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RANKING REGIONAL INNOVATION POLICIES: DEA-BASED BENCHMARKING IN A EUROPEAN SETTING

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ABSTRACT

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Keywords: regional innovation policy, region, European Union (EU), Data Envelopment Analysis (DEA), policy evaluation

Regional innovation is a complex phenomenon that often resides in the interplay of several local actors and has traditionally been resistant to attempts in evaluating and assessing its impact. This study called upon the Data Envelopment Analysis method, which has previously been successful in the evaluation of other cases, where the tacit relations between different inputs and outputs are not obvious. A conceptual model of regional innovation was devised, which was subsequently quantified into a total of twelve statistical indicators as inputs and outputs. Using Eurostat as the data source, source data for eight of these indicators was retrieved at regional level, along with one complementary national indicator, and utilized in the efficiency calculations of 45 European regions. The focus of the study was in the usability of the DEA analysis method in the context of innovation system efficiency evaluation, which has not been attempted earlier. The initial findings proved unsatisfying with exceedingly high amounts of efficiency allocated to the regions. Correctional measures to improve discrimination accuracy of the model were presented and applied resulting in more realistic efficiency scores and rankings of the regions. It was determined that DEA may prove to be an effective and interesting tool for developing evaluation practices and regional innovation policies, once issues with data availability and refinement of the model have been solved.

TIIVISTELMÄ

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Seudullinen innovaatio on monimutkainen ilmiö, joka usein sijaitsee paikallisten toimijoiden keskinäisen vuorovaikutuksen kentässä. Täten sitä on perinteisesti pidetty vaikeasti mitattavana ilmiönä. Työssä sovellettiin Data Envelopment Analysis menetelmää, joka on osoittautunut aiemmin menestyksekkääksi tapauksissa, joissa mitattavien syötteiden ja tuotteiden väliset suhteet eivät ole olleet ilmeisiä. Työssä luotiin konseptuaalinen malli seudullisen innovaation syötteistä ja tuotteista, jonka perusteella valittiin 12 tilastollisen muuttujan mittaristo. Käyttäen Eurostat:ia datalähteenä, lähdedata kahdeksaan muuttujsta saatiin seudullisella tasolla, sekä mittaristoa täydennettiin yhdellä kansallisella muuttujalla. Arviointi suoritettiin lopulta 45 eurooppalaiselle seudulle. Tutkimuksen painopiste oli arvioida DEA-menetelmän soveltuvuutta innovaatio-järjestelmän mittaamiseen, sillä menetelmää ei ole aiemmin sovellettu vastaavassa tapauksessa. Ensimmäiset tulokset osoittivat ylipäätään liiallisen korkeita tehok-kuuslukuja. Korjaustoimenpiteitä erottelutarkkuuden parantamiseksi esiteltiin ja sovellettiin, jonka jälkeen saatiin realistisempia tuloksia ja ranking-lista arvioitavista seuduista. DEA-menetelmän todettiin olevan tehokas ja kiinnostava työkalu arviointikäytäntöjen ja innovaatiopolitiikan kehittämiseen, sikäli kun datan saatavuusongelmat saadaan ratkaistua sekä itse mallia tarkennettua.

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ABBREVIATIONS

BCC	Banker-Charnes-Cooper (DEA-model)
CCR	Charnes-Cooper-Rhodes (DEA-model)
CRS	Constant Returns-to-Scale
DEA	Data Envelopment Analysis
DMU	Decision-Making Unit
EU	European Union
Eurostat	Statistical Office for the European Communities
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
ICT	Information and Communication Technology
MERIPA	Methodology for European Regional Innovation Policy Assessment
NUTS	Nomenclature des Unités Territoriales Statistiques (engl. Nomenclature of Territorial Units for Statistics)
R&D	Research and Development
SME	Small and Medium-sized Enterprise
VRS	Variable Returns-to-Scale

1 INTRODUCTION

In recent years innovation has been recognized as one of the main forces driving economic development and providing increasing welfare, along with having a multitude of other positive effects. Intensive research in innovation management has proven that it is a phenomenon which can be managed and promoted by conscious choices, rapidly raising interest in developing first national, and now regional innovation policies and programmes.

The European Union has also recognized innovation as a key theme in providing sustainable socioeconomic wellbeing. Even though some concept of how to foster innovation and what are the effects of innovation activity have been established in theory, evaluating these effects still lacks commonly agreed measures and practices, which are critical to enabling further development of innovation policies and securing the possible benefits they would bear.

1.1 Overview

The research report explores the usability of an alternative method for assessing the effectiveness and impact of implemented regional innovation policies. This benchmarking effort is crucial for identifying best practice –cases among studied regional innovation policies, providing a foundation for understanding the dynamics of regional innovation systems and the limits to which they can be affected by applying policy tools in a given regional context. The results of benchmarking are to be used as a basis for uncovering the reasons behind the performance of the examined regions which, in turn, is helpful for the formulation of well-founded policy recommendations.

DEA has been previously applied to policy efficiency evaluations in other policy areas in numerous studies, as can be verified from eg. the DEA bibliography by Gabriel Tavares (2002). The same is true for innovation-related efficiency assessment, although the bulk of research has been focused on the firm, industry or national levels, leaving the regional perspective of innovation nearly untouched. With the ever-increasing attention to regional innovation, for example by the European Commission, and the examples set by both innovation and policy DEA studies, the task of measuring regional innovation efficiency appeared to be a suitable, contemporary research area.

During the making of the report (in July 2007) Zabala-Iturriagagoitia et al. published their own paper, establishing the first attempt ever to apply DEA to measuring regional innovation system efficiency and further validating the research standpoints taken in this study. The primary differences in their research were that they based the evaluation on information provided by the European Innovation Scoreboard and employed a methodology combining qualitative analyses to quantitative ones (Zabala-Iturriagagoitia et al. 2007).

1.2 Objectives and Restrictions

Two initial standpoints come together to define the goals of the research and the restrictions that focus the study. On one hand, there is the problematic of benchmarking and assessing regional innovation policies' effectiveness and impact (see, eg. European Commission 2006), and on the other, there is the set of possibilities provided by the chosen Data Envelopment Analysis –method. Combining these has lead to the formulation of the following main research questions of this study:

Can DEA be used to benchmark and assess innovation policy effectiveness and impact?

Is it possible to provide meaningful insights to regional policy development that policymakers can act on, through a transnational comparison of regional policies with the DEA-model?

Can actual best practice –cases of regional innovation policy be identified with the model?

In addition to these research questions one main objective is to enable easy communication of the results and provide the context in which the users may position themselves, in terms of achieved efficiency, in relation to other regions. This is sought by the building of a ranking list of involved regions and assessing the realism of the proposed ranking. Ranking is seen as a powerful tool for communicating results to a wide range of non-specialist audiences, such as the regional actors involved in public policy process, and therefore exploring the possibility of building a viable ranking with the DEA -method is considered an important objective.

To sharpen the focus of the study, several restrictions are naturally derived from the initial standpoints. As the report aims to enable transnational comparison standardized source data, which is most abundantly available in Europe, is required. Thus the report adopts a predominantly European standpoint, although a similar method may prove functional in regions outside Europe as well. The choices for the theoretical framework (e.g. definition of innovation) have an impact on the choice of indicators, which also narrows the scope of research and the results to be achieved. Data Envelopment Analysis, the method of analysis applied, also imposes certain restrictions. Although the method is considerably liberal in terms of the quality of data that may be used, constraints such as nonnegativity of the input data have an effect on the choice of indicators, in addition to enabling only quantitative analysis.

1.3 Structure of the report

Figure 1, shown below, shows the structure of the report. Chapters 2 to 5 form the necessary theoretical basis for building a basic understanding of the phenomenon of regional innovation, the role of public policy and the Data Envelopment Analysis that is deployed to provide means for cross-national benchmarking of European regions. This provides the reader with the ability to comprehend the research performed in the empirical chapters 6 and 7, and acknowledging the conclusions drawn in the finishing chapter of the report, at chapter 8.

Chapter 2 provides a basic picture of the popular concept of innovation, further exploring its systematic nature and displaying the role that public policy may play in promoting it. The insight thus provided is instrumental to the development of the DEA-model later, in chapter 6. Chapter 3 deals with the regional perspective of the work, defining the concept of a region and revealing the spatial boundaries of innovation activity thus proceeding to justifying the need for regional innovation policies. Chapter 4 turns the attention towards effectiveness and impact assessment, acting as an introductional guide to the concepts of benchmarking, quantitative indicators, impact assessment and general evaluation practice. The theoretical part finishes with a concise presentation of the main research method deployed: the Data Envelopment Analysis, in chapter 5.

Chapter 6 engages with the construction of the Data Envelopment Analysis –model disclosing the process of capturing the regional innovation phenomenon in quantifiable terms in an analytical frame. Chapter 7 describes the actual benchmarking and discusses the results and their implications to some detail. Finally, chapter 8 summarizes the report and provides finishing conclusions and suggests avenues for further research.

INPUT		OUTPUT
The research sphere of the MERIPA project and background knowledge.	**Chapter 1: Introduction** The introduction to research focus and formulation of research questions.	Overview of the study. Objectives, restrictions, relevance and the structure of the Thesis.
Basic information about innovations, innovation systems and programmes based on literature.	**Chapter 2: Innovations** Defining innovation and its complex, systematic nature.	Definition of the innovation concept. Displaying the link between innovation policies and systems.
Literature review and EU perspective of regions in relation to innovation and innovation policy.	**Chapter 3: Regionality** Spatially bounded aspects of innovation; explaining the need of a regional innovation policy.	Overview of regions and rationale behind regional innovation policy.
General literature review of quantitative indicators, impact assessment and benchmarking.	**Chapter 4: Effectiveness and Impact Assessment** Basic theory and methodology for benchmarking.	Comprehension of benchmarking practise. Understanding of impact assessment and benchmarking practise.
Literature on Data Envelopment Analysis method, recent developments and applications	**Chapter 5: Data Envelopment Analysis** Presentation of the deployed analysis method.	Options available for specific choice of the model and knowledge of features and limitations of the method.
Theory-based simplification of regional innovation. Information on indicator availability.	**Chapter 6: Construction of the DEA-Model** Exposition of the model's construction process.	DEA-model for benchmarking impact and effectiveness of regional innovation policies.
Constructed model, gathered indicator data and relevant background information.	**Chapter 7: DEA Benchmarking** Benchmarking and results.	Benchmarking findings, ranking list of benchmarked regions; reasons to explain rankings.
Benchmarking findings, applicability of the method and ranking list.	**Chapter 8: Conclusions** Concluding remarks and summary of findings.	Conclusions and suggestions for topics of further research.

Figure 1. Structure of the report

2 INNOVATIONS

Innovations and innovativeness have been the concepts driving business development over recent years and are widely recognized as the primary drivers for developing companies' competitiveness, and on the macro-level, the performance of different economies. As Cooke (1998a) puts it, the firm must be competitive to survive and being competitive also means being innovative; competitiveness and innovativeness have become inextricably linked.

2.1 Definitions of Innovation

Generally it can be said that innovations refer to a (typically technological) invention or novelty that has meaning in a business context. Numerous different variances on the theme do exist though, the commonly agreed elements being a new idea (to the innovator or targeted market area) and the market-approved implementation thereof, which may have various forms.

Daft (1986) lists some of the forms the implemented novelty may have, as follows: Innovation can be a new product or a service, a new production process technology, a new structure or administrative system, or a new plan, or a program pertaining to organizational members. As for the novelty of the innovation, the following is proposed by Van de Ven (2008): "*As long as the idea is perceived as new to the people involved, it is an "innovation," even though it may appear to be an "imitation" of something that exists elsewhere.*" Thus, innovation covers a wide spectrum of business opportunities which are based on new technology (or other corresponding solution) or market combinations, ranging from minor improvements to the emergence of a new product (Kotonen, 2007). Table 1 depicts one possible classification of innovation types.

Table 1. The standard classification of innovations (Verloop 2004, p. 21)

Innovation type	Service Process Product Component Material
Incremental	Modifications, refinements, enhancements, simplification
Discontinuous	Obsoletes technologies, processes, people
Architectural	Changes, core design concept to new architecture
Systems	Dominated by societal and government regulations
Radical	Develops into major new businesses or spawns an industry
Disruptive	Brings the user a new value proposition
Breakthrough	Moments in history that set the stage for future

One common definition of reference for innovation can be found to follow broad Schumpeterian lines. The report builds on this same definition.

"An innovation can reform or revolutionize the pattern of production by exploiting an invention or, more generally, an untried technological possibility for producing a new commodity or producing an old one in a new way, by opening a new source of supply of materials or a new outlet for products by reorganizing an industry." (Schumpeter, 1912, quoted in Maskell & Malmberg, 1999)

Observing innovation from a process point of view provides further insight in to the phenomenon, and subsequently on how to further innovation efforts. Rothwell (1992) provides an overview to the development of models describing the innovation process, which is summarized in table 2 below.

Table 2. Rothwell's five generations of innovation models (adapted from Tidd et al. 2005, p. 77)

Generation	Key features
First and second	Simple linear models of *technology push* and *market pull*, placing the starting point of innovation at a new, discovered technological opportunity and at an unserved need at the market, respectively.
Third	The *coupling model* introducing the interaction between different elements and feedback loops between them as key elements in the process.
Fourth	The *parallel model* largely abandons prior sequential views and emphasizes linkages and alliances, integration within the firm and throughout the value chain.
Fifth	Coping with the rapid pace of innovation, the model evolved to the *strategic integration and networking model* where multiple actors are involved to provide for flexibility and speed to the innovation process

Adding to these, Yaklef (2006) proposes that future innovation processes will emphasize both internal R&D deployment, to maintain a level of absorptive capability (e.g. the ability to thoroughly understand and make use of acquired and emergent technologies), and collaborative open practices simultaneously. The fifth-generation model and the future extensions proposed by Yaklef imply that innovation should be seen as a phenomenon that transcends enterprise and institutional boundaries, residing in far more complex systems.

2.2 Innovation Systems

The era of "post-Fordism" (see, for example, Amin 1994) shifted the principles of economic success and competitiveness, forcing firms to discard the paradigm of classical Fordism and renew their corporate structures as competitiveness becomes dependent of innovativeness, which in turn is linking ever stronger to the concept of collaboration and networking. This collaboration extends from working tightly with suppliers to exploiting linkages to public and quasi-public agencies to pursue the company's interests for example concerning technology transfer, vocational training or enterprise support. (Cooke 1998a)

Whereas, traditionally, the larger corporates behaved almost like self-sufficient islands, sourcing internally, abiding to the closed innovation model and competing on a stand-alone basis with little regard for the "soft infrastructure" of the host location, today all that is changing (Cooke 1998a). Innovation is not an isolated process and a continuously innovating enterprise is not a secluded island of knowledge production, instead it is just the opposite. This leads to establishing a systematic perspective to innovation. In Tidd, Bessant & Pavitt (2005), innovation systems are defined as follows:

"*By innovation system we mean the range of actors – government, financial, educational, labour market, science and technology infrastructure, etc. – which represent the context within which organizations operate their innovation process. In some cases there is a clear synergy between these elements which create the supportive conditions within which innovation can flourish.* (Nelson, R. 1993; Best, M. 2001)"

On the other hand, Lundvall (1992) offers a more general definition, according to which a system of innovation consists of elements and relationships that interact in the production, diffusion and deployment of new and economically useful knowledge. The systemic perspective of innovation stresses the importance of social interaction between economic actors placing the origin of innovation in the relationships between the different elements (Cooke 1998a).

Efficient innovation systems often imply the existence of innovative clusters. The concept of innovative clusters was presented by Michael Porter (e.g. Porter 1990). Clusters are networks including companies that are engaged in collaborative interfirm relationships, even though they are still in a natural competitive setting. In addition, clusters often encompass other actors as well ranging from universities and research institutes to governance institutes and customers so they embody the systemic nature of innovation. Generally, clusters exhibit above average innovational capabilities.

The following quote underlines the importance of viewing highly complex, multi-faceted matters such as innovation policies from a systematic perspective rather than dealing with them piece by piece via narrow focus programmes. "*It is important to recognize that, by attempting to modify one part of the innovation system, policy interventions will initiate changes in other parts of the system.*" (European Commission, 2006)

According to the MERIPA (Methodology for European Regional Innovation Policy Assessment) supported view, in the system of innovation approach, innovation is seen as an interactive process where innovation is shaped by institutional routines and social conventions, seeing knowledge creation, adaptation and diffusion as the most important processes. (MERIPA 2006)

2.3 Innovation Programmes

Innovation programmes are generally understood as the practical, manageable sets of means to realize the goals set in innovation policies, visions and strategies. The European Comission (2006) defines that innovation programmes are measures, schemes, initiatives, etc. funded by (any level of) government, aimed at the promotion, support or stimulation of innovation and innovation-related activities. They may operate either directly, through the provision of funding, information or other support; or indirectly, through facilitation of the innovation process (i.e. via fiscal or regulatory reform). Some innovation programmes may have innovation as a secondary objective, or as a means to an end such as greater energy efficiency, or regional development.

The innovation system perspective that has become increasingly dominant in the design of innovation programmes raises the complexity of innovation programmes to a new level. Expanding the previous simplified linear model of innovation (see section 2.1) where R&D was seen as the primary (and the only significant) starting point of innovation to systematic perspective constitutes the need for more sophisticated and comprehensive means of evaluating innovation programme effectiveness. Indicators previously adapted from assessment of industrial R&D evaluation are no longer sufficient to display the influence of programmes on various parts of the innovation system. (European Comission, 2006)

3 REGIONALITY

The European Union has shown growing interest towards the study of regions and regionalism and in supporting political action at regional levels. This interest can be seen in the multitude of regionally focused programs and initiatives taken in recent years, such as the creation of the Innovating Regions in Europe – network and the establishment of Committee of the Regions in 1994, both of which act in coordinating numerous initiatives with a strictly regional focus.

Regions are gathering a lot of attention from both academic and political viewpoints partly due to the regional aspects of innovation activity that will be discussed in more detail later in this chapter, in section 2. This makes regional steering of economic development an increasingly viable option for policy-makers. Also, some interest may be attributed to the strong encouragement of the European Commission to promote regionalism.

3.1 The Concept of Regions

The word region has a wide range of meanings in the various disciplines of social sciences and in the historical tradition of European countries. There is a consensus that the term refers to space, but the concept of space itself can have several meanings: territorial space, political space and the space of social interaction, economic space, and functional space. A region is the result of various notions of space. It is also an institutional system, either in the form of regional government or as a group on institutions on a territory. (Keating 1998, p. 11)

Ohmae (1993) argues that (especially the more dynamic) regions represent authentic communities of interest, define meaningful flows of economic activities and are advantaged by true synergies and linkages between economic actors. According to de Vet (1993) what gives a region a strong identity, is the institutional capacity to attract and animate competitive advantage, often by promoting cooperative practices among economic actors, thus creating networks that strengthen the regional identity even further.

Notionally, regions can be defined in terms of shared normative interests, economic specificity and administrative homogeneity. In addition to these there may be such criteria as non-specific size; particular homogeneity in terms of criteria such as geography, political allegiance and cultural or industrial mix; ability to distinguish from other areas by these criteria at issue; and occupancy of internal cohesion characteristics. (Cooke 1998a, p. 15)

One standard division of regions in Europe, which is used by the Statistical Office for European Communities (Eurostat), is according to NUTS levels, which is short for the French term Nomenclature des Unités Territoriales Statistiques (engl. Nomenclature of Territorial Units for Statistics). The NUTS level division is made according to a set of basic principles that aim to strike the balance between functionality (e.g. compatibility with established governmental levels) and comparability (e.g. regions of same level should be roughly of the same size). The NUTS nomenclature was created and developed according to the following criteria. (Eurostat 2005)

1. *The NUTS favors institutional breakdowns.* Subdividing a national territory into regions is normally done according to normative or analytical criteria. Normative regions are the expression of a political will; their limits are fixed according to the tasks allocated to the territorial communities, according to the sizes of population necessary to carry out these tasks efficiently and economically, and according to historical, cultural and other factors. Analytical regions are defined according to analytical requirements, e.g. geographical or socio-economic criteria. Practicality favours institutional divisions currently in force in the Member States (normative criteria).
2. *The NUTS favors regional units of a general character.* Territorial units specific to certain fields of activity (mining regions, rail traffic regions, farming regions, labour-market regions, etc.) may sometimes be used in

certain Member States. NUTS excludes specific territorial units and local units in favour of regional units of a general nature.

3. *The NUTS is a three-level hierarchical classification.* The NUTS subdivides each Member State into a whole number of NUTS 1 regions, each of which is in turn subdivided into a whole number of NUTS 2 regions and so on. The minimum and maximum thresholds for the average size of the NUTS regions, seen in table 3, are set by the NUTS Regulation. In the near future, the question of extending NUTS to a fourth level will be discussed in the Commission. (Eurostat 2005)

Table 3. NUTS Regulation for average size of NUTS regions (Eurostat 2005)

Level	Minimum population	Maximum population
NUTS 1	3 million	7 million
NUTS 2	800 000	3 million
NUTS 3	150 000	800 000

3.2 Regional Aspect of Innovations

According to Porter (1990) even the largest, global companies draw on mainly one, or two, countries for their strategic skill and expertise in innovation strategy formulation and execution. Later research has, in part, narrowed the basis of innovative companies from a national stage to the regional level (e.g. Chung 2002; Gerstlberger 2003; Ohmae 1993 and Cooke 1998a).

Emergence of the concept of regional innovation systems in 1992 (e.g. Cooke 1992) was partly driven by the putting together of research of some key elements as the existence of regionalized technology complexes (Saxenian 1994) and large-scale “technopolis” arrangements (Castells & Hall 1994, Scott 1994), that were previously researched independently. Linking together business networking, technology transfer and vocational training provided the key pillars for the "systems house" of regional innovation (Cooke & Morgan 1994, Körfer & Latniak 1994) that sparked further interest in to the subject. (Cooke 1998a)

In most cases, ICT-enabled virtual collaboration can not effectively substitute for regional innovation systems. This inability is attributable to the impediments inherent to geographic separation of the collaborating parties and the regional factors of innovation mentioned later on. Wolfe & Gertler (1998) provide an example when investigating the regional innovation system in Ontario, Canada. In the industrial machinery sector of Ontario, most of the advanced manufacturing technologies were imported from far abroad, where they had been designed and built with a different set of cultural assumptions and practices. This led to problems in implementing the technology successfully, bringing to light the disadvantages of physical separation of user and producer: increased costs, difficulty in creating an efficient channel of communication and an altogether weak level of interaction, despite having the advantage of up to date communication technology at their disposal. This inevitably led to significantly reduced innovation performance and, as a result, inferior productivity compared to international benchmarks.

Even when modern ICT (electronic mail, video conferencing etc.) would allow for clusters that are not geographically defined, most clusters tend to be spatially bounded and able to be defined as innovative regional clusters. According to Cooke (1998b), "*the innovative regional cluster will consist of firms, large and small, comprising an industry sector in which network relationships exist or can be commercially envisaged, research and higher education institutes, private R&D laboratories, technology transfer agencies, chambers of commerce, business associations, vocational training organizations, relevant government agencies and appropriate government departments. This constitutes an integrative governance arrangement*." This definition can be summarized into a general list of essential key features, the presence of which implies the existence of an innovative regional cluster:

- Public and private sector *R&D* in the industry,
- active *supply chains* from assemblers to systems and parts,
- public and private sector *training* centres and partnerships,
- demanding intermediate and final *customers*,
- a core industry *sector*,
- a public and private sector *support infrastructure*,
- *related industries* within the region,
- *support industries* within the region and
- *promotion* of the regional specializations. (Cooke 1998b)

Basically the regional innovation system is a combination of innovative networks and institutions located in a certain geographic area, with regular and strong internal interaction that promotes the innovativeness of the companies in the region. The significance of the institutional framework surrounding a company originates from its capacity to support the innovativeness of the company. Agents operating in a regional innovation system include research institutions, organizations involved in technology transfer, technology centers, investors, financiers of R&D and regional development organizations. (Kostiainen 2002, p. 80) In summary, several factors weigh in on the regional dimension of innovation processes (Asheim & Isaksen 2003, p. 41):

1. Industrial clusters are in many cases localized
2. Educational institutions and research organizations are often tied to specific regions
3. Interaction between firms and knowledge providers, knowledge spillovers and spin-offs is often localized
4. A common organizational and technical culture may develop to support learning and innovativeness
5. Regional public institutions seem to become more active in supporting technology transfer and innovation activity

3.3 Regional Policies

There are several motives for taking a regional standpoint on innovation policy. Regional innovation policy can be justified by:

1. Deeper understanding of localized business structure
2. Manageable size of governable area enables true interaction and communication between stakeholders
3. Regional aspects of innovation (mentioned earlier)
4. Inherent connections with other regional policies
5. Easier to implement, measure and evaluate appropriately and accurately (as opposed to a national policy)
6. Enables addressing regional differences and deploying more specific actions

The degree of autonomy and political power wielded by regional authorities as governmental units vary between regions depending on the national governance structures. Keating (1998, pp. 26-27) classifies policy-making capacity to be one dimension of the power of regions. Regions with a political system, a decision making capability and ability to legitimately establish a "regional interest" can gain from this feature compared to regions which lack this unity of action and are reduced to being simply relays of other systems of actions. Capability for more or less independent policy-making combined with an intimate knowledge of their own innovation system, and the regional specific traits and needs thereof, makes regions preferable governmental units for both the development and implementation of innovation policy.

The interrelation of regional development and innovation has also been recognized in regional policymaking, both at the national and the European level. Many activities, especially those originated from EU, to support regional development have a strong focus on improving innovation performance. Support can be steered directly to RTD projects or indirectly to upgrade innovation-related infrastructure. Structural change, leading to a higher share of competitive companies and thus to economic advancement, is nearly impossible without an innovative business sector. (Kotonen 2007, p. 9)

The existence of inherent linkages to other established regional policy fields is one of the main arguments for regional innovation policies. Innovation policy can be understood as a combination of science, technology and industrial policies. In this context innovation policy is regarded as broader than any of the other policies. It also has other elements, such as environmental and energy related. The general aim of the policy is to utilize the innovation potential even in sectors of economy that are not usually innovative or innovation-intensive. (Kotilainen 2005, p. 77) This interplay of innovation policy in regard to other policy areas is illustrated by figure 2 (Kuhlmann & Edler 2003, p. 620).

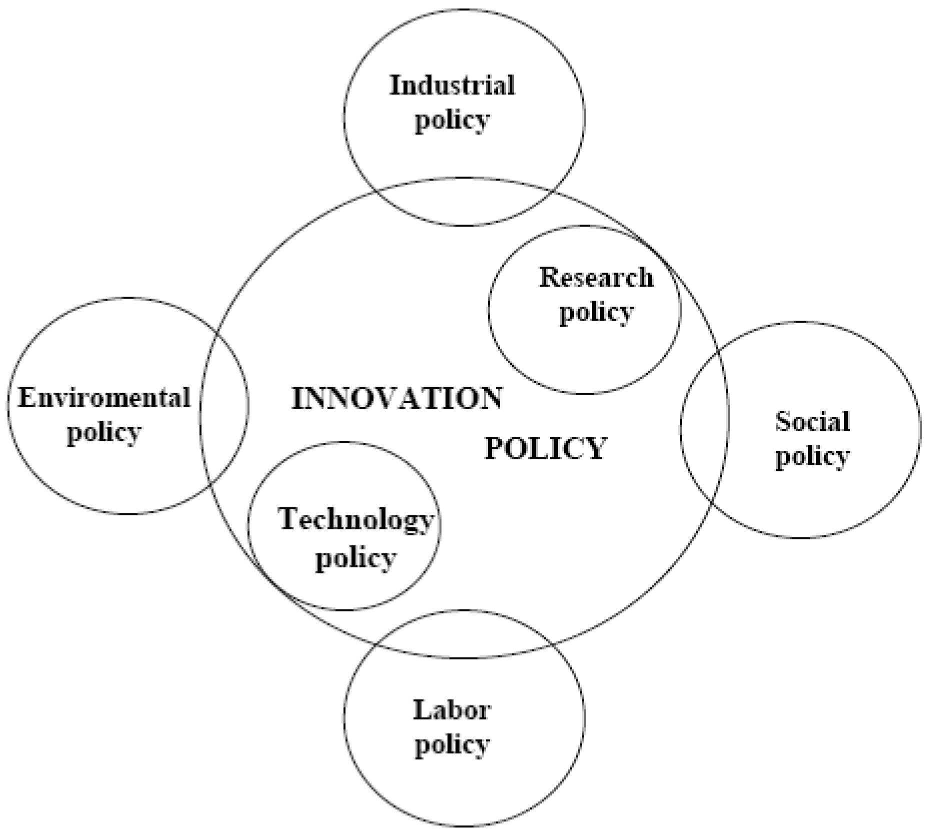


Figure 2. Innovation policy in regard to other policy areas (Kuhlmann & Edler 2003, p. 620)

Regional innovation policy comprises those targets and actions which are executed on national and regional level as well as in their co-operation in order to enhance innovation activities on geographically defined areas. By means of regional innovation related policies it is possible to boost positive, self-strengthening development of business around the companies. (Lemola 2006, pp. 14, 22). The definition of innovation policy is broad and allows for numerous significantly different approaches for policy initiatives. Regional innovation may be promoted by direct intervention (e.g. by targeted subvention or financing), subtle influence on the economic environment or anything in between. It has to be identified under which circumstances, in which countries and industries and at what times, which mechanisms are important and, on the other hand, which goals can effectively be pursued by policy measures (Brenner & Fornahl 2003, p. 3). Lessons learned through policy evaluation can help in this respect.

The relation and interplay between national and regional governance bodies in innovation policy work is one of the issues that define regional policymaking. The two main perspectives on the issue can be characterized as top-down or bottom-up perspectives. Top-down perspective on innovation policy links the regional policies tightly with national interests and priorities, which drive regional innovation policy work. The bottom-up perspective the policies are conceived at the regional level, providing for distinctive, region specific policies. The perspective also entails setting the regions to compete for funds and integration in to programs developed at the national and pan-national (e.g. EU) levels. (Howells 2005, pp. 1225-1226) In regional innovation policy, the trend is increasingly moving from the top-down to the bottom-up perspective, which is by some studies found to be more efficient at achieving the policy goals (e.g. Fritsch et al. 2004, p. 289). Supporting this view, on his research of Korean regional innovation systems, Chung (2002) suggests that a concept of regional innovation system is a good tool to generate national innovation system, developing the national system by strengthening the regional pieces that make the whole.

3.4 Innovations and Regional Competitiveness

It is now widely recognized that competitiveness and other socioeconomic goals are heavily dependent on industrial innovation (European Commission, 2006). Econometric methods have indicated that innovations and new products might be one of the key factors related to acceleration of the growth of companies (Lehtoranta & Uusikylä 2005, p. 2). Besides being recognized as the key to economic development especially for advanced, high-wage countries (Nauwelaers & Wintjes 2002, p. 201), the importance of science in creating and sustaining wealth, yielding in turn much wider social, cultural and economic benefits is significant.

The different aspects of regional competitiveness form an intertwined system where all the pieces are in constant interaction with each other (Linnamaa 1999). Innovations link in to the system of regional competitiveness, thriving in competitive regions and further feeding into their competitiveness (Sotarauta 2001). As one significant part of this, innovative enterprises generate high revenue and are good for PR, which in turn strengthen the region and attract more innovators. One intangible aspect that defines regional competitiveness is the attractiveness of the region both to external parties (e.g. foreign investors, mobile workforce) and to internal parties (e.g. deterring regional companies' interest to move operations elsewhere) (Raunio 2001; Sotarauta, Mustikkamäki & Linnamaa 2001). Etzkowitz and Klofsten (2005, p. 243) suggest that the common objective of knowledge-based economic development everywhere in the world is the creation of an 'Innovating Region'. According to them, an innovating region has the capability to move across technological paradigms and periodically renew itself through new technologies or products and firms generated from its academic base. These points combined, it can be argued that innovations act as generators of regional competitiveness, which is in turn partly measured by ability to facilitate innovational activity in the region.

It is commonly acknowledged that regions with solid institutional infrastructure, especially universities, have a distinct advantage over those that do not (see e.g.

Koschatzky 2003, pp. 277-302). The role of universities is attributable to two key effects they have. First of all, universities provide basic science, the research and technology to feed innovation and often engage in cooperation with private businesses. Secondly, they bring in talented students, building up a local competent workforce to exploit meanwhile heightening the region's attractiveness. While being ample sources of knowledge and R&D –assistance, the latter effect of universities is something that dedicated research institutes alone cannot provide.

4 EFFECTIVENESS AND IMPACT ASSESSMENT

Evaluation and measurement may employ qualitative or quantitative methods, or even both. The methodology used to assess effectiveness and impact of policies in this study adopts a quantitative focus, depicting the complex issue of regional innovation through simplified indicators aiming to allow for wide scale benchmarking on the analysis results. Sections below hold a brief introduction to quantitative measurement, indicators and benchmarking.

4.1 Indicators and Measurement

Simply described, quantitative research methods gather data in numeric form aiming towards describing and analyzing the data (Heikkilä 1998, p.17). A quantitative measurement focus has certain distinct advantages. Quantitative indicators enable comparability across several projects with the same broad attributes (e.g. different innovation promotion schemes, innovation ranking lists) and likewise comparability between different time frames, also permitting longitudinal analyses. They are also attractive due to their easy interpretation by both internal and external audiences, although the lack of contextual details that makes them easy to comprehend also entails the possibility of partial or even misinterpretation. (European Commission, 2006)

The European Commission (2006) presents the following definition: indicators are the measurable outcomes which show whether objectives of the measurable target (programme, policy etc.) are being achieved. The definition is accompanied by some general guidelines for the selection of indicators. These are presented below in table 4.

Table 4. General guidelines for the selection of indicators (European Commission, 2006)

Suggested properties of valid indicators	
Relevant	There should be a clear intuitive link between the indicator and the objective that is to be achieved. To provide a better picture of performance, indicators should be output-oriented, or if measuring relative efficiency, both input and output indicators may be combined.
Bound and comprehensive	Information should be provided with a small number of most significant indicators that cover all the main aspects of the target of evaluation.
Accepted	Indicators should be discussed with the interested parties to reach an agreement on their interpretation and acceptance.
Credible	Indicators should be unambiguous, easy to interpret and credible for reporting purposes.
Easy	The indicator data being accessible and readily obtainable means that the evaluation can be carried out without disproportionate costs for acquiring information. In addition, indicators should also be capable of independent verification.
Reliable and robust	Indicators should be impervious to manipulation and unwanted distortion, exhibiting an appropriate level of accuracy and dependability.
Consistent and comparable	Ideally indicators remain consistent from year to year and display comparability even across different contexts.

There are a number of motives and rationales for evaluating and benchmarking innovation policy performance. Essentially good evaluation practices aim towards enabling learning, establishing best practices, validating results, providing control, communicating the success (or lack of) of policies and the reasons behind it. Specific motives for carrying out policy evaluation are listed by the European Commission (2006, p. 35):

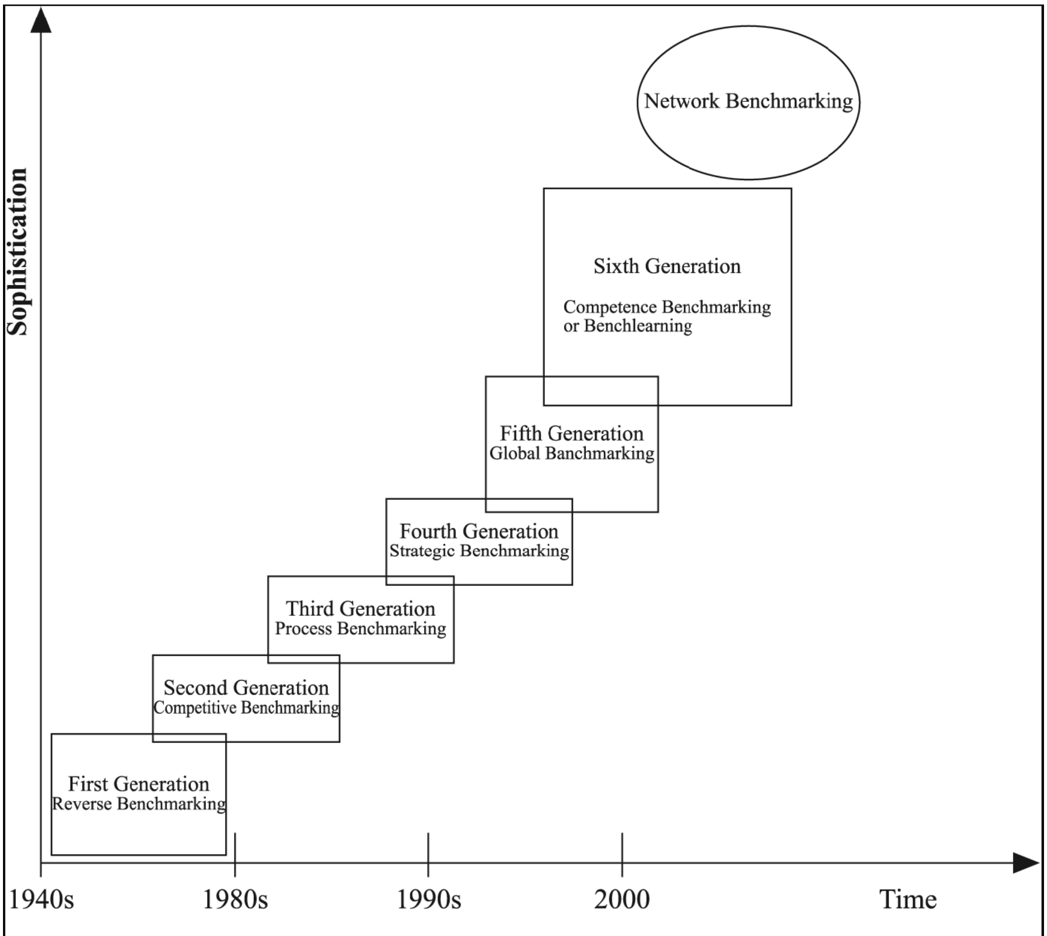
- assessing value-for-money,
- improving the design of future programmes,
- informing the priority setting process,
- enhancing policy design and
- other benefits (such as dissemination, documentation and promotion).

For evaluations and assessments to be able to provide the benefits mentioned above, the measurements must be put into use by integrating evaluation to the policy process, even as a part of the actual policy product, instead of treating it as a mandatory add-on to project reporting. The European Commission (2006, p. 22) states that "*there is a widespread view among experts ... that more evaluation in the field of innovation is needed to make Europe competitive enough to guarantee its inhabitants welfare in years to come.*"

4.2 Benchmarking

Benchmarking goes beyond the routine collection of publicly available information. It consists of comparisons amongst competing peers on specific dimensions of performance with the purpose of identifying and catching up with best practice. (Tidd et al. 2005, p. 147) Benchmarking has established its position as a tool to improve organizations' performance and competitiveness in business life and recently extended its scope also to public and semi-public sectors (Kyrö, 2003). It has started to look for its scientific basis and proceeded from practice towards theorizing (Kyrö, 2004). Definitions of benchmarking today vary between scholars, but general aspects regardless of the definer include the evaluation and improvement (of among others, performance) by learning from others (Kyrö, 2003).

Kyrö has illustrated the different generations of the evolution of benchmarking beginning from reverse engineering in the 1940s, as seen below in Figure 3. The actual benchmarking approach can be said to have started in the 1980s when US firms, with Xerox as a notable pioneer, applied benchmarking for the first time to catch up with Japanese competition. (Camp 1989) The evolutionary aspect of benchmarking is shared by several scholars (e.g. Watson, 1993; Ahmed and Rafiq, 1998) and according to Kyrö, can be seen to incorporate six distinct generations and the upcoming addition of network benchmarking. (Kyrö 2003)



Source: Modified from Ahmed and Rafiq (1998, p. 288)

Figure 3. Different generations of benchmarking (Modified from Ahmed and Rafiq, 1998, by Kyrö, 2003)

The developments most relevant for understanding benchmarking in public sector are the fourth, and newer, generations. Strategic benchmarking, the fourth generation, started in the 1990s, when benchmarking evolved into a systematic process for evaluating options, implementing strategies and improving performance by understanding and adopting successful strategies from external partners. The fifth generation complemented this by taking a global orientation. After that the concept of benchlearning was introduced by Karlöf and Östblom in 1995, reflecting the newest developments connecting benchmarking to organizational learning processes and constituting the sixth generation of its evolution. (Kyrö, 2003)

"*Even though learning as a part or as a core of benchmarking has walked all along the evolutionary development, towards the end of twentieth century its nature, scope and shape had changed. Previously the focus was on model learning and, as Bhutta and Huq (1999) suggest, with problem-based orientation. The contemporary tendency is more process-oriented.*" (Kyrö 2003)

"*On the other hand Davis (1998) proposes, that especially in the public sector, instead of benchmarking antique practices, it would be better to invent new ones*." To achieve greater results, the concept is further broadened by shifting from just learning from others to genuinely learning with others, which is one of the distinct features associated with network benchmarking. As a concept and as a practise such benchmarking activities are just emerging. Network benchmarking is thought to be more likely to lead to generative learning that is using external influences to generate completely new, improved solutions. (Kyrö 2003)

4.3 Data Collection and Reliability Analysis

The considerably extensive data set combined with the requirements considering the further applicability of the DEA-model imposed major demands on the data collection process. The data had to be readily available, reliable and robust, in addition to covering all European regions at least at NUTS 2 level accuracy. Especially data collected at NUTS 2 level is rare, most statistical sources being content with gathering and presenting NUTS 1 level statistics. At the time of the study, the only data source that supplies most of the applied indicators at NUTS 2 level is the Statistical Office of the European Communities (Eurostat). The data set used in this study ranges from 2000 to 2004.

Hence, Eurostat was used as the primary and only data source for the study, although the usability of several others was examined. The data provided can be trusted as reliable by virtue of the credibility of the institution. The data has a good level of completeness, with few singular values for various regions missing. The missing values do not constitute a problem and should not greatly affect the reliability of the results gathered, as no single region is missing several statistics and the DEA-model is able to accommodate for slightly incomplete data, by adjusting the empirically determined weights of the indicators.

5 DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis is a new method, originally developed for research purposes, that has proven useful in a diverse variety of applications in managing, examining and improving efficiency. It was originally developed to measure the performance of various non-profit organizations, such as educational and medical institutions, which were highly resistant to traditional performance measurement techniques due to the complex and often unknown, relations of multiple inputs and outputs and non-comparable factors that had to be taken into account. (Cooper W., Seiford, L. & Tone, K. 2007) In recent years it has been successfully applied in measuring both for-profit and non-profit organizations, such as researching the efficiency of bank branches of a Mideast bank by Kantor and Maital (1998) or the effectiveness of regional development policies in northern Greece by Karkazis and Thanassoulis (1998) (Bowlin 1998).

5.1 Basic Principle and Features

Efficiency is determined as the ratio of outputs in relation to inputs of a given entity that is examined, which is referred to as a Decision Making Unit (DMU). This form of relative efficiency is commonly seen in partial productivity measures, e.g. “output per worker hour”. (Cooper et al. 2007, p.1) DEA has some distinct traits that have significant implications to practical applications of the method. DEA measures the relative efficiency by the observable inputs and outputs of several, different DMUs, assigning them efficiency scores ranging from 0 to 1, the score of 1 given to the most efficient in the group measured. The fundamental difference between traditional statistical approaches and DEA is that while the former reflects the average behavior of the observations, DEA deals with best performance, evaluating all performances from the efficiency frontier formed by the most efficient DMUs (Cooper et al. 2007). This quality points out the usefulness of DEA in benchmarking applications as the notion of best performance is built in to the method itself. The method also has other qualities unique to it that imply its value in numerous applications. Such are its ability to determine the following:

- the best practice - most productive group of DMU's ;
- the inefficient - less productive DMU's compared to the best practice DMU's ;
- the amount of excess resources used by each of the inefficient DMU's ;
- the amount of excess capacity or ability to increase outputs present in inefficient DMU's without utilizing added resources ; and
- the best practice DMU's that most clearly indicates that excess resources are being used by the inefficient DMU (Sherman 1992).

This information clearly and objectively indicates which units should be able to improve productivity and the amount of resource savings and/or output augmentation that the inefficient DMU's can potentially realize to meet the level of efficiency of the best practice units. (Sherman 1992)

5.2 Charnes-Cooper-Rhodes -Model

The basic notions of relative efficiency calculations and DEA were already introduced by M.J. Farrell in 1957, which Charnes, Cooper and Rhodes further elaborated in to a linear programming model in their paper in 1978, constituting what is now considered the starting point of DEA. The DEA method determines efficiency scores by the quotient of the weighted sums of outputs and inputs. DEA assigns each unit with so called ‘benefit of the doubt’ weights that produce the optimal scores with the unit’s unique profile of inputs and outputs, still keeping the final score from exceeding 1. Thus efficiency scores, detailing the portion of inputs the DMU is allowed to use to create the current amount of outputs (in the input-oriented model), or vice versa (output-oriented), are conceived. The efficient DMUs, with a score of 1, and their linear combinations form an efficiency frontier, against which the inefficient DMUs are compared. (Cooper et al. 2007) One key property of the DEA method is that the weights, as well as the efficiency frontier, are both endogenous to the model, defined empirically from the data set. This is one of the distinguishing qualities of the method, which has important implications, for example in the case of composite indicator calculations (Cherchye et al. 2006). Also the endogenous weighting removes the need of expert consultation for assigning meaningful weights to an efficiency calculation.

Mathematically represented, DEA maximizes the ratio of virtual output and virtual input (or in other words, the weighted factors) by solving a linear programming problem. The basic multiplier form of CCR linear programming model (named by the creators Charnes, Cooper and Rhodes) seeking to maximize outputs, is the following (as adapted from Cooper et al. 2007):

$$
\begin{aligned}
&\text{maximise} \quad && \theta = \sum_{r=1}^{s} \mu_r y_{ro} \\
&\text{subject to} \quad && \sum_{i=1}^{m} v_i x_{io} = 1 \\
(1)\quad & && \sum_{r=1}^{s} \mu_s y_{sj} - \sum_{i=1}^{m} v_m x_{mj} \leq 0 \\
& && (j = 1, \cdots, n) \\
& && v_1, v_2, \cdots, v_m \geq 0 \\
& && \mu_1, \mu_2, \cdots, \mu_s \geq 0
\end{aligned}
$$

Where

$\theta =$ sum of virtual outputs

$x_{ij} =$ amount of input i used by DMU j

$y_{rj} =$ amount of output r produced by DMU j

$v_i =$ weight of input i

$\mu_r =$ weight of output r

$n =$ number of DMUs

Subscript o refers to the DMU whose efficiency is calculated.

The model is solved n times to determine the relative efficiency for each DMU. The model represented here is a most basic DEA-model. Subsequent models and elaborations have brought in additional features, such as the calculation of slacks to determine the adjustments by which an inefficient unit could achieve efficient status. Multi-stage calculation of DEA also allows the definition of peers, which are a reference set of DMUs with a similar mix of inputs and outputs. (Coelli 1996)

The CCR-model is sometimes referred to as the CRS-model, by the fact that it builds on the assumption of constant returns to scale (CRS). Constant returns to scale means that outputs increase in direct relation to an increase in the inputs, or similarly decreases in inputs bring about relative decreases in outputs. To illustrate the function of the CCR-model, an example slightly modified from Cooper et al. (2007, p. 6-8) is presented (Savolainen 2007, p. 29). The DMUs in the example are different retail stores of the same chain, where the inputs are the number of employees and the shop floor area and the output measured is sales. Example data for this two input and one output DEA is presented in table 5 below.

Table 5. Example data (Savolainen 2007, p. 29)

Store		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Employees (10)	x_1	8	18	8	16	10	10	18	22	18
Floor area (1000 m^2)	x_2	6	9	1	8	20	4	12	10	8
Sales	y_1	2	3	1	4	5	2	3	4	3

In table 6 the output (sales) is normalized to 1 under the CRS assumption, which allows for a graphical presentation of DEA. Graphically solving DEA efficiencies is possible when the model has a total of three or less inputs and outputs. (Savolainen 2007, p. 29)

Table 6. Normalized example data (Savolainen 2007, p. 29)

Store		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Employees (10)	x_1	4	6	8	4	2	5	6	6	6
Floor area (1000 m^2)	x_2	3	3	1	2	4	2	4	3	3
Sales	y_1	1	1	1	1	1	1	1	1	1

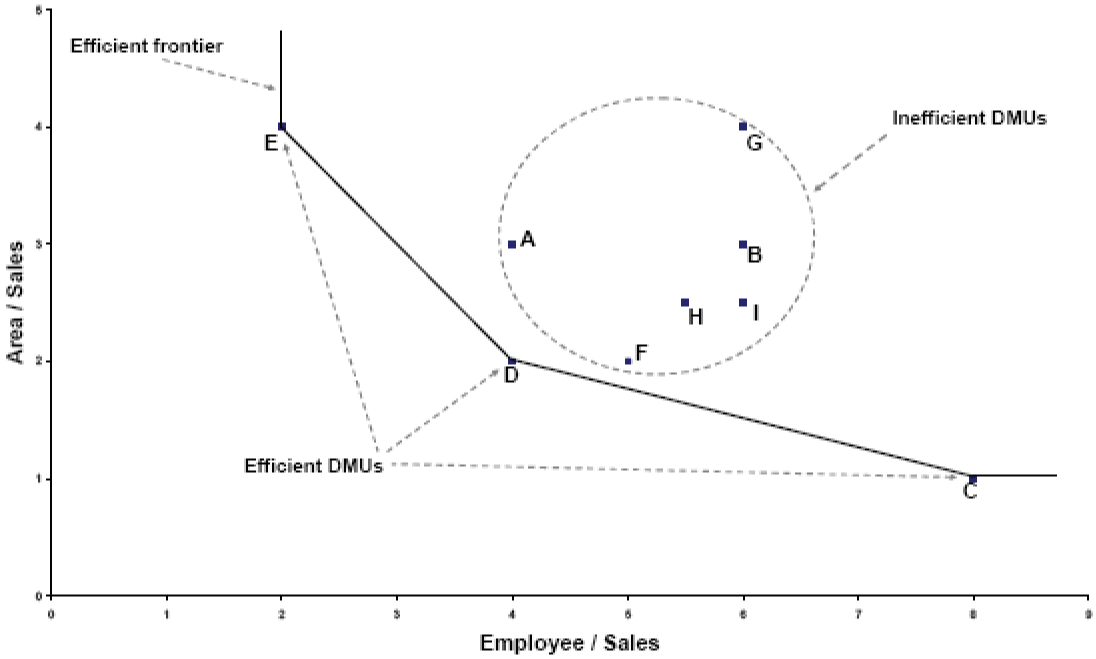


Figure 4. Graphical presentation of normalized example data (Savolainen 2007, p. 30)

The normalized data is plotted into a diagram in figure 4, setting the inputs x_1 and x_2 divided by output y as the axes. Now we are able to determine the DMUs that employ the fewest inputs to per one unit of output (DMUs C, D and E) as the most efficient and are able to connect them to each other, forming a graphical presentation of the efficiency frontier. Other DMUs that are enveloped within the connecting lines are inefficient, and the further away from the line the less efficient they are. Improving their efficiency scores would require a decrease in employees (moving them left in the diagram), a decrease in shop floor area (moving them downwards) or some combination of the both. Naturally, also increasing their output with the current resources is an option (moving them diagonally down-left in the diagram). (Cooper et al. 2007; Savolainen 2007, p. 31)

5.3 Barney-Charnes-Cooper -Model

The constant returns to scale assumption is of course not valid in all situations. In the case of prevailing scale efficiencies, which entail that the productivity of a unit is dependent upon its size, a need for employing variable returns to scale (VRS) emerges. A concrete example of such a situation could be one where investments for starting an operation are considerable enough to be taken into account. To address these needs an extension to the basic CCR-model was proposed by Banker, Charnes and Cooper in 1984. The model has been named the BCC-model after its creators (or sometimes alternatively, the VRS model) and widely accepted as the basic DEA model for cases with VRS. Mathematically, the BCC linear programming model may be represented as follows (Bowlin 1998):

$$\text{maximize:} \quad \sum_{r=1}^{s} u_r y_{ro} - u_o$$

$$\text{subject to:} \quad \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} - u_o \leq 0$$

$$\sum_{i=1}^{m} v_i x_{io} = 1$$

$$-\,u_r \leq -\varepsilon$$

$$-\,v_i \leq -\varepsilon$$

The VRS quality of the model makes it more flexible and less strict than the previous CCR-model. As a rule CCR-efficiency scores never exceed BCC-scores, although the opposite often is true. This is easiest explained graphically with an example illustration of a one input and one output DEA problem in figure 5 below. The existence of more efficient DMUs, as well as higher efficiency scores for inefficient DMUs, is explained by the convexity of the efficiency frontier when employing variable returns to scale: Compared to the efficiency frontier of the CRS model, the distance of the DMUs to the frontier, which is the graphical representation of efficiency, either shortens or remains the same. The VRS model grants the possibility to examine the returns to scale of the DMUs, providing valuable information on scale efficiencies. If a DMU has increasing returns to scale (IRS, such as the units A and B in figure 5), an increase in inputs will provide a proportionally higher increase in outputs, and in the case of decreasing returns to scale (DRS, as the units F, E and D) the increase in outputs will be proportionally smaller compared to the increase in inputs. However, all VRS-efficient units are considered to have constant returns to scale (Savolainen 2007, p. 33).

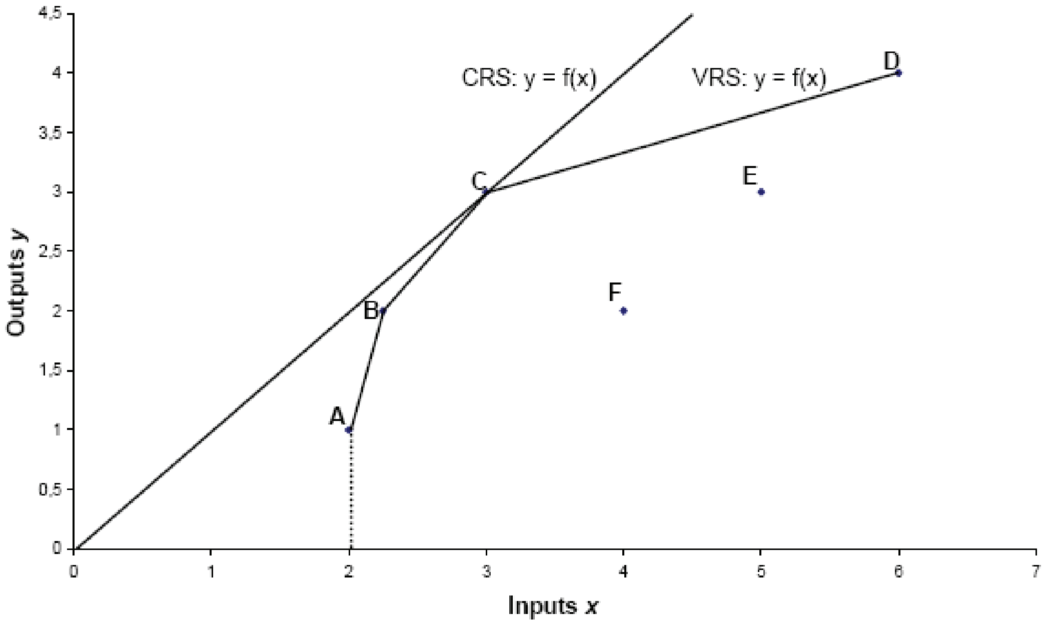


Figure 5. Example of returns to scale: one output and one input (Savolainen 2007, p. 34)

Variable returns to scale appeared to suit this study better as regional innovation can not be justified to have constant returns to scale. An increase in research capacity, for instance, does not grant proportionally equal increases in outputs in different units.

5.4 Recent Developments

DEA is a relatively new method of analysis, and as such it is still constantly evolving. In addition to the two basic models presented above, several other variations exist, such as the additive, slacks based measurement and hybrid models, just to name a few of the more common (Cooper et al. 2007, p. 89). There are also extensions and ways to modify the models to better adapt them to different scenarios, some of which are shortly introduced next.

Although the free distribution of weights empirically is one of the main properties of DEA, the weights may also be manually constrained to prevent manifesting of false efficiency through untruthful input and output profiles (Cooper et al 2007). Also inputs or outputs that the DMU has no control over may be taken into account in the analysis as environmental variables that affect performance (Honkapuro 2002, p.26). Also the efficiency scores themselves may be modified by extending the model to take into account what is known as super-efficiency. The basic concept of super-efficiency is that DMUs may be granted scores that exceed the normal maximum efficiency value of 1 by first running DEA normally and then excluding the most efficient DMU from the data set, thereby determining a lower efficiency frontier in relation to which this excluded DMU is then measured. This is a way of determining ‘the best of the best’ in a group of peers. (Cooper et al. 2007, p. 309) These are only some examples of extensions that have been made to the DEA method recently and work is constantly under way to further develop the method. According to G. Tavares, in the period of 1978 to 2001 alone, there has been more than 3600 papers, books, etc, by more than 1600 authors related to DEA and the numbers are ever growing (Cooper et al. 2007).

6 CONSTRUCTION OF THE DEA-MODEL

When building models to depict actual events, there is always the issue of adequate simplification; all models are simplifications of the real world and do not take in to account all the possible variables that may affect the observable phenomenon's outcome. The attributes that are included in the model should be the ones most relevant to the phenomenon and able to provide an ample representation of the phenomenon and the significant causalities related. The selection of attributes is thus critical to the success of the model.

To bring transparency to the procedure of constructing the DEA-model this chapter first presents the simplification of the regional innovation phenomenon and further proceeds to display the process of converting the simplified phenomenon into measurable attributes and a suitable model, and to explain the choices made.

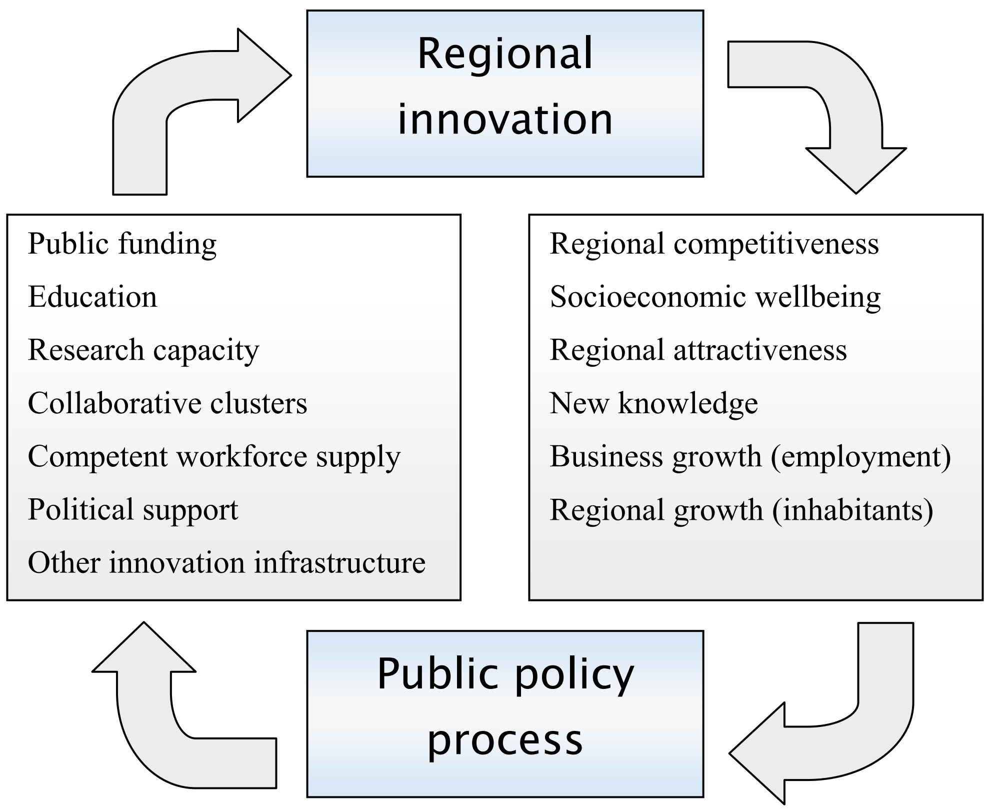


Figure 6. Inputs and outputs of the regional innovation –phenomenon

In figure 6 (above) an attempt is made to describe the phenomenon of regional innovation as a collection of inputs and outputs based on the theorem of innovation systems presented earlier in chapter 2. When choosing the viewpoint for crafting the picture of regional innovation the needs of the regional policy-makers were kept in mind. The simplification of regional innovation that is illustrated in figure 6 therefore emphasizes the inputs of the phenomenon that public policy can have an effect on and the outputs that are considered to benefit the region.

A feedback loop is represents the process-oriented view of policymaking. Verbally, the feedback feature illustrated in figure 6 may be expressed as follows. Public policy work influences the inputs either directly or indirectly: by e.g. direct intervention or subtle facilitation of input development. These inputs feed into the phenomenon of regional innovation and combined with the element of chance inherent to innovation processes determine the level of innovational activity in a region. Regional innovation produces outputs of which the most essential are listed in the figure. These outputs may be measured and the impact of policy work assessed, which provides motivation and guidance to further develop the policy, resulting in a new iteration of the cycle.

6.1 Selected Attributes

This section discusses the transformation of the input and output attributes of regional innovation (presented above in figure 6) into quantifiable, measurable variables that may be used as suitable indicators for the DEA-model. Tables 7 and 8 address the quantification of inputs and outputs, respectively, linking variables to specific attributes and providing a short reasoning for the choice of variables made. The selected indicators comprise of 6 input and 6 output indicators, all of which are relative measures to accommodate for differences in region size. Each attribute has been linked to a single indicator, except for the input broadly titled "other innovation infrastructure". It is reserved to express the notion that there are numerous aspects affecting in the input side of innovation, but not included in the model due to their comparatively low relevance in a regional context.

Table 7. Quantification of inputs

Input	Quantifiable input variable	Reasoning
Public funding	Public expenditure per capita	Total public expenditure for a region relates to the region's overall state of development which affects its competitiveness in the area of innovativeness as well
Education	Percentage of population with higher education	A high level of education builds human resources, providing companies with access to necessary skill sets
Research capacity	Total R&D personnel in the region, percentage of active population	R&D personnel in regional research facilities (research centers, universities and non-profit organizations) act as a primary source of basic research that creates technological opportunities for innovation
Collaborative clusters	Number of identified potential clusters (according to Porter's definition), if available	Confirming the genuine collaboration of a potential cluster is a process of disproportionate effort, so the assumption that number of potential clusters correlates with collaborative ones is made
Competent workforce supply	Participation of adults aged 25-64 in education and training (%)	Life-long learning participation ensures that individuals' skills are up-to-date and thus indicates the general competence of the labor force
Political support	Percentage of public funding used for regional development (economic / innovation), if available	Empowerment of regional developers is immeasurable, but public funding earmarked for development efforts implies support
Other innovation infrastructure	–	This input comprises the numerous forces that have not been taken into account representing the 'error margin' of the model

Public expenditure is the raw description of the degree of influence the decision makers are able to wield, representing the resources available for policy measures in the region. The amount of public funding can be influenced either directly by regional politicians with adequate power or indirectly by earning more interest and funding by exemplary policy making performance. Furthermore, political will to promote regional development efforts may be measured by the percentage of public funding used for economic and/or innovation promotion.

Innovation, especially pure technological innovation, requires a high level of understanding of the subject, which is provided by a functional education system that provides the region with a supply of highly trained professionals, constituting the human resource base critical to innovation. The level of renewal and adaptation of the regional skill base to shifting demands is measured by participation in life-long learning. To enable wide ranging technology transfer and education benefiting from cutting-edge science, a strong academic presence, depicted through the total amount of R&D personnel, is vital.

One controversial factor was the positioning and dealing with clusters in the model. It is granted that clusters are an important source of innovation, but on the other hand, regional innovation should also manifest as tightening collaborative relationships in a region. Policy-markers all over the world has used Porter's cluster model as a tool for promoting national, regional and local competitiveness, innovation and growth (Martin and Sunley, 2003). The verification of cluster existence cannot be reasonably performed on a large number of test regions, so a tool for mapping potential clusters (concentrations of enterprises, with no specific information on their level of co-operation) was adapted from the MERIPA project's third work package. The tool relies on readily available employment data to identify clusters according to Porter's definition (Porter 1998a; 1998b; 2000), so it provides a quick and rough approach to estimating the number of regional clusters. Thus, the assumption is made that the number of *potential* clusters correlates with the number of *active* clusters.

Table 8. Quantification of outputs

Output	Quantifiable output variable	Reasoning
Regional competitiveness	Regional Gross Domestic Product per inhabitant growth rate, PPS (Purchasing power standard)	High competitiveness of the region should manifest as above-average economical growth
Socioeconomic wellbeing	Regional Gross Domestic Product per inhabitant, PPS (Purchasing power standard)	The wealth of a region is generally reflects the prevailing socioeconomic conditions
Regional attractiveness	Private and public investment in region per capita	Willingness to invest in a region signals that it is seen as being strong, dynamic and promising continuous growth
New knowledge	Applied patents to the European Patent Office per million inhabitants	Innovations create knowledge that is applied in some form on the marketplace; number of such applications is represented by applied patents
Business growth	Regional employment growth rate (%)	Innovation-enabled profitable growth of enterprises increases the demand for employees as their business expands
Regional growth	Average annual growth rate of population (%)	A measure of growth relative to the size of the region is relevant, because population tends to concentrate in regions seen as most viable

The work done by de Vet (1993) shows, that foreign direct investment (FDI) can be used as an indicator of regional attractiveness. They studied patterns of FDI flows in seven advanced economies and came to the conclusion that investment decisions sought out regional economies with competitively advantaged regional clusters. The research provided convincing proof that investments were increasingly attracted to specific regions for a great part due to the promotional and enterprise support of regional governance institutions, or in other words, functional regional policies. In addition to foreign investment, people are also attracted to regions that they see as successful and viable in the long-term, which are traits of an innovation-driven region. Welfare and migration patterns should be reflected in the annual growth rate of population.

The competitive fitness of a region can be indicated by GDP growth rates in the region: above-average growth rates entails that the region is improving its performance relative to others and succeeding in redirecting economic (and other) interest toward itself. The wealth of a region, measured in GDP per capita, indicates directly the socioeconomic wellbeing in the region. Plentiful resources enable regions to serve their population’s needs better. Statistics are expressed in PPS (Purchasing power standards, i.e. common currency that eliminates the differences in price levels between countries and regions) allowing meaningful volume comparisons of GDP between countries and regions. For the calculation of regional GDP at level NUTS2 the same purchasing power parity is used for all regions of one country.

Innovations invigorate the economy, breathing life into enterprises. The effect of innovation policy on business growth is measured by the change in regional employment rates, following the logic that innovational activity may lead to strong growth in businesses, in turn entailing a growing demand for workforce. The creation and to desire to apply knowledge manifests in quantifiable form in patent applications. Scientific publications were left out, since they do not have to imply any marketable application and thus are not in line with the chosen innovation definition. The creation of new knowledge, new applications and the spill-over effects are one of the most desired impacts of innovation.

6.2 Limitations and Assumptions

The limitations and assumption limiting the evaluation of regional innovation performance with DEA are discussed here. Mainly, two sources for these restrictions can be identified: Some are attributable to the DEA method and its qualities and the other to the source data that is readily available.

6.2.1 Limitations of the Method

For a DEA-model dealing with the inputs and outputs described above to be able to provide reasonable results, attention must be paid to providing a sufficient amount of degrees of freedom for the model to distinguish efficient DMUs (regional innovation systems). As presented earlier in the theoretical introduction to DEA (Chapter 5), degrees of freedom are dependent upon the number of inputs and outputs and also the number of DMUs. Estimating the minimum number of DMUs required is done by applying the rule of thumb:

$$n \geq \max\{m * s, 3(m + s)\}$$

Where n = number of DMUs, m = number of inputs and s = number of outputs, resulting in the following:

$$n \geq \max\{6 * 6, 3(6 + 6)\} \rightarrow n \geq 36$$

Hence, we limit the use of the model to situations where the minimum number of estimable DMUs is 36. This minimum number of DMUs (= regions) was used as an initial data set in this study.

Taking into account the diversity of regional innovation systems and the different standpoints from which they have developed, a model deploying variable returns-to-scale appears preferable. This leads to choosing the BCC (Banker-Charnes-Cooper) –model that supports VRS (Variable Returns-to-Scale) and offers an easily communicable efficiency score. The model is chosen to be input-oriented to best address the issues that innovation policy may have an effect on. As the degree of efficiency achieved by innovation policy measures is the topic of interest, both input- and output-oriented models yield the same results (Cooper et al., 2007, p. 115), but the input-oriented model provides additional information on which inputs the regional innovation system is utilizing to greater potential. To avoid overt reliance on the VRS assumption and only one model, the calculations were also made with the CCR model under constant returns to scale.

If expert opinions or prior studies on measuring regional innovation with similar quantitative methods were available, the DEA model could be further elaborated by adding constraints to the weighting of inputs and outputs. Although according to some scholars, imposing additional restrictions to DEA compromises the free weight disposal (benefit of the doubt weighting) quality of the method and thus is not recommended.

6.2.2 Limitations Attributable to Data

Issues regarding data availability have already been briefly discussed in section 4.3. The scarcity of statistics suitable for regional innovation performance assessment is not surprising. Even though innovation has been a hot topic for some time, the regional aspects and especially measuring innovation performance on regional level are new concepts. This report constitutes one of the first attempts at assessing innovational performance regionally on a large scale to provide means for transnational benchmarking and ranking.

In the scope of this research, the size of the observed regions was limited to NUTS2 – level, largely due to availability of data. Even NUTS 2 - level data is rare and found nearly exclusively at Eurostat (as datasets that are free of charge and comprise regions of several nationalities), and NUTS 3 data is virtually nonexistent. However, the method should perform similarly when dealing with smaller and larger regions or even with various regional sizes simultaneously in one data set, provided that suitable, high-quality statistical data is available.

Measuring new knowledge creation in a region through the number of applied patents is somewhat misleading. For example, if a patentable innovation is made in the regional office of larger company, the patent application is likely to be made from the main office situated elsewhere. This makes patents as an indicator for regional knowledge creation one to be looked at critically. In addition, the model doesn't take into account the existence, or the absence of, functional capital markets, even though access to e.g. venture capital has been proved critical for innovation development. This is due to the assumption that capital markets function primarily in a national level rather than a regional level. However, the most significant data issues were related to the shortage of statistics concerning some of the chosen variables. These are best illustrated by table 9 below.

Eight of the chosen indicators were used in the DEA calculations and four were found to be unavailable at the time of the report. The exclusion of clusters and the political support indicator was a conscious choice as from the beginning on, it was clear that no data related to these indicators was yet collected and the indicators were included for future application. The only output indicator that had to be excluded from the calculation due to data availability is regional attractiveness, which is measured by regional investment. Since other output indicators were able to be successfully deployed, the shortage of this indicator was not a major issue affecting the outcome of the calculations. The greatest statistical shortfall and the most surprising as well, was the inexistence of NUTS 2 – level data on total public expenditures. Nationally these records are certainly maintained, but the data is not readily available from one unified source, such as Eurostat. This data deficiency effectively removed the important financial aspect of the model, where an investment-like comparison of financial inputs and outputs could have been performed.

Table 9. Indicator data availability: actually used and unavailable indicators

Input variables used	Output variables used
	Regional employment growth rate (%)
Percentage of population with higher education	Regional Gross Domestic Product per inhabitant, PPS (Purchasing power standard)
Total R&D personnel in the region, percentage of active population	Applied patents to the European Patent Office per million inhabitants
Participation of adults aged 25-64 in education and training (%)	Regional Gross Domestic Product per inhabitant growth rate, PPS (Purchasing power standard)
	Average annual growth rate of population (%)
Unavailable indicators	
Public funding (Input)	Public expenditure per capita
Collaborative clusters (Input)	Number of identified potential clusters (according to MERIPA Cluster Mapping –tool)
Political support (Input)	Percentage of public funding used for regional development (economic / innovation)
Regional attractiveness (Output)	Private and public investment in region per capita
Compensating indicators	
Public enterprise support (Input)	Enterprise that received funding from local or regional authorities, national percentage

A compensating indicator was thus added, from outside of those originally included in the model. The indicator differs from others by using national data that depicts regional actions, instead of employing purely regional statistics. This leads to identical values for regions with the same nationality and generally reduces the accuracy of the indicator. However, taking this indicator into account was deemed necessary to diversify the model in the face of insufficient data in regional terms. Without the compensating *public enterprise support* indicator the inputs would have been singularly descriptive of education, research and training, thus demeaning the systematic standpoint that was taken in this study. The data of this indicator is based on a Community Innovation Survey conducted in 2004 and also accessible via Eurostat.

6.2.3. Interpreting the Results

Once the actual calculations are completed, interpreting the results provided by the DEA evaluation follows. It is not recommendable to rely solely on the results of DEA as an individual analysis, but it is equally important to understand its significance in supporting decisionmaking when properly interpreted in conjunction with other information. The analysis method provides a wealth of useful information, the correct interpretation of which is essential. The most notable information in the results is embedded in the efficiency score, amount of slacks and the reference set. Utilizing generally available qualitative knowledge to complement the view provided by the analysis and critical consideration are key factors to successfully interpreting the results, both of which benefit from solid experience in the policy field.

Especially if efficient status (an efficiency score of 1) is achieved, careful thought should be given to whether the proposed efficiency is entirely attributable to innovation policy and activity. If the DMU is found inefficient, even more information becomes available. Inefficient DMUs benefit from identifying their respective reference sets, which practically translate to possible best practice cases. However, critical consideration about the sources of efficiency in these references is encouraged as already noted. Another source of learning may be found in examining the slacks, which highlight the inputs that the region is not using to their full potential when compared to peers on the efficient frontier.

7 DEA BENCHMARKING

This chapter entails the results of benchmarking that was conducted with the DEA-Solver-LV (Learning Version) developed by Kaoru Tone and attached with the book "Data Envelopment Analysis: A Comprehensive Text with Models, Applications, References and DEA-Solver Software, 2nd Edition" (2007).

First, the meaning of efficiency in regard to regional innovation policy evaluation should be established. The theoretical expression of *efficiency* in DEA is that

"A DMU is fully efficient if and only if it is not possible to improve any input or output without worsening some other input or output."

This is also referred to as Pareto-Koopmans Efficiency. (Cooper et al. 2007) Applied to policy considerations this is naturally a bit more complex. Efficiency is determined relatively to other DMUs, which means that the region is compared to others that share a similar regional mix of inputs, which translates to similar regional possibilities of innovation. These are in turn partly determined by regional conditions, and also on long term effects of prior policy decisions, which affect for example the industrial layout and the educational basis of the region. What this means that efficient regions coordinate the resources they have in a more productive way than their inefficient counterparts, which in turn denotes efficient innovation policies. Efficient status does not mean however, that the region could not improve further; only that others have not yet done so.

Much is dependent however, on the optimal weights determined. DMUs with deviant input and output structures may take advantage of the optimal weighting property of DEA to achieve misleadingly high efficiency scores, even efficient status, by effectively discarding a majority of the indicators with zero weights and overutilizing their unique strong points. This occurrence may be controlled by tweaking the model with additional constraints on allowable weighting schemes.

In previous chapters the construction of the DEA-model used in this study has been explained, but in course of performing the analysis, some issues arose, that demanded further investigation. First the initial findings are presented and subsequently some correctional measures to improve the accuracy of the benchmarking are discussed.

7.1 Initial Findings

The first benchmarking effort was undertaken by applying the input-oriented BCC-model with the VRS assumption. In addition, calculations were performed with the CCR-model under CRS assumption, using an identical data set. The results of these evaluations are displayed below in table 10. One of the DMUs, the region of Zürich, was excluded due to inappropriate data. None of the input indicator data was found for the region. The region was not replaced in the data in order to portray a realistic impression of the data availability issues surrounding the topic of regional innovation assessment. Even in a minimal data set of 36 arbitrarily chosen regions, incomplete data sets barriers for performing complete evaluations.

The results of the analysis were discouraging: as can be seen from table 11, the BCC model resulted in a total of 74 % of the evaluated regions achieving efficient status, and even the CCR-model displayed a ratio of two to one on efficient versus inefficient DMUs. Such results are certainly unrealistic and clearly signal problems with either the model or the data set used. Some measures for correcting the model in light of these findings are presented and tested in the following section.

Table 10. Results with the input-oriented BCC- and CCR-models

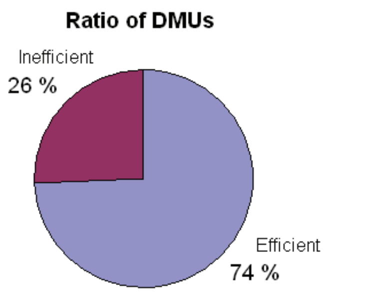
BCC Score	BCC Rank	No.	DMU	CCR Score	CCR Rank
1	1	1	AT13	0,964	24
0,901	28	2	AT32	0,873	25
1	1	4	CY00	1	1
0,858	29	5	CZ01	0,821	28
1	1	6	DE60	1	1
0,626	33	7	DK00	0,585	32
1	1	8	ES51	1	1
0,534	35	9	FI13	0,534	34
0,545	34	10	FI18	0,541	33
1	1	11	FR10	1	1
1	1	12	GR14	1	1
1	1	13	GR43	1	1
1	1	14	HU10	1	1
1	1	15	IE02	1	1
0,699	31	16	IS00	0	35
1	1	17	ITC4	1	1
1	1	18	ITD5	1	1
1	1	19	ITG1	1	1
1	1	20	LT00	1	1
1	1	21	LV00	1	1
1	1	22	MT00	1	1
0,731	30	23	NL12	0,731	30
1	1	24	NL41	1	1
0,996	27	25	NO01	0,745	29
0,656	32	26	NO05	0,634	31
1	1	27	PL43	1	1
1	1	28	PT11	1	1
1	1	29	SE01	1	1
1	1	30	SE04	1	1
1	1	31	SE08	1	1
1	1	32	SI00	1	1
1	1	33	SK01	0,858	26
1	1	34	UKF1	1	1
1	1	35	UKI1	1	1
1	1	36	UKM1	0,854	27

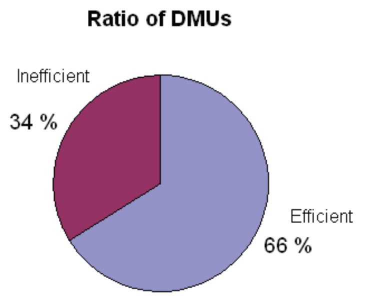
More information about the suitability of the indicators can be extracted by examining the correlations between different indicators that are presented in appendix 2. Highest correlation are found to be with the *Education* indicator and

Wellbeing, *Competent workforce* and *Research capacity* indicators, the correlations being 0,63; 0,56 and 0,44 respectively. The latter two correlations make sense, since all the factors are positively affected by the presence of higher education institutes (HEIs, eg. universities) that also contribute to research and adult education and training. The correlation to wellbeing is more surprising, but if anything, it verifies the connection between HEI presence and successful knowledge based wealth creation.

Table 11. Number of efficient and inefficient DMUs, BCC and CCR model

BCC model			CCR model	
Number of efficient DMUs	Number of inefficient DMUs	Average score (BCC)	Number of efficient DMUs	Number of inefficient DMUs
26	9	**0,930**	23	12
		Average score (CCR)		
		0,890		





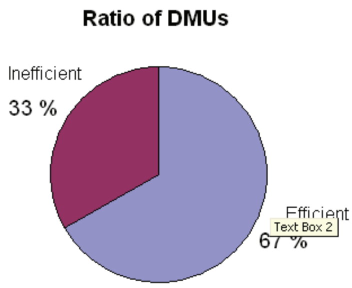
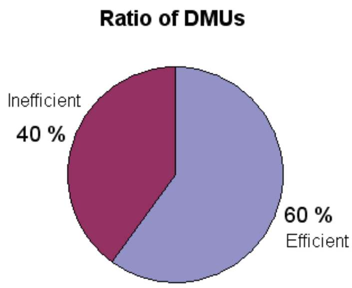
7.2 Possible Correctional Measures

Several different correctional measures may be deployed to address the problem of excessive DMU efficiencies. Modifications and corrections can be made to the data set as well as the model, without having to replace the model with an entirely new one. Three possible correctional measures are discussed here and two of them are tested on both the BCC- and CCR-models.

7.2.1 Augmenting the Data Set

When encountering unrealistically high efficiencies in DEA results, most often the cause can be found in an inadequately sized data set in regard to the amount of indicators used. Adding new DMUs to the data set is the first attempt at correcting the situation, since it does not incur any information loss, as subsequent measures do. Although attention was paid to determining the sufficient size of the data set earlier, in chapter 6, the data set was further augmented by ten additional regions, which are listed in appendix 1. The results of the models with augmented data sets, however, were to a large extent similar to those in the initial findings (see appendix 3).

Table 12. Number of efficient and inefficient DMUs, BCC and CCR model with augmented data set

BCC model			CCR model	
Number of efficient DMUs	Number of inefficient DMUs	Average score (BCC)	Number of efficient DMUs	Number of inefficient DMUs
30	15	**0,913**	27	18
		Average score (CCR)		
		0,880		

As can be seen from table 12, the percentage of efficient DMUs still remains too high, indicating the persistence of the problem despite a 25 % increase in the size of the data set. Without modifying the DEA-models, the size of a sufficient data set therefore is impractically large.

7.2.2 Reducing the Number of Indicators

A more drastic measure, resulting in a degree of information loss, is reducing the number of indicators to sharpen the discrimination between DMUs. The theoretical basis for this operation is similar to augmenting the data set, but leads to a much sharper discrimination among DMUs. Reducing the total amount of inputs and outputs results in decreasing the options by which a unit can reach efficient status. The test run was performed on the original data set in an attempt to both evaluate the effectiveness of the correctional measure and to seek for the actual minimal data set size, where it would provide meaningful results.

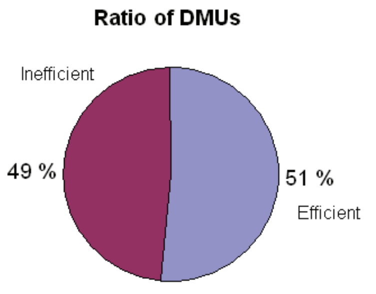
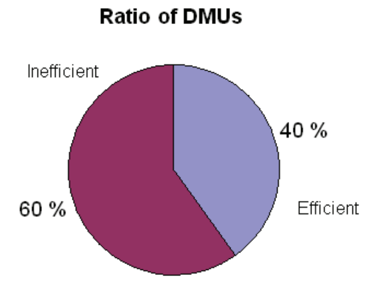
Table 13. Reduction of indicators, list remaining and excluded variables

Remaining indicators after reduction	Excluded indicators
Education (Input)	New knowledge (Output)
Research capacity (Input)	Wellbeing (Output)
Public enterprise support (Input)	Competent workforce (Input)
Regional growth (Output)	
Regional competitiveness (Output)	
Business growth (Output)	

The inputs and outputs to be excluded were selected carefully, attempting to maintain a diverse set of indicators and to primarily eliminate those that were perceived to have questionable characteristics or lesser value. The excluded indicators can be seen in table 13 above. The reasoning behind excluding *new knowledge* from the outputs is the unreliability of patent application data to convey actual regionally conceived innovations, as is discussed in chapter 6.2. *Wellbeing* is based on regional gross domestic product statistics, as is the *regional competitiveness* indicator and, thus excluding it should result in relatively little information loss. Of the remaining indicators, *competent workforce* was perceived to offer the least value as educational aspects were already covered, and the correlation to *education* indicator was among the highest. After the reduction, calculations were again performed with both the BCC- and CCR-models. Table

14 shows the effectiveness of the performed modifications to the model. A dramatic decrease in the number of efficient DMUs results in an acceptable outcome with the CCR-model and even the less strict BCC-model shows significant improvement in discrimination capability.

Table 14. Number of efficient and inefficient DMUs, BCC and CCR model with reduced indicators

BCC model			CCR model	
Number of efficient DMUs	Number of inefficient DMUs	Average score (BCC)	Number of efficient DMUs	Number of inefficient DMUs
18	17	**0,781**	14	21
		**Average score (CCR)**		
		0,713		

The actual results of the analysis can be viewed from table 15. Compared with the initial findings from the results of the original model, a larger scale among the inefficient scores can also be seen. With the reduced indicator CCR-model scores range from 0,156 to 0,953 (excluding the singular zero value for Iceland, which is present in all calculations), whereas the original model only shows scores ranging from 0,534 to 0,964. This is another verification of the significantly more accurate discrimination achieved through indicator reduction.

Some changes in the ranking of the regions that were evaluated as ineffective in both cases have also occurred. The effect of information loss, or forcing more realistic weighting schemes on regions have caused movement among their mutual ranks, although none of them have achieved higher than original efficiency in the modified model. The highest relative gains in ranks are 4 places with DMUs FI13 and NL12, and the greatest relative loss of 5 places is attributed to AT13. When taking all the relative rank shifts between these two models into account, it can be argued that the reduction of indicators has resulted in a more realistic model, opposed to resulting in distorting information loss.

Table 15. Results with the input-oriented BCC- and CCR-models, with reduced indicators

BCC Score	BCC Rank	No.	DMU	CCR Score	CCR Rank
0,477	28	1	AT13	0,472	27
0,598	24	2	AT32	0,519	25
1	1	4	CY00	1	1
0,546	26	5	CZ01	0,535	24
0,432	30	6	DE60	0,365	28
0,366	31	7	DK00	0,266	31
1	1	8	ES51	0,833	18
0,474	29	9	FI13	0,330	29
0,297	34	10	FI18	0,258	32
0,286	35	11	FR10	0,244	33
1	1	12	GR14	1	1
1	1	13	GR43	1	1
1	1	14	HU10	0,884	17
1	1	15	IE02	1	1
0,699	22	16	IS00	0	35
1	1	17	ITC4	1	1
0,959	19	18	ITD5	0,936	16
1	1	19	ITG1	1	1
1	1	20	LT00	0,785	19
1	1	21	LV00	1	1
1	1	22	MT00	1	1
0,589	25	23	NL12	0,587	23
0,504	27	24	NL41	0,499	26
0,353	33	25	NO01	0,312	30
0,365	32	26	NO05	0,156	34
1	1	27	PL43	1	1
1	1	28	PT11	0,745	20
0,956	20	29	SE01	0,953	15
1	1	30	SE04	1	1
1	1	31	SE08	1	1
1	1	32	SI00	1	1
0,670	23	33	SK01	0,655	21
1	1	34	UKF1	1	1
1	1	35	UKI1	1	1
0,774	21	36	UKM1	0,619	22

Both the data set augmentation and indicator reduction measures were combined to provide the final scores and rankings that are introduced in the next, concluding chapter of the report.

7.2.3 Imposing Additional Constraints

One option for sharpening the discrimination between DMUs is imposing additional constraints to force more realistic and strict weighting schemes. Constraints may be absolute or relative, and they may affect the weights directly or the *virtual inputs* and *outputs*, which are the values of inputs and outputs after multiplication by weights. There are several methods for restricting the weighting in DEA, such as the assurance region and cone-ratio methods (presented in detail in Cooper et al. 2007, p. 177-205).

The free disposal of weights, however, is one of the most important principles in DEA analysis. As noted before, some scholars detest the notion of imposing constraints on weighting as it goes against this property unique to the DEA method. In any case, when imposing such constraints, the choices of how to restrict the values must be based on either information acquired through other statistical approaches or expert insights and opinions. As neither was readily available in the case of the study, this approach was forfeited.

8 CONCLUSIONS

Data Envelopment Analysis is inherently attuned to benchmarking practices as it readily provides an easily interpretable efficiency score, enables building ranking lists and identifies other units that utilize a similar set of inputs to create outputs as reference points for every unit. With a reliable DEA-model, these qualities enable identification of suitable best practice cases, even with such a complex issue as regional innovation, where no 'one size fits all' –solution can be found. Even though the research presented in this report indicates that regional innovation may be evaluated with DEA, the method is still immature and unreliable, which is largely attributable to the scarcity of suitable regional statistics available.

In summary, DEA has potential to become a meaningful analysis tool even in the field of regional innovation assessment and a useful tool for evaluating the achievement of innovation policy goals at the regional level, provided that regional statistics further develop to enable proper use of the method. Although the study does not warrant any absolute conclusions, as the first attempt to combine data envelopment analysis and regional innovation from the perspective of a policymaker, it certainly does provide meaningful findings and hopefully makes way for future research.

8.1 Ranking of the Involved Regions

By refining the original model developed in the study, by both augmenting the data set form 36 regions to 45 regions and reducing the total number of inputs and outputs from 9 to 6, the DEA-model displayed reasonable discrimination capability in the final calculations. The results were used to build two ranking lists, visible in table 16, based on the BCC- and CCR-efficiency scores of each region.

Table 16. Final rankings by both models (with correctional measures)

BCC Rank	DMU
1	FR81, ES30, UKI1, CY00, UKF1, SI00, SE08, SE04, PT11, PL43, MT00, GR14, GR43, HU10, IE02, LV00, ITC4, LT00, ITG1
20	SE01
21	ITD5
22	ES51
23	UKM1
24	PT17
25	IS00
26	SK01
27	AT32
28	NL12
29	CZ01
30	NL41
31	AT13
32	FI13
33	DE91
34	FR71
35	DE21
36	DE60
37	FI19
38	NO06
39	NL31
40	BE10
41	DK00
42	NO05
43	NO01
44	FI18
45	FR10

CCR Rank	DMU
1	FR81, UKI1, UKF1, CY00, SI00, SE08, SE04, PL43, MT00, LV00, ITG1, GR14, GR43, ITC4, IE02
16	ES30
17	SE01
18	ITD5
19	HU10
20	ES51
21	LT00
22	PT11
23	SK01
24	PT17
25	UKM1
26	NL12
27	CZ01
28	AT32
29	NL41
30	AT13
31	FR71
32	DE21
33	NL31
34	DE60
35	BE10
36	FI19
37	FI13
38	NO01
39	DK00
40	FI18
41	FR10
42	NO06
43	DE91
44	NO05
45	IS00

The first places in the ranking lists are still somewhat crowded, especially when adopting the VRS assumption (in the BCC-ranking) numerous regions (constituting 42 % of all the DMUs evaluated) manage to achieve efficient status.

Examining how frequently a region has functioned as a reference to other DMUs (see Appendix 4), provides additional information. In the BCC-model four regions stand out, serving as reference to ten or more other regions: Malta, Lubuskie of Poland, Southern and eastern Ireland and Latvia. These regions have achieved efficient status by generating more outputs with a similar mix of inputs than a number of peers. By this reasoning they could be considered as best practice candidates. Although as is explained in the next section, drawing such conclusions from the results presented here is premature, as the model has insufficient prerequisites for reliable operation.

From the CCR rankings, it is worth reiterating that when compared to BCC-efficiency scores, regions gain either similar or lower scores and CCR-efficiency never exceeds BCC-efficiency. This means that the differences in ranking between the models suggest that some regions have suffered more than others from the shift to CRS assumption. Nevertheless, a third of the regions achieve efficient status, and of these the ones with highest frequency of reference are Malta, Latvia and Kriti of Greece, again proposing Malta and Latvia as best practice cases.

However, the ranking deserves a fair amount of criticism. In table 16, a tendency to overvalue regions in poor countries that are less developed is evident. These countries are experiencing a phase of ‘economic catching up’ characterized by rapid growth of GDP not because of, but despite their innovation capabilities. As economic output indicators play a great role in the model, these findings show that the model may confuse prowess in economic development with innovation ability. The distinction between the two is challenging to make in a purely quantitative research setting and the attempt is further hampered by the shortage of regional data.

8.2 Usability of the Method and Findings

The model presented in this report is still unreliable and not useable by regional policymakers in its current form. The inability to distinguish between economic prowess resulting from innovation and that from different sources especially in the models with reduced indicators is a problem when dealing with moderate data sets. Without reducing the indicators to value regions on a more diverse set of qualities, the analysis demands a significantly larger data set to be able to effectively discern between the inefficient and efficient DMUs.

The most decisive impediment to the performance of the DEA-model is the shortage of standardized regional data, which affects the model even in the quantification of the conceptual model, upon which it is based. One of the important outcomes of the report is a strong recommendation towards statistical institutions and regional authorities to collect and distribute regional data according to NUTS classification to enable heightening the culture of evaluation across Europe. The choices of the variables were constrained by data shortage and even the variables chosen exhibited some gaps in the data series that may have affected scores of select regions adversely, resulting in an untruthful ranking. Unavailability of NUTS 3 data is also a considerable issue, as a multitude of NUTS 3 regions is able and willing to develop their own regional innovation policies.

The potential of the DEA method for supporting regional benchmarking efforts is nonetheless evident. Several qualities vouch for the usefulness of DEA in regional innovation policy benchmarking. By selecting inputs, which may be influenced through well-founded policy decisions, and outputs that accurately describe the outcomes of the regional innovation system, the method provides information that may be used to identify best practice cases with roughly similar regional innovation conditions and additionally inform decision makers about which inputs are used at sub-optimal efficiency through the examination of slacks. The communicational value of DEA-justified ranking lists is naturally also a notable benefit.

To realize this potential, access to wider regional data, as well as refinement of the model is required. A central finding is the appearance of unrealistically high efficiency scores with the constructed model. This issue could be addressed by further research to explore the possibility of imposing additional constraints to the weighting scheme. This would require a careful revision of the indicators used and access to expert opinions on how they should be weighted, or alternatively acquiring justification through the use of other statistical methods of analysis.

In summary, the DEA-model presented here is ill-suited for enhancing regional policy development without further elaboration. It does, however, lay out a foundation for further study in to the subject and point out some of the obstructions that regional innovation measurement and policy impact assessment efforts encounter. The method itself is filled with potential and the conceptual depiction of regional innovation (in figure 6) is valid, provided that data issues are overcome and the model further revised.

8.3 Discussion and Suggestions for Further Work

Meeting the objectives of the study was hampered by the apparent shortage of suitable data, which was an obstacle beyond the influence of the research. With that noted, all the objectives were reached as best possible. The study indicates the usefulness of DEA in benchmarking, identifying best practice cases and assessing policy effectiveness and impact, even though the test runs with the model proved dissatisfying results. All options for finalizing the model have not been exhausted in this study, as the main focus of the study was to determine whether or not DEA could be utilized in this area at all.

Some suggestions for further work in this area could be researching the possibilities of imposing additional constraints on the weights to induce a greater degree of accuracy and discrimination capability to the model, possibly enabling it to function well without reducing indicators on a moderate data set. Other topics that may be inspired by this study are naturally other innovation evaluation attempts with DEA, possibly on a national level, where source data is abundant. Composite indices for measuring regional innovation have been developed, e.g. in the MERIPA project. Applying DEA to calculating these indices could also yield interesting results. Similarly studies that combine DEA-analysis with other methods and cross-referencing the results could lead to practical notions about the reliability and validity of DEA measurement in regional innovation. Once sufficient data becomes available and the DEA-model is refined, extending the evaluation to regions outside Europe is an obvious continuation.

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APPENDICES

Appendix 1. List of Regions Included in DEA-Calculation

Eurostat code	Name of region
DK00	Danmark
FI18	Etelä-Suomi
ITD5	Emilia-Romagna
LT00	Lietuva
SE04	Sydsverige
FI13	Itä-Suomi
ITC4	Lombardia
ITG1	Sicilia
SE08	Övre Norrland
PT11	Norte
CZ01	Praha
DE60	Hamburg
IE02	Southern & Eastern (Ireland)
GR14	Thessalia
GR43	Kriti
ES51	Kataluña
FR10	Île de France
LV00	Latvia
NL41	Noord-Brabant
AT13	Wien
AT32	Salzburg
PL43	Lubuskie
UKF1	Derbyshire & Nottinghamshire
UKI1	Inner London
UKM1	North Eastern Scotland
NO05	Vestlandet
CH04	Zürich

IS00	Iceland
NO01	Oslo og Akershus
SE01	Stockholm
SK01	Bratislavský Kraj
SI00	Slovenia
NL12	Friesland
MT00	Malta
HU10	Közép-Magyarország
CY00	Cyprus
BE10	*Région de Bruxelles-Capitale/Brussels Hoofdstedelijk Gewest*
DE21	*Oberbayern*
DE91	*Braunschweig*
ES30	*Comunidad de Madrid*
FI19	*Länsi-Suomi*
FR71	*Rhône-Alpes*
FR81	*Languedoc-Roussillon*
NL31	*Utrecht*
NO06	*Trøndelag*
PT17	*Lisboa*

Regions in *italic* are the ten additional regions included only in the calculations with the augmented data set.

Appendix 2. Correlation of Indicators

	Education	Research capacity	Competent workforce	Public enterprise support	Reg. competitiveness	Wellbeing	New knowledge	Business growth	Regional growth
Education	1	0,440098	0,557247	-0,27958	0,192615	0,631625	0,29608	-0,2817	0,034507
Research capacity	0,440098	1	0,033872	0,162193	-0,06877	0,236327	0,034156	-0,28196	-0,01275
Competent workforce	0,557247	0,033872	1	-0,36939	-0,05246	0,290069	0,415781	-0,19217	-0,19679
Public enterprise support	-0,27958	0,162193	-0,36939	1	-0,27393	0,188387	0,111234	0,319425	0,262793
Reg. competitiveness	0,192615	-0,06877	-0,05246	-0,27393	1	-0,00909	-0,07124	0,078222	-0,3785
Wellbeing	0,631625	0,236327	0,290069	0,188387	-0,00909	1	0,385918	-0,24634	0,338055
New knowledge	0,29608	0,034156	0,415781	0,111234	-0,07124	0,385918	1	-0,00589	0,155748
Business growth	-0,2817	-0,28196	-0,19217	0,319425	0,078222	-0,24634	-0,00589	1	0,161877
Regional growth	0,034507	-0,01275	-0,19679	0,262793	-0,3785	0,338055	0,155748	0,161877	1

Appendix 3. Results with input-oriented BCC and CCR, augmented data set

BCC Score	BCC Rank	No.	DMU	CCR Score	CCR Rank
0,990427	31	1	AT13	0,960118	29
0,901025	34	2	AT32	0,873297	31
1	1	4	CY00	1	1
0,857899	35	5	CZ01	0,821094	34
1	1	6	DE60	1	1
0,626256	40	7	DK00	0,584957	40
1	1	8	ES51	1	1
0,534285	45	9	FI13	0,534279	44
0,54476	44	10	FI18	0,540707	43
1	1	11	FR10	1	1
1	1	12	GR14	1	1
1	1	13	GR43	1	1
1	1	14	HU10	1	1
1	1	15	IE02	1	1
0,698971	38	16	IS00	0	45
1	1	17	ITC4	1	1
1	1	18	ITD5	1	1
1	1	19	ITG1	1	1
1	1	20	LT00	1	1
1	1	21	LV00	1	1
1	1	22	MT00	1	1
0,731046	37	23	NL12	0,730833	37
1	1	24	NL41	1	1
0,981226	32	25	NO01	0,744895	36
0,655537	39	26	NO05	0,633863	38
1	1	27	PL43	1	1
1	1	28	PT11	1	1
1	1	29	SE01	1	1
1	1	30	SE04	1	1
1	1	31	SE08	1	1
1	1	32	SI00	1	1
1	1	33	SK01	0,857669	32
1	1	34	UKF1	1	1
1	1	35	UKI1	1	1
1	1	36	UKM1	0,85423	33
1	1	37	BE10	0,983341	28
1	1	38	DE21	1	1
0,8122	36	39	DE91	0,784873	35
1	1	40	ES30	1	1

0,592238	43	41	FI19	0,580857	42
0,942588	33	42	FR71	0,932493	30
1	1	43	FR81	1	1
0,613443	41	44	NL31	0,611782	39
0,597044	42	45	NO06	0,580958	41
1	1	46	PT17	1	1

Appendix 4. DMU Frequency in reference sets

BCC-model		CCR-model	
DMU	Frequency of acting as reference to other DMUs	**DMU**	Frequency of acting as reference to other DMUs
CY00	4	CY00	3
GR14	6	GR14	7
GR43	6	GR43	11
HU10	0	IE02	7
IE02	10	ITC4	7
ITC4	5	ITG1	1
ITG1	8	LV00	15
LT00	0	MT00	22
LV00	10	PL43	0
MT00	18	SE04	1
PL43	12	SE08	0
PT11	7	SI00	0
SE04	2	UKF1	1
SE08	0	UKI1	2
SI00	4	FR81	3
UKF1	1		
UKI1	1		
ES30	2		
FR81	1		