. A2=1, A3=3 / D=1	16.67%	1 (Greece)	
Rule 5. A1=2, A4=3, A5=3 / D=1	16.67%	1 (Estonia)	
Rule 6. A3=3, A5=3 / D=2	18.18%	2 (Denmark, Sweden)	IF public R&D = 0.34-0.66; business R&D = 0.9-1.9; innovation expenditures = 0-1.14 or 2.33-3.5; tertiary education = 26.67-40; and S&E graduates = 8.33-12.5 THEN employment in manufacturing = 4.15-8.32
Rule 7. A3=1 / D=2	27.27%	3 (Bulgaria, Malta, Spain)	
Rule 8. A2=2, A6=3 / D=2	18.18%	2 (France, Ireland)	
Rule 9. A5=1 / D=2	27.27%	3 (Italy, Malta, Romania)	
Rule 10. A1=2, A2=2, A5=3 / D=2	18.18%	2 (Belgium, Ireland)	
Rule 11. A2=2, A3=3, A5=2 / D=3	25.00%	1 (Germany)	IF public R&D = 0-0.33, 0.34-0.66 or 0.34-0.66; business R&D = 0-0.8 or 0.9-1.9; innovation expenditures = 2.33-3.5; ICT expenditures = 5.9-7.9; tertiary education = 13.33-26.66; and S&E graduates = 0-8.32 THEN employment in manufacturing = 8.33-12.5
Rule 12. A1=2, A6=1 / D=3	50.00%	2 (Czech Republic, Hungary)	
Rule 13. A1=1, A2=1, A4=2 / D=3	25.00%	1 (Slovakia)	
Approximate rules			
Rule 14. A1=2, A2=1, A4=2, A5=2 / D=1 OR D=2	100.00%	2 (Portugal (-), Poland (0))	IF public R&D = 0.34-0.66; business R&D = 0-0.8; ICT expenditures = 5.9-7.9; and tertiary education = 13.33-26.66 THEN employment in manufacturing = 0-4.14 or 4.15-8.32
Accuracy of classification	between 0.7143 and 1.0000		

Quality of classification	0.9048
Core set	A1 (public R&D expenditures), A3 (innovation expenditure), A5 (tertiary education)
Quality of core	0.5238
Strength of rules	Rule 7 (27.27%), including Bulgaria, Malta, Spain Rule 9 (27.27%), including Italy, Malta, Romania Rule 12 (50.00%), including Czech Republic, Hungary

*N: 21

When looking at the country results in more detail again (Table 7), we see that Estonia, Greece, Lithuania, Luxembourg, the Netherlands, and Portugal have the lowest employment in medium-tech and high-tech manufacturing. There seems no clear explanation for this low employment, because attributes differ per country. Only a high level of population with tertiary education is relevant for three countries, Estonia, Lithuania and the Netherlands, but in the case of Portugal, a medium level of population with tertiary education is causing a low level of employment. The latter situation seems a most logical overall explanation of low employment; although for employment in manufacturing (preferably cheap) low skilled workforce is generally considered an important asset. In that case, population with tertiary education can have a negative effect. Further, public R&D expenditures seem to negatively affect employment in manufacturing, but it is unclear to what extent. Both Estonia and Portugal suffer from medium public R&D expenditures, whereas for Luxembourg low expenditures seems to have a negative effect and for the Netherlands high public R&D expenditures. For high employment in manufacturing it seems nevertheless that public R&D expenditures should be kept at least medium, but preferably low as the results of Czech Republic, Hungary and Slovakia show. These are all relatively new member states with an often greater pool of 'cheap workforce' than the more traditional EU member states, so conclusions should not be too easily drawn. When looking at the results of Germany, though, the focus on, in this case, business R&D expenditures over public R&D expenditures seems supported, especially since further results of Germany show the importance of high innovation expenditures on a firm level. An explanation for these results is that in the manufacturing sector human capital is needed for the processing of innovations, whereas in the services sector (skilled) human capital is innovation. Each form of employment therefore requires different investments, which is again different on a country level due to differences in culture and development.

Table 7 Summary of rough set results with decision variable: employment in medium-tech/high-tech manufacturing

	Public R&D expenditures	Business R&D expenditures	Innovation expenditures	ICT expenditures	Population with tertiary education	S&E graduates	Employment medium and high-tech manufacturing
Belgium	0	0			+		0
Bulgaria			-				0
Czech Republic	0					-	+
Denmark			+		+		0
Estonia	0			+	+		-
France		0				+	0
Germany		0	+		0		+
Greece		-	+				-
Hungary	0					-	+
Ireland	0	0			+	+	0
Italy					-		0
Lithuania				0	+	+	-
Luxembourg	-	0					-
Malta			-		-		0
Netherlands	+		0		+		-
Poland	0	-		0	0		0
Portugal	0	-		0	0		-
Romania					-		0
Slovakia	-	-		0			+

Spain			-					0
Sweden			+		+			0

- (low development); 0 (medium development); + (high development)

Finally, the relative importance of the attributes can be investigated by dropping them one at the time from the core. The lower rows in Table 8 show the number of countries and the quality (percentage) of classifications whenever an attribute is excluded. The 5th line from above indicates that when the attribute public R&D expenditures is excluded, the quality of the classification is lowest; then, only 85.7% of the countries can be classified on the basis of employment in the high-tech services and 66.7% on employment in medium-tech and high-tech manufacturing. Table 8 also shows that public R&D expenditures and tertiary education are indispensable for both employment in high-tech services, and in medium-tech and high-tech manufacturing. For employment in manufacturing, business innovation expenditures are also of considerable importance. These results support our previous findings about what attributes can be assigned to the core. Further, it shows that within these cores the attribute public R&D expenditures has the highest explanatory quality, i.e. explains the level of employment for the largest number of countries. So, public R&D expenditures have the highest influence on employment in both high-tech services and medium-tech and high-tech manufacturing. In the case of high-tech services the results are most straight-forward, with low public R&D expenditures being associated with low employment, medium expenditures with medium employment and high expenditures with high employment. For employment in manufacturing, outcomes are less obvious, although high public R&D expenditures are not to be preferred in order to achieve high employment in manufacturing. Rather the medium-tech and high-tech manufacturing sector should focus on innovation expenditures on a firm level. Finally, population with tertiary education seem to have an overall positive effect on employment in high-tech services, but far less so on employment in manufacturing.

Table 8 Lower approximation for rough set classes

N=21	Employment in high-tech services			Quality of classifications	Employment in med-tech/high-tech manufacturing			Quality of classifications
	low	medium	high		low	medium	high	
With core attributes	2	15	6	1.000	5(1)	12(1)	4	0.905
With a temporarily reduced condition attribute								
Public R&D expenditures	1(1)	15(2)	7	0.857	3(3)	10(2)	2(2)	0.667
Business R&D expenditures	2	19	9	1.000	5(1)	12(1)	4	0.905
Innovation expenditures	2	14	6	1.000	4(2)	11(2)	4	0.810
ICT expenditures	2	15	6	1.000	5(1)	12(1)	4	0.905
Tertiary education	2	13(1)	5(1)	0.905	5(1)	11(2)	3(1)	0.810
S&E graduates	2	21	7	1.000	5(1)	11(1)	4	0.905

() Approximate rules

4.3 Rough set analysis of innovation performance

We are further curious what the role of these different factors is in the innovation process as a whole. For measuring the overall innovation performance, we base ourselves on the five dimensions of innovation of the EIS (see Table 3). Overall innovation performance is here calculated on the basis of 25 indicators covering the five dimensions of innovation: A1) Innovation drivers (measure the structural conditions required for innovation potential); A2) Knowledge creation (measures the investments in R&D activities); A3) Innovation & Entrepreneurship (measures the efforts towards innovation at the firm level); A4) Applications (measures the performance expressed in terms of labour and business activities

and their value added in innovative sectors); A5) Intellectual property (measures the achieved results in terms of successful know-how).

We will now present the results of applying the rough set methodology to the degree of innovativeness (based on the 2007 Summary Innovation Index) of 26 EU member states (Slovenia was omitted due to missing data). There are 7 rules and these are concerned with the categories: (5) high degree of innovativeness between 1.00 and 0.81, (4) a medium-high level of innovativeness between 0.80-0.61, (3) a medium level of innovativeness between 0.60-0.41, (2) a medium-low level of innovativeness between 0.40-0.21, and (1) a low level of innovativeness between 0.20-0.00. Due to the high degree of comparability of re-scaled scores, we have used a five-point-scale here. This will further improve accuracy of the results. Here, like in Table 4, the accuracy and the quality of the rough set approximation equal 1, meaning that the reliability of the classification for the dependent variable and the overall quality are at their maximum (see Table 9). The dimensions 'innovation drivers' and 'knowledge creation' are assigned to the core with a quality of 0.808, meaning that these two condition attributes explain 80.8 % of the level of overall innovation performance in the EU, which is considerable. In this analysis, especially the coverage rates of rules 1, 2 and 10 stand out (see Table 9). The dimensions innovation drivers, knowledge creation and innovation & entrepreneurship, i.e. innovation input, seems especially important for countries with low or medium-low innovation performance, whereas applications and intellectual property, i.e. innovation output, seems particularly of influence for countries with a high innovation performance.

Table 9 Rules overall innovation performance based on the Rough Set Analysis

Conditions	Strength of rules	Number of countries**	Generalization*
Rule 1. A1=2,A2=1,A3=2 / D1	100%	2 (Latvia, Romania)	IF Innovation drivers = 0.21-0.40; Knowledge creation = 0.00-0.20; and Innovation & entrepreneurship = 0.21-0.40 THEN overall innovation performance=0,00-0,20
Rule 2.A2=2 / D2	53.85%	7 (Bulgaria, Cyprus, Czech Republic, Greece, Hungary, Poland, Spain)	IF Innovation drivers = 0,00-0,20 or 0,41-0,60; Knowledge creation = 0,21-0,40; Innovation & entrepreneurship = 0,00-0,20 or 0,21-0,40; and Intellectual property = 0,00-0,21 or 0,21-0,40 THEN overall innovation performance = 0,21-0,40
Rule 3. A1=3, A5=1 / D2	23.08%	3 (Estonia, Lithuania, Spain)	
Rule 4. A1=1 / D2	15.38%	2 (Malta, Portugal)	
Rule 5. A3=1 / D2	7.69%	1 (Slovakia)	
Rule 6. A3=2, A5=2 / D2	7.69%	1 (Italy)	
Rule 7. A4=3, A5=2 / D3	50.00%	4 (Belgium, France, Ireland, UK)	IF Applications = 0,21-0,40 or 0,41-0,60; and Intellectual property = 0,21-0,40 or 0,41-0,60 or 0,61-0,80 THEN overall innovation performance 0,41-0,60
Rule 8. A4=2, A5=3 / D3	25.00%	2 (Austria, Netherlands)	
Rule 9. A5=4 / D=3	25.00%	2 (Germany, Luxembourg)	
Rule 10. A4=3, A5=3/ D4	100.00%	3 (Denmark, Finland, Sweden)	IF Applications = 0,41-0,60; and Intellectual property = 0,41-0,60 THEN overall innovation = 0,61-0,80
Accuracy of classification	1.0000		
Quality of classification	1.0000		
Core set	A1 (Innovation drivers), A2 (Knowledge creation)		
Quality of core	0.8077		
Strength of rules	Rule 1 (100%), including Latvia, Romania Rule 2 (53.85%), including Bulgaria, Cyprus, Czech Republic, Greece, Hungary, Poland, Spain Rule 10 (100%), including Denmark, Finland, Sweden		

** For calculating the dimensions, the indicator data of the EIS are re-scaled (see <http://www.proinno-europe.eu/> for more detail). The maximum re-scaled score is equal to 1 and the minimum value is equal to 0.

*N=26

When looking at the individual country results in Table 10, what becomes apparent is that especially a low to medium level of innovation drivers, as well as a low to medium-low level of knowledge creation has a negative effect on innovation performance, as we can see for the countries Latvia and Romania (low innovation performance between 0-0.20) and Bulgaria, Cyprus, Czech Republic, Estonia, Greece, Hungary, Italy, Lithuania, Malta, Poland, Portugal, Slovakia, and Spain (medium-low level between 0.21-0.40). This supports the findings of our previous rough set analysis, insofar that indicators like public R&D expenditures and tertiary education influence innovation output. Innovation output indicators applications and intellectual property, in turn, seem to be especially influential for countries with a medium to medium-high level of innovation performance. Austria, Belgium, France, Germany, Ireland, Luxembourg, the Netherlands and the UK seem to owe their medium innovation performance to either a medium level of applications in combination with a medium-low level of intellectual property and vice versa. The medium-high growth innovation countries, i.e. Denmark, Finland and Sweden, on the other hand, have a medium level for their output dimensions, so both applications and intellectual property. This implies that in order to achieve a high level of innovation performance especially a combination of both medium-high to high innovation output is important. To achieve a medium level of innovation performance, though, first the structural conditions, i.e. innovation drivers, and the investments, i.e. knowledge creation, should be in order. An implication of this result is that overall innovation performance, like economic growth (see for example Rostow, 1960), may very well be taking place in stages.

Table 10 Summary of rough set results with decision variable: overall innovation performance

	Innovation drivers	Knowledge creation	Innovation & entrepreneurship	Applications	Intellectual property	Innovation performance
Austria				-	0	0
Belgium				0	-	0
Bulgaria		-				-
Cyprus		-				-
Czech Republic		-				-
Denmark				0	0	+
Estonia	0				--	-
Finland				0	0	+
France				0	-	0
Germany					+	0
Greece		-				-
Hungary		-				-
Ireland				0	-	0
Italy			-		-	-
Latvia	-	--	-			--
Lithuania	0				--	-
Luxembourg					+	0
Malta	--					-
Netherlands				-	0	0
Poland		-				-
Portugal	--					-
Romania	-	--	-			--
Slovakia			--			-
Spain	0	-			--	-
Sweden				0	0	+
UK				0	-	0

-- (0,00-0,20); - (0,21-0,40); 0 (0,41-0,60); + (0,61-0,80); ++ (0,81-1,00)

Finally, to investigate the relative importance of the attributes, we drop them one by one from the core again. The lower rows in Table 11 show the number of countries and the quality (percentage) of classifications whenever an attribute is excluded. In the case of overall innovation performance, when the attribute knowledge creation is excluded, the quality of the classification is lowest; then, only 88.5% of the countries can be classified. This supports the findings of our previous rough set estimations. Investments in R&D activities have a great influence on innovation performance and especially public R&D expenditures affects human capital output, but also the level of education which is represented in the dimension innovation drivers. Innovation drivers and knowledge creation are, according to Table 11, indispensable for overall innovation performance, especially in the first stages of innovation development. Our results show that for measuring innovation performance, besides accounting for the development level of countries, attention should be paid to the sector of innovation. Innovation in the services sector seems to require different input than innovation in the manufacturing sector. Although this may seem obvious, in measurements of innovation performance it is often not accounted for. The reason why innovation & entrepreneurship has a lesser influence than the other two input dimensions on overall innovation performance, may be caused by a relative important role of the service sectors in most European countries. We have seen that innovations at the firm level appear especially important for growth in the manufacturing sector, yet employment in high-tech and medium-high tech manufacturing sectors is overall much lower than in the knowledge-intensive service sectors.

Table 11 Lower approximation for rough set classes

N=26	Overall innovation performance					Quality of classifications
	low	medium-low	medium	medium-high	high	
With core attributes	2	13	8	3	0	1.0000
With a temporarily reduced condition attribute						
Innovation drivers	1(1)	13(1)	8	3	0	0.9231
Knowledge creation	1(1)	13(2)	9	3	0	0.8846
Innovation & entrepreneurship	2	14	8	3	0	1.0000
Applications	2	14	9	3	0	1.0000
Intellectual property	2	13	9	3	0	1.0000

() Approximate rules

Finally, to further support our findings, by means of a Multi-Criteria Analysis (MCA) model called regime analysis, a sophisticated ranking (and rating) of the overall innovation performance of each individual country is given. Table 12 is the basis for a 'MCA' in order to identify whether the combination of the 5 innovation indicators of the EIS leads to some overall ranking of the innovation performance of the EU-26 of the above rough set analysis. The Regime method is applied to the first 5 columns of Tables 9 and 10, and the results are given in the 6th column (MCA) of Table 12. The results show rather robust results that seem to match the results of the rough set estimation. Sweden, Finland, Germany, Denmark and the United Kingdom are the innovation leaders, with Sweden being the most innovative country overall. Luxembourg, Ireland, Austria, the Netherlands, France, Belgium, Italy, Spain, Slovenia, Cyprus, Czech Republic and Estonia have a more medium overall level of innovation performance. Portugal, Hungary, Malta, Greece, Poland, Lithuania, Latvia, Slovakia, Bulgaria and Romania, then, are considered catching-up countries.

Table 12 Results of national ranking on the basis of the European Innovation Scoreboard (2007) and the MCA

	Innovation drivers	Knowledge creation	Innovation & Entrepreneurship	Applications	Intellectual property	MCA
Austria	0,46	0,58	0,44	0,39	0,56	20
Belgium	0,57	0,41	0,51	0,48	0,33	17

Bulgaria	0,36	0,23	0,25	0,32	0,00	2
Cyprus	0,40	0,23	0,69	0,18	0,17	13
Czech Republic	0,33	0,38	0,41	0,58	0,07	12
Denmark	0,82	0,52	0,64	0,46	0,57	24
Estonia	0,56	0,15	0,67	0,34	0,05	11
Finland	0,81	0,73	0,56	0,59	0,53	26
France	0,60	0,51	0,44	0,48	0,33	18
Germany	0,41	0,62	0,55	0,67	0,71	25
Greece	0,30	0,29	0,41	0,23	0,03	7
Hungary	0,28	0,39	0,21	0,41	0,04	9
Ireland	0,61	0,55	0,53	0,50	0,27	21
Italy	0,30	0,46	0,23	0,40	0,31	16
Latvia	0,36	0,11	0,37	0,10	0,03	4
Lithuania	0,52	0,19	0,40	0,21	0,02	5
Luxembourg	0,35	0,49	0,64	0,57	0,61	22
Malta	0,12	0,09	0,34	0,73	0,13	8
Netherlands	0,61	0,54	0,35	0,38	0,56	19
Poland	0,36	0,21	0,24	0,33	0,04	6
Portugal	0,20	0,16	0,47	0,23	0,11	10
Romania	0,25	0,03	0,21	0,38	0,00	1
Slovakia	0,32	0,07	0,20	0,55	0,03	3
Slovenia	0,49	0,44		0,46	0,10	14
Spain	0,43	0,30	0,25	0,38	0,20	15
Sweden	0,79	0,91	0,89	0,55	0,60	27
UK	0,73	0,57	0,72	0,59	0,31	23

5. Results of Rough Set Analysis

The results of our rough set analyses seem consistent. For innovation output, in the form of the human capital functions employment in high-tech services and employment in medium-high and high-tech manufacturing, the input factors public R&D investments and tertiary education seem especially influential. Low and medium employment in the high tech service sectors is influenced mainly by a lower level of public R&D expenditures and business R&D expenditures and to a lesser extent innovation expenditures. In the case of high-tech services employment, high R&D investments and tertiary education appears to lead to high employment. At this stage, public R&D investments are of less importance than business R&D expenditures. The influence of tertiary education at this stage of innovation may be explained also by the large dependency of the services sector on human capital and in this case on high-skilled human capital. For employment in medium-high and high-tech manufacturing results are less clear but overall the effect public R&D expenditures and tertiary education also seem apparent here, although the results are less linear. Low employment in manufacturing is mainly affected by a high level of population with tertiary education and to a lesser extent S&E graduates, but overall attributes differ per country. Here too, public R&D expenditures influence employment, but the level differs between countries, although for high employment in manufacturing public R&D expenditures should preferably be kept at a medium or low level. Innovation expenditures in the firm seem, at this level, a more effective means to increase employment in manufacturing, although only Germany was affected.

With regard to overall innovation performance, the results show a large overlap with the previous rough set analyses. Innovation drivers and knowledge creation explain 80.8% of the level of overall innovation performance in the EU. It should be noted that, based on the results, structural

conditions, or innovation drivers, and investments in R&D activities, i.e. knowledge creation, appear especially important for countries with low or medium-low innovation performance, i.e. the majority of EU countries. For a large part, these countries are the new member states that joined the EU in 2004, but also several southern European countries like Spain, Greece, Portugal and Italy score low. The further north in the EU, the innovation performance level rises. With a medium leveled innovation performance appearing in Belgium, France, Ireland, UK, Austria, the Netherlands, Germany and Luxembourg, and high innovation in the Scandinavian countries, Denmark, Finland and Sweden. In those countries, where the structural conditions and investments in R&D are overall more constant, it is innovation output that seems most influential. At this level, especially achieving a higher level of applications and intellectual property is important for higher innovation performance. The high scoring countries, Denmark, Finland and Sweden, share a medium level of applications and intellectual property, a combination that no other EU country seems to have achieved. The analysis largely leaves open the question how such a level of output can be achieved, although both countries share at least a medium to high level of business R&D expenditures, innovation expenditures and population with tertiary education. The fact that public R&D has not come up as an influential factor, seems rather a result of their well-stabilized character than their non-existence. The results further assume the existence of social capital factors that can explain the clear cultural divide that seems apparent. Factors like trust, religion, politics, and temperature may be better able to clarify this divide.

In this light, it is important to distinguish between economically (and politically) developing countries and developed countries. One should be careful to compare new member states with traditional EU member states, because innovation performance seems an economic activity that only becomes important after economic development in a country has reached a certain stage. Besides, there is the difference between cultures, in this case broadly the differences between southern, middle and northern Europe, which in turn cannot be compared with the differences in development. With regards to innovation performance, then, lower growth countries should focus more on improving their innovation input factors, whereas higher growth countries should concentrate especially on their output in order to achieve better innovation results. New member states are usually still in the process of optimizing their structural conditions and investments in R&D activities, often their public R&D expenditures. For the southern European countries, however, when looking at the results of our first set of analyses, it is especially their business R&D expenditures that seem too low. This supports the idea that a distinction between these countries is important. For the high level innovation countries, it is more difficult to draw similar conclusions, because the analyses looked specifically at the effect of innovation input factors on innovation output. So, the only conclusion that can be drawn from our first set of analyses is that Denmark and Sweden both have high employment in high tech services and medium employment in medium and high tech manufacturing, but this is also the case for Belgium, France and Ireland. When looking at the results of overall innovation performance, though, the latter three countries lack a consistent level of intellectual property. Also, with regards to input, the Scandinavian countries score especially high for business R&D expenditures and innovation expenditures on a firm level. But more research into differences between specifically innovation output factors for these countries is necessary in order to validate these results.

6. Conclusion

Measuring overall innovation performance should be done with care, as it is dependent on a number of factors. In this study alone, we have found that innovation performance is different per culture, per level of development which in turn can be economic, political, institutional, etc., per sector and basically per country (especially if country size, for example, is not accounted for). There are also

some overlaps visible, however, that may at least explain some of the differences in innovation performance in Europe. New member states, for example, seem to benefit from public R&D expenditures. The state of public institutions, at this level, is probably also not yet optimal, which is in line with the arguments developed by North (1981) that history matters for current economic outcomes; an argument that has gotten recent support from empirical research by Hall and Jones (1999), Acemoglu et al. (2005) and Tabellini (2005). Such findings, then, point towards social capital as important determinant in explaining differences in innovation performance and economic growth. Such a determinant would maybe also be able to explain differences between northern and southern countries in more detail. Our estimates suggest that research into this direction would be promising. What our results do show, nevertheless, is that for a high level of growth especially business R&D expenditures and innovation expenditures on a firm level appear most effective. Also, the level of population of tertiary education seems to have a considerable effect on innovation performance, especially when the human capital factor employment is used as dependent variable. However, as the service sectors produce the highest share of high-tech employment in Europe, human capital is an important push factor of economic growth, and, as a result, there should be a large focus on expenditures on education as a form of R&D investment. This supports the idea that for developed countries in particular public R&D expenditures should consist mainly of expenditures on education.

Our rough set analysis also has some limitations. The categorization of the Scoreboard data makes the results, of course, less precise, although it does offer the opportunity to generalize data and have a broader overview. Individual country differences make it often impossible to make generalizations when using regressions. And factor analysis has as a disadvantage that it looks at relations between factors, but cannot measure the effect of a set of independent variables on dependent ones. Rough set analysis can do both, in the sense that it can discover most significant relationships between independent and dependent variables and reduce all superfluous variables, while at the same time it can rank the objects, in this case the countries, in different classes of development. Due to large differences between countries, this would otherwise be more difficult. Of course, this method is best used for exploratory purposes, so for finding relationships, cores, and regularities and irregularities. As an exploratory tool, especially for such complex issues as innovation performance which seems dependent on many different factors, rough set analysis can be clarifying. In this case, we have taken only a small sample of six indicators from the 15 innovation input indicators of the European Innovation Scoreboard, and thus our results do not gain insight into output so much. The use of Eurostat composite variables may further strengthen the results. Also, the data coverage, i.e. the way data is collected or processed, may vary between countries. Our aim was, however, to focus especially on public and private investments and for several indicators insufficient data was available, which made rough set analysis impossible. The large overlap in estimates of the analysis of the overall innovation performance, which includes all indicators, nevertheless, seems to support our overall findings, and so does the outcome of the Regime analysis.

References

- Acemoglu, D., S. Johnson, and J. Robinson (2005), The rise of Europe: Atlantic Trade, Institutional Change, and Economic Growth, *American Economic Review*, 95(3), pp. 546-79.
- Arrow, K.J. (1962), Economic welfare and the allocation of resources for invention, *The Rate and Direction of Inventive Activity*, pp. 609-625.

- Arundel, A., M. Kanerva, A. van Cruysen, and H. Hollanders (2007), *Innovation Statistics for the European Service Sector*, Pro Inno Europe Inno Metrics, UNU-MERIT, Final draft.
- Barro, R.J. (1991), Economic Growth in a Cross Section of Countries, *Quarterly Journal of Economics*, 106(2), pp. 407-433.
- Bilbao-Osorio, B., and A. Roderiguez-Pose (2004), From R&D to innovation and economic growth in the EU, *Growth and Change*, 35(4), pp. 434-455.
- Cameron, G. (1998), Innovation and Growth: A Survey of the Empirical Evidence, *Mimeo*.
- Cios, K., W. Pedrycz, and R. Swiniarski (1998), *Data Mining Methods for Knowledge Discovery* (Boston, Mass: Kluwer Academic).
- Davies, J., B. Hamilton, and J. Whalley (1989), Capital income taxation in a two-commodity life cycle model : The role of factor intensity and asset capitalization effects, *Journal of Public Economics*, 39(1), pp. 109-126.
- Ella Hassanien, A., M.E. Abdelhafez, and H.S. Own (2007), Rough set analysis in knowledge discovery: a case of Kuwaiti diabetic children patients, *Advances in Fuzzy Systems*, ID 528461, pp. 1-13.
- European Commission (1996) *First Action Plan for Innovation in Europe*, <http://cordis.europa.eu.int/innovation/en/policy/communications/communications2.htm>.
- European Innovation Scoreboard (2007), *Comparative Analysis of Innovation Performance*, Luxembourg: Office for Official Publications of the European Communities (http://www.proinno-europe.eu/admin/uploaded_documents/European_Innovation_Scoreboard_2007.pdf).
- Presidency of the European Union (2000), *Employment, Economic Reforms and Social Cohesion: Towards a Europe based on innovation and knowledge*. Council of the European Union: Document from the Presidency, 5256/00.
- Fagerberg, J. (1994), Technology and international differences in growth rates, *Journal of Economic Literature*, 32(3), pp. 1147-1175.
- Foray, D. (2004), *The Economics of Knowledge*, Cambridge MA: MIT Press.
- Freudenberg, M. (2003), *Composite indicators of country performance: A critical assessment*, STI Working Paper 2003/16, Paris: OECD.
- Griliches, Z. (1998), *R&D and Productivity* (Chicago: University of Chicago Press).
- Grossmann, G.M., and E. Helpman (1994), Endogenous innovation in the theory of growth, *Journal of Economic Perspectives*, 8, pp. 23-44.
- Grupp, H., and M. Moguee (2004), Indicators for national science and technology policy: how robust are composite indicators, *Research Policy*, 33, 1373-1384.
- Guellec, D., and B. van Pottelsberghe (2001), *R&D and productivity growth: Panel data analysis of 16 OECD countries*, OECD STI Working Paper No. 3.
- Hall, R.E., and C.I. Jones (1999), Why do some countries produce more output per worker than others?, *Quarterly Journal of Economics*, 114(1), pp. 83-116.
- Hollanders and Celikel Esser (2007), *Measuring Innovation Efficiency*, INNO-Metrics Thematic Paper, http://www.proinno-europe.eu/admin/uploaded_documents/eis_2007_Innovation_efficiency.pdf.
- Kleinknecht, A., K. van Montfort and E. Brouwer (2001), The Non-Trivial Choice between Innovation Indicators, *Economics of Innovation and New Technology*, 11(2), pp. 109-121.
- Lichtenberg, F.R. (1992), R&D investment and international productivity differences, *NBER Working Paper*, N. 4161.
- Nadiri, I. (1993), *Innovations and technological spillovers*, NBER Working paper no. 4423.
- Nijkamp en Poot (2004), Meta-analysis of the effect of fiscal policies on long-run growth, *European Journal of Political Economy*, 20, pp. 91-124.
- North, D. (1981), *Structure and Change in Economic History*, New York: Norton.

- OECD (1998), *Science and Technology Outlook*, Paris: OECD.
- Pawlak, Z. (1991), *Rough Sets: Theoretical Aspects of Reasoning about Data*, Dordrecht: Kluwer.
- Polkowski, L. and A. Skowron (1998), *Rough Set in Knowledge Discovery*, Berlin: Springer Physica Verlag.
- Romer, P. (1990), Endogenous technological change, *Journal of Political Economy*, 98, pp. 90-108.
- Rosenberg, N. and L.E. Birdzell, Jr. (1990), Science, technology and the western miracle, *Scientific American*, 263(5), pp. 42-54.
- Salter, A.J., and B.R. Martin (2001), The economic benefits of publicly funded basic research: A critical review, *Research Policy*, 30, pp. 509-532.
- Slowinski, R. (1992), A generalization of the indiscernibility relation for rough set analysis of quantitative information, *Rivista di Matematica per le Scienze e Sociali*, 15(1), pp. 65-77.
- Slowinski, R. (ed.) (1993), *Intelligent Decision Support: Handbook of Applications and Advances of the Rough Sets Theory*, Dordrecht: Kluwer.
- Slowinski, R. and J. Stefanowski (1993), Roughdas and roughclass software implementations of the rough sets approach, in: R. Slowinski (ed.), *Intelligent Decision Support: Handbook of Applications and Advances of Rough Sets Theory*, Dordrecht: Kluwer.
- Tabellini, G. (2005), *Culture and Institutions: Economic Development in the Regions of Europe*, Working Paper, Bocconi University and IGER.
- Tijssen, R.J.W. (2002), Science dependence of technologies: evidence from inventions and their inventors, *Research Policy*, 31, pp. 509-526.
- Trajtenberg, M. (2002), Government support for commercial R&D: Lessons from the Israeli Experience, in A.B. Jaffe, J. Lerner and S. Stern (eds), *Innovation Policy and the Economy*, 2, pp. 79-134.
- Zhong, N., and A. Skowron (2005), Rough set based knowledge discovery process, *International Journal of Applied Mathematics and Computer Science*, 11(3), pp. 603-619.