Knowledge investments, business R&D and innovativeness of countries. A qualitative meta-analytic comparison

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A qualitative meta-analytic comparison

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Abstract

The relationship between knowledge investments, innovation and competitiveness is an important topic in both academic research and economic policy and has been studied extensively over the past decades. Nowadays, investments in private and public R&D are believed to make up the heart of a modern knowledge economy. The present paper adopts an evolutionary economics perspective and investigates whether, in addition to private R&D activities, also institutional support systems and policy interventions play a role in inducing innovation initiatives and creating impacts on the performance and competitiveness of industries. We aim to find support for the hypothesis that the competitiveness of industries in the international arena is sustained by the dynamic interaction between national, regional and sectoral innovation systems. This may provide stakeholders with a better understanding of the context in which they operate. Since according to the evolutionary metaphor, the growth of an innovation system follows complex dynamics that cannot simply be analysed within a static quantitative equilibrium framework, here we use an alternative approach based on qualitative pattern recognition analysis originating from artificial intelligence analysis. Besides R&D expenditures, human capital expenditures are regarded as the major input in the knowledge creation process in our analytical framework. To this end, in our paper a qualitative causal model that maps out conditional relations between key factors in national innovation systems will be described. The focus of our investigation is on systematic patterns in the competitiveness of the EU Member States, using statistical information on innovation input and output data from the European Innovation Scoreboard. In our analysis we find support for the hypothesis that there are indeed significant interactions between distinct institutional levels, which may provide guidance to the strategic orientation of nations and the European Union in terms of the emphasis on competitiveness vis-à-vis cohesion.

Key words: competitiveness innovation, social cohesion, evolutionary economic geography, R&D, human capital, rough set analysis

1. Introduction

The study of the relationships between innovation and competitiveness is an important topic in both academic research and economic policy. The mainstream R&D spillover approach is most common in the economics literature (Romer, 1986; Aghion and Howitt, 1992; Nadiri, 1993). In this approach, the key aspect of the innovative process is the R&D activity undertaken by private firms. The focus of policy making is, first and foremost, on the level of R&D expenditures of private firms, and the rationale is to create an appropriate system of incentives and resources to stimulate the production of new technological knowledge by economic agents. Policies especially focus on the support of innovativeness and competitiveness of advanced regions in the hope of strengthening regional harmonization. Evolutionary economists, on the other hand, especially emphasize the sector specific nature of innovation and investigate its impact on the competitiveness of different systems of innovation (Nelson and Winter, 1977; Freeman et al., 1982; Dosi, 1988; Devezas, 2005). In particular, they point towards the great importance of the characteristics of the national or local system of innovation in shaping sectoral innovation, and claim that the co-evolution of national and sectoral systems is a major factor to drive international competitiveness (Mowery and Nelson, 1999; Murmann and Homburg, 2001; Malerba, 2005). A similar process is visible between regional and sectoral systems of innovation. In this paper, we aim to research whether the economic environment does indeed play such a seminal role, and if policies should not, as a result, be targeted more towards specific characteristics and needs of different national, and regional systems. In Europe, innovation policy initiatives are still largely pursued in parallel on a national and regional level (Kuhlmann and Edler, 2003). This layer structure has left open a governance gap of poor integration and coordination. Clearly, the process of catching up is more complex than envisaged in economic theory, and requires a complementary development of capabilities, skills and institutions (Sharp, 1998). This paper supports the view that deeper understanding of national and regional systems of innovation is necessary to better target national innovation programs, and improve complementary integration and coordination of regional innovation programs.

In this paper, we aim to find support for the idea that sectoral innovation is shaped by the characteristics of the national system of innovation, and vice versa, as well as by regional systems of innovation. National institutional support systems and policy interventions are considered to be a major channel of interaction, and therefore have a central position in our analytical framework. Special focus is on R&D and human capital expenditures. R&D expenditures are central because of the major input that they provide in the knowledge creation process. In addition, the strong focus in the literature on the knowledge infrastructure of the economy and its ability to sustain the formation of human capital and learning capabilities of all economic agents seems to point towards the special importance of human capital for innovation performance. Exploring national expenditures on R&D and human capital may explain us something about the particularities of national institutional support systems and their level of competitiveness, especially when it is compared to the real GDP growth of the countries under study. At the same time, the performance of national systems may give us deeper insight in regional characteristics of innovative activities, i.e. the tacitness of the knowledge base, the existence of public resources, and the regional cumulativeness of European regions. For this goal, we use rough set analysis, which is a more recent classification method of an ‘if-then’ nature originating from the artificial intelligence literature (see Pawlak, 1991; Slowinksi, 1993;

Polkowski and Skowron, 1998). Rough set analysis is especially interesting here because it does not so much study the interactions of the factors but rather offers a classification of European countries on the basis of the relationships between input and output factors of the innovative process in different sectors of the economy. It can in this respect be especially helpful in discovering qualitative causality patterns in national and regional innovation systems. Such an approach may shed a new light on innovation and competitiveness research and policy.

After a concise description of innovation and competitiveness according to evolutionary economics, we will introduce rough set analysis as an alternative framework for measuring the innovativeness of the 27 EU Member States. By doing this, we hope to answer the question: What, given that R&D activities constitute a major factor to sustain the international competitiveness of industries, determines sectoral, regional, and national differences in innovativeness? As the different strands of research within evolutionary economics have not agreed upon a standard set of models, methodology, and stylized facts, our research will solely explore country and regional (here: sets of countries) differences in innovativeness in the manufacturing and services sectors. By doing this, we aim to test the policy recommendations in the evolutionary framework, and hopefully gain some further insight into the complex set of factors of an economic, institutional, and historical nature for future theoretical and analytical research.

3. R&D expenditures and the role of human capital

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). There is less of a consensus, however, regarding the capacity of different countries to profit from technology and investments in R&D. Different Schumpeterian strands of research indicate that, in a long-run perspective, the international competitiveness of industries is robustly related to two major factors: namely, their own innovative activities and the inter-sectoral diffusion of advanced knowledge. The first is inspired by a traditional view of economic policy based on a market-oriented approach, while the second evolutionary-based view is consistent with the idea that institutional arrangements and policy interventions also play a fundamental role in shaping innovation patterns and their impacts on the competitiveness of industries (Castellacci, 2008). In this study, we aim to explore this institutional-dynamic hypothesis a bit further by investigating patterns in the competitiveness of the EU Member States. When looking at current EUROSTAT data of the 27 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 account for the majority of expenditure in this area in most EU Member States. With 3.73 and 3.45 per cent 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. Real GDP growth rates show that economic growth experienced a decrease in 2001, after which rates started to rise again, thereby generally exceeding 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 in 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 from 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 had the biggest impact on output in most EU countries. Overall, however, the share of total government expenditure as a percentage of gross domestic expenditure on R&D (GERD) was still in the range of 40-50 per cent in the EU. It would appear from Tables 1 and 2 that most countries still fall short of the R&D expenditure target set by the Lisbon Strategy for Growth and Jobs (2000), which requires an annual R&D expenditure of at least 3 per cent 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 this 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 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 business R&D expenditures and lower public R&D expenditures seems important, but also high expenditures on higher education. This may be related to the 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). Overall, then, a combination of high business R&D expenditures, low government R&D expenditures and high expenditures on higher education seems to positively correlate with high real GDP growth. Further, highly innovative countries like Sweden, Finland and Denmark seem to have especially high higher education expenditures. This supports the idea of the important role of human capital in the innovation performance of companies, countries and regions.

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	36.0	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	35.0	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	1.10	0.46	0.18	:

Source: EUROSTAT.
(a) 2005 instead of 2006.
(b) 2003.
(c) 2004.
(:) Not available.

Growth, it appears, is driven less by investments in buildings and equipment than by the generation of ideas and the accumulation of knowledge (see, for example, Aghion and Howitt, 1998; Foray, 2004; Neef, 1998). As a factor of production, 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). The components of a system of innovation include not only private firms and their R&D activities but also public organizations such as universities, public research institutes, science parks, and so on. They play a key role in the innovation system, as they represent the knowledge infrastructure of the economy, whereby they sustain the formation of human capital and learning capabilities of all economic agents, and enable the accumulation and diffusion of advanced knowledge in the innovation system. In this respect, three channels of interaction are considered particularly important between sectoral patterns and national systems. Country- and sector-specific technological trajectories and specialization patterns often show continuity and persistence over long periods of time (Archibugi and Pianta, 1994; Dalum et al., 1998; Begg et al., 1999; Laursen, 2000; Cefis and Orsenigo, 2001; Fai and von Tunzelmann, 2001; Laursen and Salter, 2005). Sectoral innovative activities and intersectoral knowledge flows contribute to shaping the specialization patterns, productivity dynamics and trade performance of the system of innovation. Secondly, the policy level constitutes a major channel of interaction between the meso- and the macro-level. If national policies actively promote core industrial areas for a prolonged period of time and neglect others, this policy strategy will affect the entire national system of innovation. Also, national policies may directly affect sectoral innovative activities, cooperation patterns, inter-sectoral linkages, and university-industry collaborations through a wide variety of incentives, schemes and regulations (Lundvall and Borras, 2005; Mowery and Sampat, 2005). Thirdly, there is a broad range of other country-specific factors of a social, institutional and cultural nature that are affected and shaped by the degree of trust and cooperation in the system.

With regard to the process that is visible between regional and sectoral systems of innovation, the empirical literature considers two distinct causal mechanisms. The first is called the geography of innovation and economic clustering (Breschi and Malerba, 2001). This mechanism emphasizes the clustering aspect of innovative activities, a process which is developing specifically in successful regions (Porter, 1990; Narula and Zanfei, 2005). Here, the focus is on the cluster in determining success. The regional-systems-of-innovation approach, on the other hand, argues that innovation is primarily shaped by the characteristics of the regions where innovative activities are located (Gertler et al., 2000; Cooke, 2001; Todtling and Trippl, 2005). In this theory, the region is key. In particular, three main factors determine the success of innovative activities in this respect (Asheim and Gertler, 2005): the tacitness of the knowledge base; the existence of public resources of technological opportunities; and a mechanism of regional cumulativeness. First, the tacitness of the knowledge base refers to the localized and embedded nature of learning and innovation and the idea that learning through interacting mechanisms and vertical linkages frequently requires the geographical proximity of suppliers, producers and users of new technologies. Secondly, the existence of public resources further highlights the importance of the availability of public facilities and infrastructures (e.g. R&D labs, universities, technical schools), and the strong incentive they provide for innovators to locate in advanced regions. Thirdly, regional cumulativeness represents the notion that successful regions are better able to attract advanced resources (skilled labour, specialized suppliers, engineers, etc.) that will ensure further technological and economic success in the future. The cognitive approach to spatial spillovers specifies this idea further by highlighting the construction of knowledge through cooperative learning processes, nourished by spatial proximity (atmosphere effects), network relations (long-distance, selective relationships, interaction, creativity and recombination capability (Capello, 2009). In this approach, the focus lies on the ability of local actors to manage information in order to identify and solve problems, or, in the economic sphere, to transform information and inventions into innovation and productivity increases through cooperative or market interactions. Cognitive success or regional receptivity of a region is the outcome of a combination of institutions, rules, practices, producers, researchers and policy makers that make a certain creativity and innovation possible (OECD, 2001, p. 15).

In this paper, regional refers broadly to European Member States with identical innovation performance patterns. In order to analyse such regional clusters, we need to take into account that there exists a strong interaction between national and regional institutional support systems in this respect. On top of the national efforts and in parallel with Europe's economic and political integration, there exists a European innovation policymaking system (Peterson, 1998). This system is officially restricted to and concentrates on the creation of 'European added value' (Kuhlmann and Edler, 2003). This stems from the principles of 'subsidiarity and European added value', which means that each programme or project has to be justified through trans-border cooperation that would not be effectively managed by national administrations and that promise synergy effects not attainable within national borders. When we then consider the three factors that determine regional success of innovative activities, The tacitness of the knowledge base, the existence of public resources, and regional cumulativeness only exists in the form of Framework Programmes (FPs), Regional Technology Plans (RTPs) or intergovernmental initiatives like COST and EUEKA to name a few European innovation initiatives. The majority of public initiatives is still mainly developed in national policy arenas, with a significant relation to the own economy. Even though EU programmes in support of research and innovation have been increasing in volume since the end of the 1980s, their actual reach is still considered limited, in particular in larger EU Member States (Kuhlmann and Edler, 2003). As innovation systems appear to have developed in very country-specific manners, nationally rooted innovation systems are essential. However, for European Member States with identical innovation performance patterns a European innovation system may be useful that focuses explicitly on regional innovation support.

By comparing the innovativeness of the countries of the EU, we hope to find explanations for the differences in levels of innovativeness in these countries. At the same time, we aim to trace regional innovation performance patterns among the EU Member State countries. As our research is exploratory, our comparison of countries and regions will serve mainly as indicative, i.e. to give an idea of the possibilities for further research in this direction. First, however, in the next section, European innovativeness will be discussed in more detail, i.e. how it is documented and measured by the European Innovation Scoreboard. Next, we introduce our analytical framework, i.e. the qualitative meta-analysis, and the attributes under study here.

4. The European Innovation Scoreboard

According to Mairesse and Mohnen (2002), innovation output is viewed as resulting from a process of transformation of inputs into outputs. They believe that this linkage can be represented in terms of an innovation function and an innovation accounting framework, similar to a production function, on the basis of which changes in innovation output between periods on differences between periods or differences between spatial units can be ascribed to changes or differences in the factors of innovation and in the residual that they call innovativeness, or the unexplained ability to turn innovation inputs into innovation output. Thus, innovativeness is to innovation what TFP is to production. We have applied this notion to our rough set framework. The European Innovation Scoreboard (EIS, 2007), which was developed at the request of the Lisbon European Council in 2000, is in this respect especially helpful as a data source, because to calculate the Summary Innovation Index (SII), which is considered the core of the EIS, 25 indicators covering different aspects of innovation are used. 15 of them are innovation input indicators; the other 10 are based on innovation outputs. We have used a selection of input and output indicators and dimensions of the scoreboard (see Table 3). R&D expenditures, in principle, say nothing about the output side of the innovation process (Kleinknecht et al., 2001). By analysing their relation to employment, however, we hope to obtain some 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 such as S&E graduates, population with tertiary education, ICT expenditures on a firm level and innovation on a firm level in the model. 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 innovativeness by showing the relationship of the five dimensions of the scoreboard (see Table 3) to 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(RSA)

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 cooperating 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

Note: * = indicators and dimensions selected for our RSA

In the next section, rough set analysis will be put into practice. First, we conduct a rough set analysis of a specific sub set of innovation indicators, followed by an analysis of the innovation dimensions.

5. Rough set analysis of innovation output and performance

5.1 Introduction

In order to measure innovativeness in EU Member States, we now apply rough set analysis. The conceptual foundation of rough set analysis is the consideration that perception is subject to granularity. The mathematical machinery is derived from the assumption that granularity can be expressed by partitions and their associated equivalence relations on a set of objects (i.e. EU Member States). The objective of the analysis is to identify under which conditions certain features (here: innovation input indicators) are necessary to 'explain' the existence of a feature of the response variable (i.e. innovation output). The rough set approach analyses a set for which the classification of a group of certain objects is not entirely certain, by forming decision rules that are implication relationships between the description of the condition attributes and that of decision attributes. It basically evaluates the importance of attributes for a classification of objects, reduces all superfluous objects and attributes, discovers the most significant relationships between condition attributes and assigns objects to decision classes, and represents these relationships as a set of decision rules called a 'classifier'. Such rules have the potential to reveal new patterns in the data material. In our case, there are different expenditures (direct or indirect) that influence innovativeness, but which particular combination of expenditures is more effective and creates higher output is unclear. Furthermore, combinations of expenditures are different for different countries, and rough set analysis has the ability to classify the limits or boundaries of the countries on the basis of the different expenditures. Usually, rough set analysis is used to perform classification analysis on 'soft' categorical data. Here, we will use a collection of data from the EIS. In the light of the guidelines of the Oslo Manual (OECD, 1992), under which statistical agencies have started conducting surveys that directly ask firms about their innovations, rough set analysis may be especially interesting as it is also able to process qualitative data, for example, dealing with yet-to-be-developed indicators dealing with knowledge or technology diffusion. These are indicators that may be less easily captured in quantitative measures.

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 the core. An attribute is indispensable if the classification of the objects becomes less precise when the attribute is left out. A set is termed 'rough' if it is not equal to a union of elementary sets. The decision rules that rough set specifies are of an 'if-then' nature. These rules are the outcome of prior knowledge of reality that is represented in an information table. This information table is a matrix (objects in rows, and attributes in columns) that contains the values of the attributes of all objects. Vollet and Bousset

(2002) formulate the working of rough set analysis as follows: in an information table the attributes have to be partitioned into condition (background (α)) and decision (response (β)) attributes. A decision rule is then an implication relationship between the description of the condition attributes (α) and that of a decision attribute (β). Such a rule may be exact or approximate. A rule is *exact* if the combination of the values of the condition attributes in that rule implies only one single combination of the values of the decision attributes. An *approximate* rule, on the other hand, only states that more than one combination of values of the decision attributes correspond to the same values of the condition attributes. Decision rules may thus be expressed as 'if-then' conditional statements ($\alpha \rightarrow \beta$).

The rough set analysis generally consists of two stages: preprocessing and processing (Ella Hassanien et al., 2007). 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, the derivation of rules from reducts, and classification processes. These stages lead towards the final goal of generating rules from the information or decision system of the innovation database (see also Pawlak, 1982, 1991; Komorowski et al., 1999). 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, the classification rules produced are categorized into certain and possible (Slowinski, 1992). 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.

5.2 Rough set analysis of expenditures and employment

The general functional form of the relevant variables in an explanatory comparative model for employment in the high-tech services and in medium-high/ high-tech manufacturing can be summarized as follows (Stanley and Jarell, 1989; van den Bergh et al. 1997):

$$E = f\ (P, X, R, T, L) + \text{error}, \tag{1}$$

where *E* denotes the dependent variable studied (e.g. levels of employment in the high-tech services and in medium-high/ high-tech manufacturing); *P* represents the specific cause of the problem (e.g. levels of public R&D expenditures, business R&D expenditures, innovation expenditures on a firm level, and ICT expenditures on a firm level); *X* represents the characteristics of the individuals concerned by the problem (e.g. population with tertiary education, and S&E graduates); *R* represents the characteristics of the research method used in each study (here: EIS panel data and CIS-4 data); *T* indicates the period covered for each study (e.g. 2007); and *L* states the location of the study (e.g. EU 21 – Austria, Cyprus, Finland, Latvia, Slovenia and the United Kingdom were omitted due to missing data). For our first rough set analysis, equation (1) can be specified for employment in the high-tech services as:

$$\mathrm{E_S} = f\ (p, b, i, c, t, s) \tag{2}$$

where *p* represents public R&D expenditures; b represents business R&D expenditures; *i* indicates innovation expenditures on a firm level; *c* states ICT expenditures on a firm level; *p* indicates population with tertiary education; and *s* represents S&E graduates.

Using the computer software programme ROSE, we find that there are 7 rules for the level of employment in the high-tech services (Table 4). 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 per cent 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 per cent, which means that for both countries the rule is 100 per cent true. Rule 2 and Rule 5 also have a high coverage rate with respectively 69.23 per cent and 66.67 per cent, 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 for employment in high-tech services

Conditions	**Strength of rules**	**Number of countries***	**Interpretation/ generalization**
Rule 1. If $(p=1) \cap (b=1) \cap (i=2) \Rightarrow E_s=1$	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. If $(P=2) \cap (B=1) \Rightarrow E_s=2$	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. If $(S=1) \Rightarrow E_s=2$	30.77%	4 (Czech Republic, Hungary, Luxembourg, Malta)	
Rule 4. If $(I=3) \cap (T=2) \Rightarrow E_s=2$	15.38%	2 (Germany, Greece)	
Rule 5. If $(B=2) \cap (T=3) \Rightarrow E_s=3$	66.67%	4 (Belgium, Denmark, Ireland, Netherlands)	**IF** public R&D expenditures = 0.67-1; business R&D expenditures = 0.9-1.9 or 2-3; population with tertiary education = 26.67-40; and S&E graduates = 16.67-25 **THEN** employment in high tech services = 3.67-5.50
Rule 6.If $(B=3) \Rightarrow E_s=3$	16.67%	1 (Sweden)	
Rule 7. If $(P=3) \cap (S=3) \Rightarrow E_s=3$	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

Note: * = 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 to be 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, the Czech Republic, Estonia, Germany, Greece, Hungary, Italy, Lithuania, Luxembourg, Malta, Poland, Portugal and Spain, employment in high-tech services is medium level, i.e. between 1.83 and 3.66 per cent of total workforce. Medium public R&D expenditures and low business R&D expenditures seem to have particular 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. In the long term, however, the effect may become negative, because less people will be necessary for the same job, especially if innovation expenditures on the firm level remain an exception rather than the rule in most firms. This may explain why Germany, which is at the top 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. Finally, Belgium, Denmark, France, Ireland, the Netherlands and Sweden 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 the 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 arena, public R&D expenditures seem of less influence, although they positively affect 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 with the other countries that have 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		o			+		+
Bulgaria	o	-					o
Czech Republic						-	o
Denmark		o			+		+
Estonia	o	-					o
France	+					+	+
Germany			+		o		o
Greece	o	-	+		o		o
Hungary	o	o				-	o
Ireland		o			+		+
Italy	o	o					o
Lithuania	o	-					o
Luxembourg						-	o
Malta						-	o
Netherlands		o			+		+
Poland	o	-					o
Portugal	o	-					o
Romania	-	-	o				-
Slovakia	-	-	o				-
Spain	o	-					o
Sweden		+					+

Note: - (low development); o (medium development); + (high development), i.e. open space indicates that variables were not selected by RSA.

For employment in medium-high and high-tech manufacturing an identical equation is specified

$$E_m = f\ (p, b, i, c, t, s), \tag{3}$$

where *p* represents public R&D expenditures; b represents business R&D expenditures; *i* indicates innovation expenditures on a firm level; *c* states ICT expenditures on a firm level; *p* indicates population with tertiary education; and *s* represents S&E graduates.

Here, 14 rules are found (Table 6). 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 per cent 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, e.g. ‘cheap workforce’. High coverage rules for employment in the medium-tech and high-tech manufacturing are Rules 7, 9 and 12 which 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 for employment in manufacturing

Conditions	Strength of rules	Number of countries*	Generalization
Rule 1. If (c=2) $\cap$ (t=3) (s=3) $\Rightarrow E_m$ =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. If (p=1) $\cap$ (b=2) $\Rightarrow E_m$ =1	16.67%	1 (Luxembourg)	
Rule 3. If (p=3) $\cap$ (i=2) (t=3) $\Rightarrow E_m$ =1	16.67%	1 (Netherlands)	
Rule 4. If (b=1) $\cap$ (i=3) $\Rightarrow E_m$ =1	16.67%	1 (Greece)	
Rule 5. If (p=2) $\cap$ (c=3) (t=3) $\Rightarrow E_m$ =1	16.67%	1 (Estonia)	
Rule 6. If (i=3) $\cap$ (t=3) $\Rightarrow E_m$ =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. If (i=1) $\Rightarrow E_m$ =2	27.27%	3 (Bulgaria, Malta, Spain)	
Rule 8. If (b=2) $\cap$ (s=3) $\Rightarrow E_m$ =2	18.18%	2 (France, Ireland)	
Rule 9. If (t=1) $\Rightarrow E_m$ =2	27.27%	3 (Italy, Malta, Romania)	
Rule 10. If (p=2) $\cap$ (b=2) $\cap$ (t=3) $\Rightarrow E_m$ =2	18.18%	2 (Belgium, Ireland)	
Rule 11. If (b=2) $\cap$ (i=3) $\cap$ (t=2) $\Rightarrow E_m$ =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. If (p=2) $\cap$ (s=1) $\Rightarrow E_m$ =3	50.00%	2 (Czech Republic, Hungary)	
Rule 13. If (p=1) $\cap$ (b=1) $\cap$ (c=2) $\Rightarrow E_m$ =3	25.00%	1 (Slovakia)	
Approximate rules			
Rule 14. If (A1=2) $\cap$ (A2=1) $\cap$ (A4=2) $\cap$ (A5=2) $\Rightarrow E_m$ =1 $\Rightarrow E_m$ =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

Note: * = 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. A high level of population with tertiary education is relevant for only 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) a low skilled workforce is generally considered an important asset. In that case, population with tertiary education can have a negative effect. Furthermore, 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, while for Luxembourg low expenditures seems to have a negative effect and for the Netherlands high public R&D expenditures are disadvantageous for employment in manufacturing. Nevertheless, for high employment in manufacturing it seems 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 often with a 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, however, 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 itself 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	o	o			+		o
Bulgaria			-				o
Czech Republic	o					-	+
Denmark			+		+		o
Estonia	o			+	+		-
France		o				+	o
Germany		o	+		o		+
Greece		-	+				-
Hungary	o					-	+
Ireland	o	o			+	+	o
Italy					-		o
Lithuania				o	+	+	-
Luxembourg	-	o					-
Malta			-		-		o
Netherlands	+		o		+		-
Poland	o	-		o	o		o
Portugal	o	-		o	o		-
Romania					-		o
Slovakia	-	-		o			+
Spain			-				o
Sweden			+		+		o

Note: - (low development); 0 (medium development); + (high development), i.e. open space indicates that variables were not selected by RSA.

Finally, the relative importance of the attributes can be investigated by dropping them one at a 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 down indicates that, when the attribute public R&D expenditures is excluded, the quality of the classification is lowest; then, only 85.7 per cent of the countries can be classified on the basis of employment in the high-tech services and 66.7 per cent on the basis of employment in medium-tech and high-tech manufacturing. Table 8 also shows that public R&D expenditures and tertiary education are indispensible for employment both 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. Furthermore, they show 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 straightforward, 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, the 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 classifica-tions**	**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

Note: () = approximate rules.

4.3 Rough set analysis of innovation performance

We are further curious what the role of these different factors is for the innovation process as a whole. Although the general functional form of the explanatory comparative model is identical, the relevant variables are not and are thus explained as follows:

$$I = f\ (P, X, R, T, L) + \text{error}, \qquad (4)$$

where I denotes the dependent variable studied[1]; P represents the specific cause of the problem (i.e. level of input represented by the dimensions: innovation drivers; knowledge creation; and innovation & entrepreneurship); X represents the characteristics of the output affected by the problem (e.g. applications; and intellectual property); R represents the characteristics of the research method used in each study (e.g. EIS panel data and CIS-4 data); T indicates the period covered for each study (e.g. 2007); and L states the location of the study (e.g. EU 26 – Slovenia was omitted due to missing data). For this rough set analysis equation (5) is specified as

[1] e.g. degree of innovativeness based on the 2007 EIS Summary Innovation Index, whereby the following categories are used: (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.

$$I = f\ (i, k, e, a\ , p), \tag{5}$$

where i represents innovation drivers; k represents knowledge creation; e indicates innovation & entrepreneurship; a states applications for patents; and p represents intellectual property.

There are 7 rules and these are concerned with the five categories of innovativeness listed in footnote 1: Due to the high degree of comparability of re-scaled scores, we have used a 5-point scale here. This will further improve the accuracy of the results. Here, as 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 per cent of the level of overall innovation performance in the EU, which is considerable. In this analysis, the coverage rates of Rules 1, 2 and 10 stand out from those of the other rules (see Table 9). The dimensions: innovation drivers, knowledge creation and innovation & entrepreneurship, i.e. innovation input, seem especially important for countries with low or medium-low innovation performance, whereas applications and intellectual property, i.e. innovation output, seem of particular influence for countries with a high innovation performance.

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

Conditions	Strength of rules	Number of countries**	Interpretation/ generalization*
Rule 1. If $(A1=2) \cap (A2=1) \cap (A3=2) \Rightarrow I=1$	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.If $(A2=2) \Rightarrow I=2$	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. If $(A1=3) \cap (A5=1) \Rightarrow I=2$	23.08%	3 (Estonia, Lithuania, Spain)	
Rule 4. If $(A1=1) \Rightarrow I=2$	15.38%	2 (Malta, Portugal)	
Rule 5. If $(A3=1) \Rightarrow I=2$	7.69%	1 (Slovakia)	
Rule 6. If $(A3=2) \cap (A5=2) \Rightarrow I=2$	7.69%	1 (Italy)	
Rule 7. If $(A4=3) \cap (A5=2) \Rightarrow I=3$	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. If $(A4=2) \cap (A5=3) \Rightarrow I=3$	25.00%	2 (Austria, Netherlands)	
Rule 9. If $A5=4 \Rightarrow I=3$	25.00%	2 (Germany, Luxembourg)	
Rule 10. If $(A4=3) \cap (A5=3) \Rightarrow I=4$	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

Note: ** 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 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 of innovation performance between 0.21-0.40). This supports the findings of our previous rough set analysis, insofar as indicators like public R&D expenditures and tertiary education influence innovation output. Innovation output indicators applications and intellectual property, in turn, seem to be particularly 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 or 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 this refers to 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, however, 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				-	o	o
Belgium				o	-	o
Bulgaria		-				-
Cyprus		-				-
Czech Republic		-				-
Denmark				o	o	+
Estonia	o				--	-
Finland				o	o	+
France				o	-	o
Germany					+	o
Greece		-				-
Hungary		-				-
Ireland				o	-	o
Italy			-		-	-
Latvia	-	--	-			--
Lithuania	o				--	-
Luxembourg					+	o
Malta	--					-
Netherlands				-	o	o
Poland		-				-
Portugal	--					-
Romania	-	--	-			--
Slovakia			--			-
Spain	o	-			--	-
Sweden				o	o	+
UK				o	-	o

Note: -- (0.00-0.20); - (0.21-0.40); o (0.41-0.60); + (0.61-0.80); ++ (0.81-1.00) , i.e. open space indicates that variables were not selected by RSA.

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 per cent 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 in particular public R&D expenditures affect human capital output, and so does the level of education which is represented in the dimension innovation drivers. Innovation drivers and knowledge creation are, according to Table 11, indispensible 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 also 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 (innovation drivers and knowledge creation) on overall innovation performance may be caused by the relatively important role of the service sectors in most European countries. We have seen that innovations at the firm level appear to be 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

Note: () = approximate rules.

6. Results of the Rough Set Analysis

Although measuring overall innovation performance should be done with care, as it is dependent on a number of factors, the results of our rough set analyses seem consistent with the results of a larger set of evolutionary studies that argue that different sectors tend to follow very distinct technological trajectories over time (Nelson and Winter, 1977; Malerba, 2005). 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 by innovation expenditures. In the case of high-tech services employment, high business R&D investments and tertiary education appears to lead to high employment. At this stage of innovation, public R&D investments are of less importance than business R&D expenditures. The influence of tertiary education at this stage may also be explained by the great dependency of the services sector on human capital and, in this case, on high-skilled human capital. This supports the idea that exists in the literature that the nature of learning processes, which are specific to a given technological environment, seem essential here. For employment in medium-high and high-tech manufacturing, the results are less clear, but, overall, the effect of public R&D expenditures and tertiary education seem apparent. Low employment in manufacturing is mainly affected by a high level of population with tertiary education and to a lesser extent by S&E graduates, but overall attributes differ per country. Here too, public R&D expenditures influence employment, but the level differs between countries. However, 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 this only applied to Germany.

With regard to overall innovation performance, the results show a large overlap with previous rough set analyses. The results seem to support the hypothesis that there is a co-evolution between sectoral patterns and national systems of innovation. In our case, innovation drivers and knowledge creation explain 80.8 per cent of the level of overall innovation performance in the EU. It should be noted that, on the basis of 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 several southern European countries, such as Spain, Greece, Portugal and Italy, also score low on innovation performance. The further north in the EU, the more the innovation performance level rises: with a medium level of innovation performance occurring 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 (patent) 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. However, the analysis largely leaves open the question how such a level of output can be achieved, although all three 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 for these countries, seems rather a result of its very stable character than its non-existence.

Further, our research supports the assumption that innovation is a systemic process that is inherently shaped by the characteristics of the regions where innovative activities are located (Gertler et al., 2000; Cooke, 2001; Todtling and Trippl, 2005). In this study alone, we have found that innovation performance is different per culture, and 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, however, also some overlaps visible that may explain some of the differences in innovation performance in Europe. New Member States, for example, seem to benefit from public R&D expenditures. For developing countries in particular, the policy level seems to constitute a major channel of interaction. In Eastern European countries, for example, national policies have often promoted core industrial areas for a prolonged period of time, but have neglected others, a policy strategy that affects the entire national system of innovation and may eventually turn out to be locked into a specific path (Narula, 2002). Our study further shows that 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 two groups of EU countries is important. For the high level innovation countries, it is more difficult to draw similar conclusions. Denmark and Sweden both have a high level of employment in high-tech services and a medium level 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, however, the latter three countries lack a consistent level of intellectual property. Also, with regard 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 specific innovation output factors for these countries is necessary in order to validate these results.

7. Conclusion and policy recommendations

The evolutionary framework points towards the effectiveness of innovation policies that encompass a broader set of interventions to foster and upgrade the technological and learning capabilities of the various components of an innovation system (Metcalfe and Georghiou, 1998; Nyholm et al., 2002). Our results support such a viewpoint. Such innovation policies should be developed on both a national level and European level. There seems some form of correlation between R&D and human capital expenditures, which underlines that R&D activities undertaken by private firms greatly benefit from the existence of a well-functioning set of institutional support systems in the science and technology domain. On a national level, therefore institutional support systems need to be aware that the components of a system of innovation include not only private firms and their R&D activities but also public organizations such as universities, public research institutes, science parks, and so on. Another important aspect of policy making according to an evolutionary framework is, therefore, to support and foster those connections and interactions which constitute the basic structure which defines the properties of a system and its dynamic trajectory over time (Conceição et al. 2003). Private R&D activities are an important element of the innovative process, but by no means the only aspect to look at in order to support the competitiveness of industrial systems. The high relevance of the level of population with tertiary education for innovativeness in our analysis underlines this claim. Policies should take into account the interactions existing between the different institutional levels, and coordinate as much as possible sector-specific innovation and industrial policies at the national level which govern the macro-economic environment, the trade and financial regimes, and the education system. Regional policies also play a relevant role in the innovative process. The outcomes of our analysis show the distinction between economically (and politically) developing countries and developed countries in Europe, and, as a result, underline the importance of cohesion policies aimed at actively fostering the technological capability and absorptive capacity of backward regions (Cappelen et al., 2003) rather than a focus on competitiveness-enhancing interventions in advanced industrial 'clusters'. This cohesion objective is given considerable attention in the Maastricht Treaty and a good example of a European initiative in this direction is the Structural Funds where financial assistance is provided to resolve structural economic and social problems. Much of the discussion on 'catching-up' of less privileged regions concentrates on macro-economic characteristics, i.e. inflation, the public sector deficit, external account and so on (Sharp, 1998). However, there appears to be little evidence to support this view. Others have therefore suggested that regional growth differences can better be understood by looking at micro-economic factors (Fagerberg and Verspagen, 1996). The results of our analysis support this view and provide directions to improve both regional innovation policy and national competitiveness. Our results further show that the focus of European policy should in this respect be more strongly on the socioeconomic impacts of innovation programs while national focus should rather be on the actual impacts in the economy, i.e. the micro-aspects of growth of firms, expansion of industries or increase in gross domestic product. The 'socio' in 'socio-economic' in this respect represents any goals that are not obviously economic. In this particular case, regional focus should thus be in particular on social cohesion, even more so with regards to the fortcoming enlargement(s) which would add more countries and regions to the list. Competitiveness and cohesion are in this respect mutually reinforcing: a competitive, thriving

EU should set aside resources to promote cohesion regions, while narrowing the gaps between advanced and laggard regions enhances the competitiveness of the EU as a whole (Havas, 2008). National economies, on the other hand, are due to historical origins, characteristics and unique industrial, scientific, state and political institutions traditionally more strongly related to technological and scientific specialization, innovation cultures and economic growth and should therefore focus much more on national systems for optimal result.

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