Regional Innovation Systems Analysis and Evaluation: The Case of the Czech Republic

Jan Stejskal, Helena Kuvíková, and Beáta Mikušová Meričková

Abstract Regional innovation systems (RIS) have become a very important regional policy instrument. This instrument is based on linkages among the region's institutions from the public and private sector. These linkages are very important because they provide an environment for the innovation process, which is the primary goal of the RIS. In this paper, we have defined and described the main characteristics common to every RIS. Knowledge of these characteristics allows us to create a new method to make it possible to analyze individual RISes. The goal of this chapter is to present a new method for evaluating RISes. The method must by easily applied in order for it to be used practically to map the development of the individual innovative systems in a region. The method is based on evaluating both qualitative and quantitative indicators and on applying WSA methods. The paper presents the application of this method on individual regions in the Czech Republic (NUTS3).

1 Introduction

Many regional policy instruments integrate elements operating on the principles of triple helix, especially: networking, industrial clusters, cluster initiatives, learning regions, innovation systems at the national and regional level and others. These systemic tools often incorporate other designated instruments. Thus, supporting their formation and their effective use should be able to produce a significant positive synergistic effect.

According to many studies related to innovation systems (for an overview of these studies see Tödtling and Trippl 2005), regions (defined as smaller than a national

J. Stejskal (✉)
Faculty of Economics and Administration, University of Pardubice, Pardubice, Czech Republic
e-mail: jan.stejskal@upce.cz

H. Kuvíková · B. M. Meričková
Faculty of Economics, Matej Bel University, Banská Bystrica, Slovakia
e-mail: helena.kuvikova@umb.sk; beata.mikusovamerickova@umb.sk

© Springer International Publishing AG 2018

J. Stejskal et al. (eds.), *Knowledge Spillovers in Regional Innovation Systems*,
Advances in Spatial Science, https://doi.org/10.1007/978-3-319-67029-4_3

region and larger than a local unit) are considered to be the key to innovation systems working effectively for the following reasons (Cooke et al. 2000):

- First: regions differ according to their industrial specialization and their innovation performance (Howells 1999; Breschi 2000; Paci and Usai 2000).
- Second: knowledge spillover effects play the key role in the innovation process and are usually geographically bounded (Audretsch and Feldman 1996; Bottazzi and Peri 2003; Asheim and Coenen 2005; Stejskal and Hajek 2015).
- Third: the growing importance of "tacit" knowledge has been indicated (Polanyi 1966; Howells 2002; Gertler 2003; Matatkova and Stejskal 2013) for a successful innovation process. The latter is often influenced by interventions due to political representation or by public administration institutions. However, interventions due to political representation are more often seen at the regional or local level.

The regions are the most suitable area (space) for innovation. Next, it is necessary to define the framework and instruments that enhance the innovation process (Cooke et al. 1997; Morgan 2007; Sternberg and Arndt 2001; Antonioli et al. 2014). The original paradigm for national innovation systems was thereby temporarily[1] refuted and attention was transferred to the concept of the regional innovation system (RIS), which was introduced in the 1990s.

There are many scholars who analyzed the regional innovation systems and of course define it (for the overview see Cooke 2006). Majority of them is in line with Cooke's definition (Cooke 2006):

> RIS are useful for studying economic and innovative performance; they are also functional tools to enhance the innovation processes of firms. They do this by knitting together knowledge flows and the systems on which they rely, building trust and confidence in institutional reliability; and above all, they do it by generating institutional self-knowledge and a certain kind of collective dissatisfaction with the status quo. RIS comprise a set of institutions, both public and private, which produce pervasive and systemic effects that encourage firms in the region to adopt common norms, expectations, values, attitudes and practices, where a culture of innovation is nurtured and knowledge-transfer processes are enhanced (Matatkova and Stejskal 2011b).

Asheim and Coenen (2005; in Stejskal and Matatkova 2011b) divide the RIS this way:

- territorially embedded regional innovation systems,
- regionally networked innovation system,
- regionalized national innovation system.

Territorially embedded regional innovation systems are similar to grassroots RIS by Cooke (2006), the best examples of this type are networks of small and medium enterprises (SMEs) in industrial districts. These systems provide bottom-up,

[1]That it was temporary refers to the fact that, in the past 15 years, certain researchers have pointed to the significance of national innovation systems, even proposing the creation of national systems by using regional ones (e.g., Chung 2002; Guan and Chen 2012; Borrás and Edquist 2013; Lyasnikov et al. 2014) to the significance of national innovation systems, even proposing the creation of national systems by using regional ones (e.g., Chung 2002; Guan and Chen 2012; Borrás and Edquist 2013; Lyasnikov et al. 2014).

network-based support through, for example, technology centers, innovation networks, or centers for real service providing market research etc. (Storper and Scott 1995 in Asheim and Coenen 2005).

Regionally networked innovation system means that firms and organizations are also embedded in a specific region and characterized by localized, interactive learning. This type is very similar to network RIS by Cooke. We can say that a networked innovation system is a result of policy intervention to increase innovation capacity and collaboration.

Regionalized national innovation system is different from the two systems above in two main points. First, parts of industry and the institutional infrastructure are more functionally integrated into national or international innovation systems. Second, the collaboration between organizations within this type of RIS conforms more closely to the linear model, as the co-operation primarily involves specific projects to develop more radical innovations-based on formal analytical-scientific knowledge. Cooke named this type of RIS system dirigiste RIS. The concrete example of this system could be technopoles or science parks. For more information see Asheim and Coenen (2005b).

Braczyk et al. (1998), Asheim and Coenen (2005), Cooke (2006) divide the RIS according to the size of the region's incorporated companies, their financing methods or the territorial limits of the regional innovation system. It is also possible to divide regional innovation systems according to the degree of their infrastructure development within the region:

- RIS with hard elements but without any soft infrastructure elements,
- RIS with highly developed hard and highly undeveloped soft infrastructure,
- RIS with highly developed hard and partially developed soft infrastructure,
- RIS with highly developed hard and highly developed soft infrastructure,
- RIS with a developed network for knowledge diffusion.

Many other authors tried to create own divisions of RISes. There are two scholars many times mentioned in references (Braczyk et al. 1998; Asheim and Coenen 2005b). The first division is according to Braczyk (in Cooke 2006). He says that there are three types of RIS emerged (Matatkova and Stejskal 2011a):

- localist,
- interactive,
- globalized.

The localist type has few major public innovation or R&D resources, but may have smaller private ones. There will be high degree of associativeness among entrepreneurs and between them and local or regional policymakers.

The mix of public and private research institutes and laboratories in the interactive RIS is balanced, reflecting the presence of larger firms with regional headquarters and a regional government keen to promote the innovation base of the economy.

The innovation system in globalized RIS is dominated by global corporations, often supported by clustered supply chains of rather dependent small and medium-sized enterprises (SMEs). The research reach is largely internal and private in nature rather than public, although a more public innovation structure aimed at helping SMEs may have developed.

The second division is provided by Cooke (2004 in Cooke 2005) and it is based on the government dimension. There are three forms of RIS again:

- grassroots,
- network,
- dirigiste.

Grassroots is where the innovation system is generated and organized locally, at town or district level. Financial support and research competences are diffused locally, with a very low amount of supra-local or national coordination. Local development agencies and local institutional actors play a predominant role.

A network RIS is more likely to occur when the institutional support encompasses local, regional, federal and supranational levels, and funding is often guided by agreements among banks, government agencies and firms. The research competence is likely to be mixed, with both pure and applied, blue-skies and near-market activities geared to the needs of large and small firms.

A dirigiste system is animated mainly from outside and above the region itself. Innovation often occurs as a product of central government policies. Funding is centrally determined, with decentralized units located in the region and with research competences often linked to the needs of larger, state-owned firms in or beyond the region.

2 Characteristics of RIS

There are many definitions of the RIS. Cooke (2002) describes the RIS as the wide infrastructure that helps in the innovation creation processes realized in interactions among many entities. Hudec (2007) states that RIS (from systematic point of view) is defined as the system that stimulates the innovation abilities of firms in a region and aims at the economic and social development and the level of the competitiveness.

Stejskal and Matatkova (2011b) offer that we should try to imagine RIS as a framework which includes, according to Cooke (2002), two sub-systems:

- the knowledge application and exploitation sub-system,
- the knowledge generation and diffusion sub-system.

The first is principally concerned with firms while the second is mainly concerned with public organizations like universities, research institutes, technology transfer agencies, and regional and local governance bodies responsible for innovation support practices and policies. In reality, there may be some overlaps since firms conduct knowledge creation activities, especially where they have formalized R&D laboratories, and universities and public or private research institutes conduct knowledge application activities.

Cooke et al. (2000), Cooke and Memedovic (2003) in Tödtling and Trippl (2005) add to above mentioned subsystems another one. The third dimension is the regional policy because policy actors at this level can play a powerful role in shaping regional innovation processes, provided that that there is sufficient regional autonomy to formulate and implement innovation policies. Tödtling and Trippl (2005) further add that in the ideal case, there are intensive interactive relationships within and between these subsystems facilitating and continuous flow or exchange of knowledge, resources and human capital. On the other hand, there are several types of RIS problems and failures such as deficits with respect to organizations and institutions and lack of relations within and between subsystems (Matatkova and Stejskal 2011b).

Therefore, the RISs encompass (as already showed above) the institutions from both the private and public sector. These institutions we can call "basic components" of every RIS. Due to these necessary parts of the network we can determine whether there is some RIS in selected regions. The RIS existence and the evaluation (level of development) was discussed by many economists, i. e. Cooke et al. (1997), Cooke (2001), Doloreux (2002), Andersson and Karlsson (2004), Doloreux and Parto (2005). On the basis of their work we can define the basic components of the RIS, which we can summarize into three fundamental groups: (a) the core of the RIS, (b) auxiliary and complementary organizations and (c) infrastructure, institutions and technical support.

According to the above mentioned, the regional innovation system is composed of three fundamental layers:

(a) entrepreneurs,
(b) supporting organizations,
(c) environment and infrastructure.

In layer (a) companies, businesses and firms that are localized in the region are included. They should be focused on the creating of innovation, i.e. those who produce the market innovations, produce the patents, or spend public and private funds for research, development and subsequent development of innovations. In the layer (b) supporting organizations layer we include those organizations which helps and support the firms included in the first layer and provide complementary support services to them. The supporting organizations are primarily providers of knowledge, cooperating organizations for subcontracting, institutions for collaboration (they are the central part of industrial clusters and manage the cluster activities; Stejskal and Hajek 2012).

The layer (c) "environment and infrastructure" consists of three sub-layers (separate sub-system):

(a) Institutions making up the innovation environment (or ecosystem)

- Institutions forming the legal framework for business, preparing the strategic documents that support innovative business activities, innovation absorption, creativity, and development of innovation in firms;

- Facilitators providing facilitation of the entities in RIS. These organizations are established to support the industrial clusters or business networks births,
- Institutions and organizations that make up the convention, customs and usage in the ethics in business. They are often higher education providers (universities), often also entrepreneurial esprit chambers. These organizations support the social capital.

(b) Incentives and initiatives

- Public incentives to innovation creation and development or infrastructure suitable for innovations financially,
- Private incentives that have decided to financially support the ideas of firms that do not have sufficient investments or capital. we can include venture capital or business angels in this group.

(c) Hard and soft infrastructure

- Fixed infrastructure (industrial zones, technological parks, scientific research parks, innovation and high-tech centers, etc.),
- The infrastructure necessary for high-technology use (technological centers, testing and research centers or other scientific research centers and laboratories),
- Knowledge infrastructure (high schools, universities, and other knowledge organizations that allow horizontal or vertical transfer of knowledge between knowledge producer and firms recipients).

In all the layers we can find private organizations (firms), followed by public institutions (mostly regional governments or their representatives—regional development agencies) and other supporting public (often private or NGO) agencies, which are necessary components of a favorable innovation environment. Collaborating ties among the entities in the RIS are often referred to as triple (sometimes quadruple) helix (Leydesdoff and Etzkowitz 1996).

Every RIS should have, for example industrial clusters, the specialization (be focused on productions of something special). All authors cited above regard the RIS as a general system that is fixed into the socioeconomic environment of the region and integrated in the system that involves entities from the various sectors. We cannot completely agree with the general view of the RIS. We believe that the RIS should focus on some range of industries and this focus should be reflected by regional (public) policy, which is one of the RIS's subsystems. It will increase the efficiency of public policy and also the efficiency of financing because it cannot be assumed that the rule "all-does not fit-to all" will always be applicable.

The important components of each RIS are special activities resulting from geographical proximity, trust and willingness to cooperate. We cannot miss also the communication links between subjects of the RIS. These components determine the efficiency and quality of results arising from RIS existence in region.

3 Methods for RIS Analysis

There is no one shot method to be used universally for analysis and evaluation of the regional innovation system. Numerous authors have employed various methodologies when it comes to regional innovation system assessment. This piece of writing will take a critical review of some of the various methods that have been used to analyze the regional innovation system.

3.1 Participatory Evaluation

This method for assessing the regional innovation system is quite new and has not been widely accepted if we assess how credible it is (Diez and Esteban 2000). This method actively calls for allowing actors that are involved in the regional innovation system the chance to share their views and ideas when it comes to knowing how the regional dynamics of knowledge flow and innovation. The Participatory evaluation method is seen as an inner approach that does not rely on external factors or actors. This method is built on the premise that, regions are composed of numerous actors and stakeholders who are constantly interacting in the so when we want to get a clear understanding of how the system is working we need to involve all the active participants during the evaluation process. The active participation of the entities will ensure that outcomes achieved by the evaluation will be effective because it helps the regional actors in the process to perform the current evaluation and therefore come out with their results that can change the assessment into new ways of doing things.

The evaluation process is an important component of the learning process and this allows us to get a clear understanding based on the perspective of all the participants. It is precisely the very participants in the policy of economic development who contribute to understanding and learning about the processes of change underlying the program and to the development of a new awareness regarding the policy under evaluation (Diez 2001). Evaluation ceases to be an exercise of assessment where the predominant perspective comes from only one angle, that of the objectives of the policy designer as the only criteria for evaluation, and becomes an exercise stimulating the appearance of a learning process (Kuhlmann 1998).

We can summarize that the knowledge creation and transfer takes place inside and outside of the region (there is a so-called regional migration of knowledge). This knowledge “movement” helps to motivate the public organizations (regional governments, NGOs, agencies) to support these knowledge-based activities (described for example Finne et al. 1995; Diez 2001). This is the example of so-called participative development (if the funds are used and shared, we can called it participatory budgeting). The spill-over effects are learning during the co-operation and practice, and at the same time there is a significant cultivation of public policy that re-emphasizes the importance of knowledge as a production factor.

3.2 Interdisciplinary Methodology/Network Analysis

The interdisciplinary methodology has been described as the "appropriate tool" that can be used to evaluate network capital in the regional innovation system (Krätke 2002). Social network analysis is the mapping and measuring of relationships and flows between people, groups, organizations, computers or other information/knowledge processing entities (Krebs 2002). Social network or network analysis centers on the arrangement of relationships among actors and assess how resources are exchange among the various actors (Scott 1991; Wasserman and Faust 1994). The RIS is composed of numerous interactions among the various social entities and this result in the creation of network capital. So to evaluate the how this social network thrives, the interdisciplinary methodology can be used. Social Network Analysis has therefore proven to be useful because it enables the visualization of how people are connected, thereby enabling users of this methodology to find out how best people and institutions interact to share knowledge in the RIS. This methodology is built on the belief that social network are very important for the collaborating entities (Wassermann and Faust 1994) and society as a whole because of the end product that leads to transformation of the entities and society as a whole.

This analytical tool can be used to identify the vital properties of the RIS (Wassermann and Faust 1994; Jansen 1999). For a better and comprehensive understanding of networks and the participants involved, one needs to evaluate where the network is taking place (its location) and composition of actors that make up the network. These procedures provide us with a better understanding into the various roles and categories in a network—who constitute the connectors, where are the clusters and their makeup, who forms the center of the network, and who is on the periphery. This methodology can be relied upon in RIS when we endeavor to assess the rate at which knowledge and information flow across functional and institutional borders as in triple helix. It can also be useful when we want to find out who knows who (social relationships) and who might know what (expertise) in groups where individuals play key roles. One advantage of using this methodology in RIS is that, it provides it helps us to understand and simplifies the complex nature of interorganizational networks. It allows for comparative analysis by first of all mapping the already established network and its properties.

This methodology is able to generate data about network by using surveys. Since the network consists of industries and institutions, surveys will be able to determine the networked relationship by questioning the various actors involved. If the network structure is known, then an evaluation of its properties can follow to establish the extent of how they are interconnected and what role does the various actors play in the network can also be known. Haythornthwaite (1996) used the network analysis to study how information is exchanges in social networks and concluded that, the network analysis helped to create awareness of already established information exchange paths, and that information sources can act on information opportunities and alter information directions to improve the delivery of information services.

The overview of the case studies is presented in Table 1.

Table 1 Overview of interdisciplinary methodology/network analysis studies

Authors	Study regions	Objectives	Results
Fritsch and Kauffeld-Monz (2010)	16 German regional innovation networks	To analyze information and knowledge transfer	Strong ties are more beneficial for the exchange of knowledge and information than weak ties; broker positions tend to be associated with social returns rather than with private benefits.
Love and Roper (2001)	UK, Germany and Irish	To assess the location and network effects on innovation success	Inter-firm linkages do not affect the success of innovative activities, intra-group links have positive effect
Haythornthwaite (1996)	General	To study how information is exchanges in social networks	That information sources can act on information opportunities and alter information directions to improve the delivery of information services
Fritsch (2001)	3 German regions	To examine the co-operative relationships of manufacturing firms	Spatial proximity is obviously of particular importance for horizontal co-operation and for relationships to publicly funded research institutions
Ter Wal and Boschma (2009)	General	To shed light on the untapped potential of social network analysis techniques in economic geography To describe how these challenges can be met through the application of network analysis techniques, using primary (survey) and secondary (patent) data	Network analysis has a huge potential to enrich the literature on clusters, regional innovation systems and knowledge spillovers The choice between these two types of data has strong implications for the type of research questions that can be dealt with in economic geography, such as the feasibility of dynamic network analysis
Leydesdorff and Fritsch (2006)	Germany	Measuring the knowledge base of regional innovation systems in Germany	The configuration of medium-tech manufacturing can be considered a better indicator of the knowledge-based economy than that of high-tech manufacturing
Lee et al. (2010)	Korea Republic	Assess the effect of firm size on the effectiveness of innovation	Networking as one effective way to facilitate open innovation among SMEs

Source: Own

3.3 Cluster Analysis

Over the past two decades cluster analysis technique has been usage has increased (Everitt 1979; Gower 1967). Cluster Analysis also known as taxonomy analysis or segmentation analysis based on the techniques ability to produce classification (Everitt 1979). “Cluster analysis groups data objects based only on information found in the data that describes the objects and their relationships. The goal is that the objects within a group be similar (or related) to one another and different from (or unrelated to) the objects in other groups. The greater the similarity (or homogeneity) within a group and the greater the difference between groups the better or more distinct the clustering” (Nowak et al. 2008). According to (Romesburg 2004), cluster analysis refers to combinations of mathematical models that can be utilized to group objects that are similar into the same group. All objects have their attributes which might not be the same, but when has many objects, there is bound to be different attributes, so these can be arrange to for a cluster. Cluster analysis is the best and widely used research method when it is necessary to examine the similarity of the objects.

In the RIS, clusters analysis strongly focuses on the all the linkages and interactions that exist among various actors and people that results in the efficient creation of innovation, new products and services (Roelandt and Den Hertog 1999). The cluster in reference here is not assumed to be the same as happens in other forms of interaction they are very similar and linked in the value chain. Clusters can either be horizontal or vertical (cross-sectorial) network that consist of industries that are not the same but complementary firms that have a specific specialization that can result in the creation of innovation (Morgan 1997). The cluster analysis approach differs from other conventional research approaches because it takes into account collaborations and knowledge flow within the network (Rouvinen and Ylä-Antilla 1999). Comparatively, the conventional research approaches have focuses on networks that have homogenous firms producing same products, but the cluster have proven to be a reliable alternative because, it offers a different view in the RIS in the sense that, it places premium on the interaction-based theories of innovation which many authors now called “triple helix” (see Leydesdorff 2012; Vaivode 2015). This dynamic nature of the cluster analysis has made it a reliable alternative to the other traditional research approaches (Roelandt and Den Hertog 1999). Another reason that has made cluster analysis so important is its focus on vertical relationship and interdependence of actors who may not necessarily be similar firms or institutions (Roelandt and Den Hertog 1999).

Many studies have used cluster analysis methodology (Punj and Stewart 1983; Ketchen and Shook 1996; Feser and Luger 2003; Beuther and Sutherland 2007). The cluster analysis was used by Fesser and Bergman (2000) to study 23 national industry cluster template and the results proved that template clusters are useful to discover gaps and knowledge about extended product chains and therefore represents a useful first step in the detailed examinations of local cluster patterns. Arthur (1994) also used the cluster analysis to study the effects of Human resource system on manufacturing performance and turn over and concluded that “human resource

Table 2 Overview of cluster analyses

Authors	Study regions	Objectives	Results
Feser and Bergman (2000)	23 US manufacturing clusters	Using templates as an illustrative analysis of the manufacturing sector in a single US state	Template clusters help detect gaps and specializations in extended product chains and therefore constitute a useful first step in more comprehensive examinations of local cluster patterns
Almeida and Kogut (1999)	2 regions, Route 128 and Silicon Valley	investigate the relationship between the mobility of major patent holders and the localization of technological knowledge through the analysis of patent citations of important semiconductor innovations	Knowledge localization was found only in some specific regions (for example, Silicon Valley), the degree of localization varies regionally Mobility within inter-company cooperation enhances knowledge transfer (which is affected within regional labor networks)
Kronthaler (2005)	2 German regions (East Germany and West Germany)	Analyses the economic capability of East German regions compared with West German regions	Weak evidence that the economic capability of East German regions can be compared with West Germany. Development barriers have been observed: lower technological progress, low industrial activity and poor quality of transport networks
Baptista and Swann (1998)	248 manufacturing firms in the UK	To analyse whether firms located in strong industrial clusters or regions are more likely to innovate than firms outside these regions	A firm is considerably more likely to innovate if own-sector employment in its home region is strong; Congestion effects outweigh any benefits that may come from diversification within clusters
Sternberg and Arndt (2001)	11 European regions based on data from the European Regional Innovation Survey (ERIS)	To assess the absolute as well as the relative impact on innovation behavior of firm-specific (i.e. internal) factors on the one hand and region-specific characteristics on the other	Firm-specific determinants of innovation are more important than either region-specific or external factors; high-tech regions dominated by a small number of

(continued)

Table 2 (continued)

Authors	Study regions	Objectives	Results
			very large firms the innovation behavior of the smaller firms is more strongly influenced by regional factors than by factors internal to the firm
Poledníková (2014)	The Visegrad Four (the Czech Republic, Hungary, Poland and Slovakia)	To evaluate regional disparities in the case of the Visegrad Four (V4) countries in the year 2010	NUTS 2 regions with capital cities (Praha, Bratislavský kraj, Mazowieckie and Közép-Magyarország) still occupy the dominant positions in comparison with other regions in the V4; Significant disparities between clusters are visible, especially regarding the economic and innovative performance and territorial cohesion
Dümmler and Thierstein (2002)	Zurich (EMRZ)	Identification of the major manufacturing and service industries that are located within the EMRZ	The EMRZ can be regarded as a meta-cluster of several specialized economic clusters with regard to high-tech and high-services industries

Source: Own

system moderated the relationship between turnover and manufacturing performance”.

The overview of the case studies is presented in Table 2.

3.4 Data Envelopment Analysis

Data envelopment analysis or DEA for short has increasingly become a famous management tool since the method first came into practice (Charnes et al. 1978). Many studies have been done in relation to DEA (see Banker et al. 1984; Dyson and Thanassaoulis 1988; Seiford and Thrall 1990; Anderson and Peterson 1993; Banker 1993). According to Boussofiane et al. (1991), “DEA is a linear programming based techniques used for measuring the relative performance of organizational units where the presence of multiple inputs and outputs makes comparison difficult." The mathematical component of the DEA make it a useful tool that can be used to control and assess past activities and also useful for future planning. They have proved to be very vital for "ex post" evaluation of efficiency in management circles (Banker et al. 1984).

The DEA can also be employed to assess the performance of activities carried out by organization using output and input data (Lertworasirikul et al. 2003). In the knowledge based economies, universities produce knowledge using inputs in the form of labour (tutors), computers etc. to create output (knowledge). When one is given output and input data, it becomes easy to establish how the organization will perform using the DEA technique. They have become "powerful tools" that is used to measure efficiency and have since then been used to evaluate the efficiency of educational and research institutions in terms of their knowledge production functions (Lertworasirikul et al. 2003). The DEA is in the sense that it helps to characterize efficiency and inefficiency of decision making units (Zhu 2001).

To measure organization efficiency has been a source of worry for many years because there was no clear cut formula that provided the solution (Farrell 1957). As a mathematical model, it is not faced with deficiencies, (Andersen and Petersen 1993) have concluded that the DEA methodology has been very successful in determining the relative efficiency in decision making units but the method does not allow us to rank how efficient these units are. In addition Kao and Liu (2000) have also described the use of DEA to measure efficiency as very difficult because of its (DEA) use of complex economic and behavioral entities. This becomes more difficult when multiple outputs and inputs need to be aggregated in isolation to determine efficiency.

In a study to evaluate the comparative efficiency of ten Chinese third-party logistics providers 3PLs, Zhou et al. (2008) used the DEA approach and concluded that there was a decline in efficiency of Chinese 3PLs and this coincided with a steep decline in transportation activities as a result of the outbreak of the deadly SARS virus. The study also found out that technical expertise and sales opportunities directly correlate with operational efficiency of 3PLs at the same time, there was no direct correlation between the size of 3PLs and their performance. Abbott and Doucouliagos (2003) also used the DEA model to evaluate the efficiency of Australian universities. Their result proved that irrespective of the blend of input and outputs, Australian universities recorded high levels of efficiency relatively when compared one by one. In a study to measure the performance of 500 manufacturing firms in Turkey Düzakın and Düzakın (2007) used the DEA methodology and came out with the conclusion that during 2003 nine firms efficiently performed in Turkey, and out of these nine firms ranked among themselves. Furthermore, each of the firms in the analysis was ranked within each industry, and the results were that 65 firms were efficient among the industries.

The overview of the case studies is presented in Table 3.

Table 3 Overview of inputs and outputs in data envelopment analyses

Authors	Inputs	Outputs
Guan and Liu (2003)	**Impact of institutions** Innovation efficiency	**Decreasing returns to scale** Innovation capacity
Kutvonen (2007)	**Public funding** Public expenditure per capita **Education** Percentage of population with higher education **Research capacity** Total R&D personnel in the region, percentage of active population **Collaborative clusters** Number of identified potential clusters **Competent workforce supply** Participation of adults aged 25–64 in education and training (%) **Political support** Percentage of public funding used for regional Chen and Guan (2012)	**Regional competitiveness** Regional GDP per inhabitant growth rate, PPS **Socioeconomic wellbeing** Regional GDP per inhabitant, **Regional attractiveness** Private and public investment in region per capita **New knowledge** Applied patents to the European Patent Office per million inhabitants **Business growth** Regional employment growth rate (%) **Regional growth** Average annual growth rate of population (%)
Chen and Guan (2012)	**Technical development** Technological commercialization	**Regional growth** Improved performance of regional innovation systems
Fu (2008)	**FDI**	Positive absorptive capacity Regional economic growth Knowledge-based development
Guan et al. (2006)	Technological innovation capability	Competitiveness
Zhong et al. (2011)	**R&D activities** R&D expenditure R&D personnel	Number of patent applications Sales revenue of new products Profit of primary business
Liu and Lu (2010)	Funds Advanced human resources Basic human resources, and project time	License fee and royalty License fee/royalty Production investment
Zabala-Iturriagagoitia et al. (2007)	Innovation system performance	The higher the technological level of a region, the greater the need for system coordination

Source: Own
The bold means the title of the "group" of indicators

3.5 *Case Studies*

The case study methodology can also be used to evaluate the regional innovation system. The case study approach has been defined by many scholars (see below). Robson (2002) defines the case study as "a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence". The case study as an approach can be adopted for a study based on the research questions and the objectives the researcher wants to achieve. The case studies are pertinent when the research being undertaken addresses either a descriptive question or an explanatory question (Shavelson and Towne 2002). The case study therefore seeks to provide a rich description and detailed explanation of the reason behind a complex phenomenon, and why they have happened or remained as they are.

The case study is a more appropriate methodology for evaluating the RIS because it provides more detailed information comparatively to the other methods. This information gathered from individual cases can be compared to find out why the differences exist. It also allows researchers to collect data from multiple methods such as surveys, interviews, and observations among others that can be validated through triangulation. The required data for the case study are likely to come from diverse and not a singular source of evidence (Denscombe 2003; Yin 2003).

Case study research assumes that scholars need to study the conditions and factors what appear in similar case studies to understand them more closely. The major limitation of case study approach is that it does not allow for generalization since findings are unique to the particular case as against the other cases. It however provides in-depth information and enough bases for improvement in the case under study.

Huggins et al. (2011) used the case study in their study on small firm-University Knowledge Networks using evidence from the United Kingdom and the US. They used this methodology to study 16 Small and Medium Scale enterprises (SMEs) from the UK and US (8 SMEs in the UK, and 8 SMEs in the US). They used the firm level case study to compare these firms and generated data from semi-structured interviews with Chief Executive Officers of these companies. Their study found out that, the bulk of firms were <10 years old, but their global customer base indicated that they were innovative firms as they have started exporting their products contributing to the regional economies supporting the empirical evidence that innovative firms are very important in economic development (Siegel et al. 2003).

The overview of the case studies is presented in Table 4.

3.6 Regression Models

Regression analysis is a quantitative research technique used research or studies that involve modeling and examining several variables, where the relationship consists of a dependent variable and independent variables (Mosteller and Tukey 1977). The regression analysis is mainly used to get a detailed understand of the relationship that exist between a dependent variable and an independent variables (Ai and Norton 2003). Regression analysis allows researchers to identification and classification of relationships among multiple components (Schneider et al. 2010). This technique has become a key to economic statistics and it's mainly used to achieve several

Table 4 Overview of case studies

Authors	Inputs	Outputs
Asheim and Isaksen (2002)	Place-specific local World-class knowledge	Strengthen competitiveness
Fritsch and Schwirten (1999)	Enterprise-university cooperation Public research institutions	Absorbing knowledge beyond the region Spatial proximity important
Asheim and Coenen (2005)	Knowledge base	Regional level innovation policy embedded in networks of actors
Acs et al. (2002)	Patents	Regional production of new knowledge
Koschatzky and Sternberg (2000)	Regional innovation potential	Network-building and regional innovation system
Doloreux and Parto (2004)	Regional innovation systems	Territorial dimension Role of institution
Love and Roper (2001)	1700 UK plants, 1300 German plants and 500 Republic of Ireland businesses	The effectiveness of R&D, knowledge transfer and network activities significantly influence the outputs of knowledge activities (confirmed in the UK, Germany). However, the results depend strongly on local conditions
Fischer et al. (2001)	Cooperation with government agencies	Innovation service/information service/ supervision service departments
Cooke et al. (2000)	Cooperation with intermediary institutions	Technology intermediaries, venture capital organizations, industrial associations
Romijn and Albaladejo (2002)	Innovation performance	Annual turnover of new products, products innovation index

Source: Own

objectives like predicting, forecasting, and finding the effect of one causal variable on another (Sykes 1993).

Regression analysis is preferred among statisticians because it allows users to make assumptions and it easily solves problems that are very complicated of because this method is very flexible (Oliver 2014). There are many types of regression techniques. The basic ones include linear regression, nonlinear regression, and the least squares method. According to Schneider et al. (2010), the linear regression is used to evaluate the linear relationship between a dependent variable and other independent variables.

3.7 Comparative Studies

Many authors believe that the RIS are specific entities that should be analyzed and evaluated individually. The findings should be compared with similar (and also foreign) regions. The researchers seek for the similarities (hits) or differences, and the analysis of the causes and consequences. The overview of the most important studies that dealt with RIS is given in the Table 5 below.

The overview of the case studies is presented in Table 5.

3.8 Qualitative Content Analysis

Qualitative content analysis has been defined as "a research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying Themis or patterns" (Hsieh and Shannon 2005). Zhang et al. (2005) claim that "these three definitions illustrate that qualitative content analysis emphasizes an integrated view of speech/texts and their specific contexts. Qualitative content analysis goes beyond merely counting words or extracting objective content from texts to examine meanings, themes and patterns that may be manifest or latent in a particular text. It allows researchers to understand social reality in a subjective but scientific manner." There are some international studies what used the qualitative content analysis.

The overview of the case studies is presented in Table 6.

The practice shows that RIS analysis is not a simple process. Many studies have not been mentioned at all in this part of the publication, because they were too focused on specifics of individual regions and often cannot be generalized as the widely applicable methodology. Many of these studies tried to apply a combination of qualitative and quantitative approaches.

4 Application of the WSA Method for Regional Innovation Systems in Selected Regions of the Czech Republic[2]

Regional innovation systems are suitable and often used tool of regional policy also in the Czech Republic. The importance of these systems is even more emphasized after joining the EU. The significant decentralization of the regional policy was realized after 2004 and the emergence of RISs is good example of this trend (the same trend was noted in Western countries in past). The regional innovation strategies were created in all Czech regions (NUTS 3), i.e. documents in which the strategy how to create and promote RISs are contained. However, the emergence of regional strategies was left in the hands of the regional governments. This caused that the quality of strategies in different regions is different. It determines that the

[2]Methodological approach published in Nekolova, K., Rouag, A., & Stejskal, J. (2015). The Use of the Weighted Sum Method to Determine the Level of Development in Regional Innovation Systems – Using Czech Regions as Examples. *Ekonomický časopis*, 63(03), 239–258.

Table 5 Overview of comparative studies

Authors	Study regions	Objectives	Main results/lessons
Doloreux and Parto (2005)	11 Regions in the EU: Eastern and Central Europe (Baden-Württemberg, Wallonia, Brabant, Tampere, Centro, Féjer, Lower Silesia, Basque country, Friuli, Styria, Wales)	Explore theoretically key organization and institutional dimensions that provide a regional innovation system	Highly detailed info re different regions in terms of innovation performance potential for strong and weak regions
Sternberg (2000)	11 European regions (Vienna, Stockholm, Barcelona, Alsace, Baden, Lower Saxony, Gironde, S. Holland, Saxony, Slovenia, S. Wales)	Study the qualitative and quantitative determinants for innovation potential of any region and the innovative linkages and networks between different players	Innovation activities and business innovation process can be viewed as a network process in which business and interaction with other partners play a significant part
Asheim et al. (2003)	13 Nordic regions (Oslo, Stockholm, Helsinki, Gothenburg, Malmö/Lund, Aalborg, Stavanger, Linköping, Jyväskyla, Horten, Jaeren, Salling, Icelandic regions)	Explore the existence of similarities and differences between regional clusters of SMEs in different regions in the Nordic countries	Social networks are a major determinant of Nordic clusters. They help to gain social capital and trust. SMEs draw on available knowledge bases and innovate through science-driven R&D (e.g. in biotech). SMEs want to collaborate with global actors and acquire knowledge from them. SMEs now often collaborate with regional partners. (Doloreux and Parto 2005)
OECD (2001)	10 European regional clusters: ICT regional clusters in Finland, Ireland, Denmark, Spain, Flanders, and Netherlands; mature regional clusters: agro-food cluster (Norway) and construction cluster (Denmark, Netherlands, Switzerland)	Question the relevance of regional clusters in innovation policy	Regional clusters in every country/region have unique cluster blends; regional clusters are variation and selection environments that are inherently different; regional clusters may transcend geographical levels
Isaksen and Karlsen (2010)	2 regional industries in Norway (STI (marine biotechnology in Tromsø) and DUI (oil and gas equipment suppliers in Agder)	Analyse innovation and cooperation with universities in two regional industries in Norway	Universities play plays different roles in these two regional industries; The University of Tromsø is the main organization behind the development of the marine biotechnology industry in Tromsø and is an important knowledge node and source of biotechnology spin-offs

Source: Own

Table 6 Overview of qualitative content analyses

Authors	Study region	Objectives	Main results/lessons
Suorsa (2014)	93 scientific articles that use the RIS approach as their theoretical framework	Examine the concept of 'region' in research on regional innovation systems (RIS)	Regions and their boundaries are taken for granted in research; RIS research will gain new perspectives if the ontological basis is shifted to social constructivism
Shapira et al. (2006)	1800 Malaysian firms in 18 manufacturing and services industries	Assess the methodology and results of a project to develop sectoral knowledge content measures in Malaysia	Positive associations between technological innovation and at least one knowledge content variable are evident across all but four industries, although generally the results suggest that knowledge-based innovation is modest in Malaysia
Ceci and Iubatti (2012)	15 SMEs in the CISI consortium (Consorzio Italiano Subfornitura Impresa), operating in the automotive industry in Val di Sangro (Abruzzo, Italy)	Investigates the role played by personal relationships within networks	The coexistence of personal and professional relationships shapes a unique context that alters the usual dynamics of innovation diffusion; Honda Italia has a central role in professional activities

Source: Own

application in the coming years is not always good and efficient. The suitable conditions for the RIS emergence are created in all Czech regions; in some regions created RIS latently (clear evidences of RIS existence are missing).

In 2016, the national Czech government decided to create a central regional innovation strategy (RIS3) and in all regions there the regional innovation strategies were initiated. These new versions of regional RIS3 strategies are based on the national RIS3 strategy. The regional characteristics and specifics are taken into account by close cooperation (the national coordinators of RIS3 strategy collaborated with regional representatives). The RIS3 has to be the key conditionality for approving the operational programs and boosting the investments to the research, development, innovation and ICT (financed from EU Structural funds in programming period 2014–2020). After past experiences, we afraid that the strategies will lead to investment, but without noticeable positive effect (the goals of RIS3). Therefore, we need to develop methods that help to analyze the quality of the RIS, to support and to assess the regional innovation system development and level.

4.1 WSA Method Characteristics

The weighted sum method (WSM) is based on the principle of utility maximization (Fiala et al. 1997). This method has been simplified by using only a linear utility function. Calculations are then manageable without the use of specialized software. First, we created a normalized criteria matrix $R = (r_{ij})$ whose elements are obtained from the criteria matrix $Y = (y_{ij})$ using the transformation rule, (1):

$$r_{ij} = \frac{y_{ij} - D_j}{H_j - D_j}, r \in 0; 1, \forall i = 1, \ldots, pj = 1, \ldots, k \tag{1}$$

where r_{ij} is the normalized value for the *i*-th alternative and *j*-th criterion, D_j is the basal value, the lowest possible value an alternative acquires in the *j*-th criterion, H_j is the ideal value, the best possible value an alternative acquires in the *j*-th criterion.

Obviously, $r_{ij} = 0$ for the basal alternative, and $r_{ij} = 1$ for the ideal alternative (Chyna et al. 2012). When using the additive form of multi-criteria utility functions, the utility of the option ai is then expressed by (2):

$$u(a_i) = \sum_{j=1}^{k} v_j r_{ij}, \forall i = 1, \ldots, p \tag{2}$$

where v_j is the corresponding element from the weight vector, r_{ij} is the normalized value gained from (1).

Obviously, the alternative with the highest utility value is considered as a compromise. In addition, the WSM makes it possible to arrange all the alternatives with respect to their utility values (Chyna et al. 2012).

The option that reaches the maximum utility value is selected as being the best, or the results can allow the variants to be classified according to their decreasing utility values.

As seen in Eq. (2), the vector of criteria weights must be determined for calculating utility. In the context of this analysis, we use the Fuller's triangle method. The determination of weights is based on a pairwise comparison between criteria (Subrt et al. 2011). Because of the pairwise comparison, the number of comparisons is equal to:

$$N = \binom{k}{2} = \frac{k(k-1)}{2} \tag{3}$$

Each comparison may be performed inside Fuller's triangle. Criteria are numbered as serial numbers 1, 2,. . ., *k*. Users then work with the triangular diagram; the double lines formed by serial numbers are arranged in pairs so that each pair of criteria appears exactly once. The user indicates (by encirclement) which criterion is more important for comparing each pair. We mark the number of encirclements of *i*-th criterion as n_i. The weight of the *i*-th criterion is then calculated as:

$$v_i = \frac{n_i}{N}; i = 1, 2, \ldots, k \quad (4)$$

The main advantage of this method is the simplicity of the information required from users. If it is necessary to exclude zero weight, the number of encirclements may be increased by one with the condition that the denominator in Eq. (4) must also be increased accordingly.

4.2 The Definition of RIS Characteristics

Using study findings and detailed results coming out of references (e.g. Cooke et al. 1997; Andersson and Karlsson 2004; Doloreux and Parto 2005; Hudec 2007; Skokan 2010), Table 7 defines set characteristics for a "standard" form for the RIS.

If the set of characteristics cited above exists within one region, the authors agree that we can say that a regional innovation system exists in its basic form. At the same time, none of the authors mention the degree of development, precisely because the degree to which a characteristic has been achieved will vary from one RIS to another. Therefore, the degree to which they have been achieved increases the likelihood of positive effects being created when an RIS exists in a given region. For example,

Table 7 Regional innovation system characteristics

RIS layer	Characteristic	Abbr.
Companies	Existence of industrial clusters	A1
	Existence of specific innovating enterprises in the fields	A2
	Number of patents in the fields	A3
Support organizations	Existence of IPS	B1
	Existence of business incubators	B2
	Existence of regional development agencies	B3
	Existence of other support and complementary organizations	B4
Environment and infrastructure	Existence of an RIS not older than (or updated for longer than) 5 years	C1
	Existence of animators (actors) in the region and the fields	C2
	Existence of an organization shaping the professional community in the fields	C3
	Existence of professional societies or associations in the fields	C4
	Existence of public finance (funding) schemes	C5
	Existence of private finance (funding) initiatives	C6
	Existence of hard innovation infrastructure elements	C7
	Existence of technological infrastructure	C8
	Existence of knowledge infrastructure	C9
Relationships, Links	Existence of communication channels	D1
	Existence of projects confirming cooperation and synergy	D2

Source: Matatkova and Stejskal (2011)

these effects can be observed via an increase in regional GDP or a decrease in the unemployment rate.

However, many of these effects bring positive measurable results over the long term, which precludes the causal analysis of economic indicator changes. Consequently, it is not relevant to analyze the effects of the RIS directly.

The RIS characteristics that have been defined (see Table 7) represent criteria which will be quantified and then used to constitute the members of the criteria matrix used when applying the WSM. The quantification of the criteria must be done on the basis of descriptive analysis and information obtained from expert assessments or controlled interviews with experts on regional issues.

Particular characteristics were grouped on the basis of results derived from research findings on RIS layers. The characteristics cited above also contain those of the triple helix (these concern enterprises, support organizations, knowledge and public organizations as well as the environment and investment infrastructure). Relationships and links are two of the most important characteristics and should not be overlooked.

For the purposes of this analysis, the characteristics mentioned above are divided into three groups (see Table 8). The first two groups describe characteristics that are necessary and supportive in the region (physical infrastructure including industrial zones, technological parks, scientific research parks, innovation centers, etc.) and

Table 8 The weight assigned to each criterion based on the Fuller's triangle calculation

Criterion	v_i
I. Group: necessary characteristics	0.333
A2	0.222
B1	0.167
B2	0.028
C1	0.042
C2	0.042
C3	0.181
C5	0.083
C6	0.152
C7	0.083
II. Group: supporting characteristics	0.167
A1	0.499
B3	0.167
B4	0.167
C4	0.167
III. Group: qualitative characteristics	0.5
A3	0.3
C8	0.133
C9	0.3
D1	0.067
D2	0.2

Source: Authors' own calculations

institutions. The existence of these characteristics does not reflect whether the RIS is working or not. They only describe the physical substance of the RIS and can be used as a binary variable (whether present or not) or to quantify the number of institutions. The third group consists of characteristics that have a quantitative nature or contain characteristics whose quality significantly depends on the scope and quality of the individual RIS (typically, the number of patents). On the basis of their analysis, we can conclude that an existing RIS leads to cooperation, knowledge spillovers and a synergic effect and, thus, the creation of innovation. This type of RIS will have a positive impact as a result of the public interventions that have been created and supported.

It is logical that each characteristic will not have the same meaning for RIS existence and operation. We need to assign a weight to each characteristic inside each group; this weight provides information about the significance of each characteristic. The Fuller's triangle method was used to assign weights. Preference ranking was done by ten experts.

The expert evaluation of preferences makes it possible to determine the criteria weights and their appropriate grouping according to Eq. (4). The resulting weights are summarized in Table 8.

The sum of the weights assigned to groups I–III equals one, just as the sum of the weights within each group is also equal to one.

Next, the WSM was applied for determining the weight of each characteristic. The method's application will be divided into three progressive steps corresponding to the division of criteria from the three groups cited above. All the steps of the analysis process will correspond to the WSM as explained above.

For the case study (realized in 2015) we chose six regions[3] of the Czech Republic (NUTS 3 level):

- Kralovehradecky (KHK),
- Pardubicky (PK),
- Jihomoravsky (JMK),
- Moravskoslezsky (MSK),
- Liberecky (LK),
- Stredocesky (STC).

4.3 *The Evaluation of Necessary RIS Quantitative Characteristics*

Criteria included in the group of quantitative characteristics are listed in Tables 7 and 8. Descriptive analysis was provided by an expert appraisal from the creator of the Czech Republic's RIS in April 2015. The results are summarized in Table 9.

[3]The capital city is not included in any analyzed regions.

Table 9 Necessary quantitative characteristics

Region/ Criteria	A2[a]	B1	B2[c]	C1	C2[b]	C3	C5	C6	C7
KHK	6th place	Yes	Yes (2/9)	Yes	Yes (2)	Yes	No	No	Yes
PK	4th place	Yes, few	Yes (1/0)	No	Yes (6)	Yes	No	No	Yes
JMK	2nd place	Yes, many	Yes (5/33)	Yes	Yes (9)	Yes	Yes	Yes	Yes
MSK	9th place	Yes	Yes (6/78)	Yes	Yes (2)	Yes	Yes	Yes	Yes
LK	2th place	Yes	Yes (1/0)	Yes	Yes (2)	Yes	Yes	Yes	Yes
STC	6th place	Yes	Yes (3/16)	Yes	Yes (2)	Yes	Yes	Yes	Yes

Source: Authors' own calculations
[a]Order established under the World Competitiveness Yearbook 2015
[b]The number in parentheses indicates the number of animators (actors) working in the region
[c]The number in parentheses indicates the number of business incubators and the number of firms working in the region

When establishing a criteria matrix, it is necessary to give a point value to each indicator. Scoring was used for the sequence of the regions according to the assessment of each criterion. The poorest result was recorded as zero and the best as three. After point evaluation maximizing all criteria, it is possible to establish an initial criteria matrix where rows and columns correspond to Table 9:

$$\begin{bmatrix} 1 & 2 & 1 & 1 & 1 & 3 & 2 & 0 & 3 \\ 2 & 1 & 0 & 0 & 2 & 3 & 2 & 0 & 3 \\ 3 & 3 & 2 & 3 & 3 & 3 & 3 & 3 & 3 \\ 0 & 2 & 3 & 2 & 1 & 3 & 3 & 3 & 3 \\ 3 & 2 & 0 & 3 & 1 & 3 & 2 & 2 & 3 \\ 1 & 3 & 2 & 3 & 1 & 3 & 2 & 1 & 3 \end{bmatrix}$$

Criteria in this matrix are maximized; we can therefore determine the maximum value H and the minimum value D from each column j: $H = (3; 3; 3; 3; 3; 3; 3; 3; 3)$; $D = (0; 1; 0; 0; 1; 3; 2; 0; 3)$.

Using Eq. (1), the initial criteria matrix is transformed into a normalized criteria matrix. Elements of this matrix express the indicator value of each variant according to certain criteria:

$$\begin{bmatrix} 0.33 & 0.5 & 0.33 & 0.33 & 0 & 0 & 0 & 0 & 0 \\ 0.67 & 0 & 0 & 0 & 0.5 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0.67 & 1 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0.5 & 1 & 0.67 & 0 & 0 & 1 & 1 & 0 \\ 1 & 0.5 & 0 & 1 & 0 & 0 & 0 & 0.67 & 0 \\ 0.33 & 1 & 0.67 & 1 & 0 & 0 & 0 & 0.33 & 0 \end{bmatrix}$$

The normalized criteria matrix makes it possible to calculate the indicator value cited in Table 9 in each region on the basis of Eq. (2). It is important for that calculation to determine the weighting vector v1; its compilation is based on values presented in Table 8: $v_1 = (0.222; 0.167; 0.028; 0.042; 0.042; 0.181; 0.083; 0.152; 0.083)$. The following results are those for the RIS development level in the selected regions according to indicator value calculations. These results are presented in Table 12.

4.4 The Evaluation of RIS Supporting Quantitative Characteristics

This group of characteristics was also analyzed using an expert appraisal and focused on their level of development in the selected regions. The completed results are summarized in the Table 10.

Once again, each criterion was evaluated using points and by following the same method used for the necessary quantitative characteristics. The results consist of a criteria matrix whose rows and columns correspond to Table 10:

$$\begin{bmatrix} 1 & 3 & 2 & 3 \\ 0 & 3 & 1 & 3 \\ 2 & 3 & 3 & 3 \\ 3 & 3 & 2 & 3 \\ 0 & 3 & 2 & 3 \\ 2 & 3 & 2 & 3 \end{bmatrix}$$

Because the criteria matrix is maximized, we can specify the maximum and the minimum values H and D for each column j: $H = (3; 3; 3; 3)$; $D = (0; 3; 1; 3)$.

Table 10 Supporting quantitative characteristics

Region/Criterion	A1	B3	B4	C4
KHK	Yes (3)	Yes	Yes	Yes
PK	Yes (2)	Yes	Yes, very little	Yes
JMK	Yes (3–5)	Yes	Yes, very little	Yes
MSK	Yes (10)	Yes	Yes	Yes
LK	Yes (1)	Yes	Yes	Yes
STC	Yes (6)	Yes	Yes	Yes

Source: Authors' own calculations

The following is the normalized criteria matrix formed on the basis of the transformation formula, (1):

$$\begin{bmatrix} 0.33 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0 \\ 0.67 & 0 & 1 & 0 \\ 1 & 0 & 0.5 & 0 \\ 0 & 0 & 0.5 & 0 \\ 0.67 & 0 & 0.5 & 0 \end{bmatrix}$$

The calculation of the effects' values for regions resulting from Table 10 is computed according to Eq. (2) using the normalized criteria matrix. The value of each effect is then calculated according to weighting vector v_2. Values are compiled using Table 8: $v_2 = (0.499; 0.167; 0.167; 0.167)$. The calculation of the effect values gives the results summarized in Table 12.

Quantitative characteristics are concerned only with innovation infrastructure. On their basis, we can decide whether organizations that contribute and diffuse knowledge in each region exist and to what extent they exist; they make it possible to evaluate each region's innovation potential. Therefore, evaluating the use of this potential is made possible by the analysis of the third group of characteristics—the group of qualitative characteristics.

4.5 Evaluating the Effect of the Existing Qualitative Characteristics

The results of the experts' appraisal for the cited criteria's existence, their degree of evolution, all is summarized in Table 11.

The criteria were also point evaluated using the same methods. The result consists of a criteria matrix whose rows and columns correspond to Table 11:

Table 11 Qualitative characteristics

Region/Criterion	A3	C8	C9	D1	D2
KHK	37	Yes	Yes	Yes, few	Yes, few
PK	31	Yes, limited	Yes	Yes, few	Yes, very few
JMK	105	Yes	Yes	Yes	Yes
MSK	69	Yes	Yes	Yes, few	Yes
LK	27	Yes	Yes	Yes, few	Yes, few
STC	32	Yes	Yes	Yes, few	Yes, few

Source: Authors' own calculations

Table 12 Effect values within each group

Indicator value						
Criterion group/region	KHK	PK	JMK	MSK	LK	STC
Required quantitative characteristics	0.17986	0.16974	0.72676	0.37464	0.44934	0.35118
Supporting quantitative characteristics	0.24817	0	0.50133	0.58250	0.08350	0.41783
Qualitative characteristics	0.33200	0	0.70000	0.60100	0.33200	0.33200

Source: Authors' own calculations

$$\begin{bmatrix} 1 & 3 & 3 & 2 & 2 \\ 0 & 2 & 3 & 2 & 1 \\ 3 & 3 & 3 & 3 & 3 \\ 2 & 3 & 3 & 2 & 3 \\ 1 & 3 & 3 & 2 & 2 \\ 1 & 3 & 3 & 2 & 2 \end{bmatrix}$$

Because the criteria matrix has been maximized, we can specify the maximum H and the minimum value D for each column j: $H = (3; 3; 3; 3; 3)$; $D = (0; 2; 3; 2; 1)$. Next follows the normalized criteria matrix formed on the basis of the transformation formula, (1):

$$\begin{bmatrix} 0.33 & 1 & 0 & 0 & 0.5 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 \\ 0.67 & 1 & 0 & 1 & 1 \\ 0.33 & 1 & 0 & 0 & 0.5 \\ 0.33 & 1 & 0 & 0 & 0.5 \end{bmatrix}$$

The calculation of the effects' values in the regions resulting from Table 11 is computed according to Eq. (2) using the normalized criteria matrix. The value of each effect is calculated according to weighting vector v_3, and values are compiled using Table 9: $v_3 = (0.3; 0.133; 0.3; 0.067; 0.2)$. The calculation of the effects' values gives the results summarized in Table 12.

4.6 *The Assessment of RIS Level for the Selected Regions*

The previous sections have also assessed the effects resulting from existing RIS characteristics. This step consists of the overall quantification of RIS effects. This part analyzes the key instruments that have been assigned to each group of the regional innovation system characteristics described in Table 8. The vector of their weight is v_4, and its value is the following: $v_4 = (0.333; 0.167; 0.5)$.

The value of indicators within the selected regions obtained for each group of characteristics is summarized in Table 12.

Table 13 Overall indicator values for RIS development level

Region	Total value of the effect	Ranking
JMK	0.72676 × 0.333 + 0.50133 × 0.167+0.7 × 0.5 = 0.67573	1
MSK	0.37464 × 0.333 + 0.5825 × 0.167 + 0.601 × 0.5 = 0.52253	2
STC	0.17986 × 0.333 + 0.24817 × 0.167+ 0.332 × 0.5 = 0.26734	3
LK	0.35118*0.333 + 0.41783*0.167 + 0.332*0.5 = 0.35272	4
KHK	0.44934*0.333 + 0.0835*0.167 + 0.332*0.5 = 0.32957	5
PK	0.16974 × 0.333 + 0 × 0.167 + 0 × 0.5) = 0.05652	6

Source: Authors' own calculations

The overall values of the effects resulting from the existing RIS in the selected regions are calculated using the weighted sum of each effect. The values are listed in Table 13.

4.7 Conclusions

The level of RIS development was determined by the level to which the defined characteristics had been developed. The level of RIS development was depicted by determining values using the WSM and by the descriptive analysis summarized in Table 13.

The use of the WSM is simple in terms of calculating and obtaining specific values. On the other hand, the use of this method has some drawbacks in that it does not show the effects resulting from each characteristic. It only gives the accumulated value for the effects of each indicator. Furthermore, using such a method requires the weighting vector to be expressed numerically. The results derived from the use of the WSM can be authenticated by the use of another multi-criteria evaluation of the alternative. This method consists of the analytic hierarchy process (AHP) for validating results and is appropriate because it works on the same principle as the WSM, and its results are easy to compare. The use of the AHP method provides more detailed values than the WSM. On the other hand, the application of the AHP makes it easier to evaluate the degree of RIS advancement.

There are some limitations for generalizability of the results. The disadvantage of this approach is the lack of any discussion or international comparison of results (the comparable results on a wide platform are lacking).The results should be verified by another method. The adjustment of weights and subjectivity of criteria evaluation are the weakness of this method. The removal of these weaknesses can be subject to further research in this area.

Acknowledgement This research is supported by the project GA16-13119S—Performance management in public administration—theory vs. practices in the Czech Republic and other CEE countries.

References

Abbott M, Doucouliagos C (2003) The efficiency of Australian universities: a data envelopment analysis. Econ Educ Rev 22(1):89–97

Acs ZJ, Anselin L, Varga A (2002) Patents and innovation counts as measures of regional production of new knowledge. Res Policy 31(7):1069–1085

Ai C, Norton EC (2003) Interaction terms in logit and probit models. Econ Lett 80(1):123–129

Almeida P, Kogut B (1999) Localization of knowledge and the mobility of engineers in regional networks. Manag Sci 45(7):905–917

Andersen P, Petersen NC (1993) A procedure for ranking efficient units in data envelopment analysis. Manag Sci 39(10):1261–1264

Andersson M, Karlsson C (2004) Regional innovation systems in small & medium-sized regions: a critical review & assessment. CESIS 10:2–25

Antonioli D, Marzucchi A, Montresor S (2014) Regional innovation policy and innovative behaviour: looking for additional effects. Eur Plan Stud 22(1):64–83

Arthur JB (1994) Effects of human resource systems on manufacturing performance and turnover. Acad Manage J 37(3):670–687

Asheim BT, Coenen L (2005) Knowledge bases and regional innovation systems: comparing Nordic clusters. Res Policy 34(8):1173–1190

Asheim BT, Isaksen A (2002) Regional innovation systems: the integration of local 'sticky'and global 'ubiquitous' knowledge. J Technol Transfer 27(1):77–86

Asheim TB, Coenen L, Svensson-Henning M (2003) Nordic SMEs and regional innovation systems. Final report. Lund University, Lund

Audretsch D, Feldman M (1996) Innovative clusters and the industry life cycle. Rev Ind Organ 11(2):253–273

Banker RD, Charnes A, Cooper WW (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manag Sci 30(9):1078–1092

Banker RD (1993) Maximum likelihood, consistency and data envelopment analysis: a statistical foundation. Manag Sci 39(10):1265–1273

Baptista R, Swann P (1998) Do firms in clusters innovate more? Res Policy 27(5):525–540

Beuther DA, Sutherland ER (2007) Overweight, obesity, and incident asthma: a meta-analysis of prospective epidemiologic studies. Am J Respir Crit Care Med 175(7):661–666

Borrás S, Edquist C (2013) The choice of innovation policy instruments. Technol Forecast Soc Chang 80(8):1513–1522

Bottazzi L, Peri G (2003) Innovation and spillovers in regions: evidence from European patent data. Eur Econ Rev 47(4):687–710

Boussofiane A, Dyson RG, Thanassoulis E (1991) Applied data envelopment analysis. Eur J Oper Res 52(1):1–15

Braczyk H, Cooke P, Heidenreich M (eds) (1998) Regional innovation systems. UCL Press, London

Breschi S (2000) The geography of innovation: a cross-sector analysis. Reg Stud 34(3):213–229

Buunk W, Hetsen H, Jansen AJ (1999) From sectoral to regional policies: a first step towards spatial planning in the European Union? Eur Plan Stud 7(1):81–98

Ceci F, Iubatti D (2012) Personal relationships and innovation diffusion in SME networks: a content analysis approach. Res Policy 41(3):565–579

Charnes A, Cooper WW, Rhodes E (1978) Measuring the efficiency of decision making units. Eur J Oper Res 2(6):429–444

Chen K, Guan J (2012) Measuring the efficiency of China's regional innovation systems: application of network data envelopment analysis (DEA). Reg Stud 46(3):355–377

Chung S (2002) Building a national innovation system through regional innovation systems. Technovation 22(8):485–491

Chyna V, Kuncova M, Seknickova J (2012) Estimation of weights in multi-criteria decision-making optimization models. In: Proceedings of 30th international conference mathematical methods in

economics, Karviná, 11–13 September. Silesian University in Opava, School of Business Administration in Karviná, Karviná
Cooke P (2001) Regional innovation systems, clusters, and the knowledge economy. Ind Corp Chang 10(4):945–974
Cooke P (2002) Regional innovation systems: general findings and some new evidence from biotechnology clusters. J Technol Transfer 27(1):133–145
Cooke P (2005) Regionally asymmetric knowledge capabilities and open innovation: exploring 'globalisation 2'—a new model of industry organisation. Res Policy 34(8):1128–1149
Cooke P (2006) Regional innovation systems as public goods. UNIDO, Vienna
Cooke P, Memedovic O (2003) Strategies for regional innovation systems: learning transfer and applications, vol 3. UNIDO Policy Papers, United Nations Industrial Development Organization (UNIDO), Vienna, p 38
Cooke P, Gomez Uranga M, Etxebarria G (1997) Regional innovation systems: institutional and organisational dimensions. Res Policy 26(4–5):475–491
Cooke PN, Boekholt P, Tödtling F (2000) The governance of innovation in Europe: regional perspectives on global competitiveness. Cengage Learning EMEA
Denscombe M (2003) The good research guide: for small scale social projects. Open University, Maidenhead, PA
Diez MA (2001) The evaluation of regional innovation and cluster policies: towards a participatory approach. Eur Plan Stud 9(7):907–923
Diez MA, Esteban MS (2000) The evaluation of regional innovation and cluster policies: looking for new approaches. 4. EES Konferansında Sunulan Tebliğ, pp 12–14
Doloreux D (2002) What we should know about regional systems of innovation. Technol Soc 24:243–263
Doloreux D, Parto S (2004) Regional innovation systems: a critical synthesis. Institute for New Technologies, United Nations University
Doloreux D, Parto S (2005) Regional innovation systems: current discourse and unresolved issues. Technol Soc 27(2):133–153
Dümmler P, Thierstein A (2002) The European metropolitan region of Zurich: a cluster of economic clusters? In: Proceedings from ERSA congress
Düzakın E, Düzakın H (2007) Measuring the performance of manufacturing firms with super slacks based model of data envelopment analysis: an application of 500 major industrial enterprises in Turkey. Eur J Oper Res 182(3):1412–1432
Dyson RG, Thanassoulis E (1988) Reducing weight flexibility in data envelopment analysis. J Oper Res Soc 39(6):563–576
Everitt BS (1979) Unresolved problems in cluster analysis. Biometrics 35:169–181
Farrell MJ (1957) The measurement of productive efficiency. J R Stat Soc Ser A Gen 120(3):253–290
Feser EJ, Bergman EM (2000) National industry cluster templates: a framework for applied regional cluster analysis. Reg Stud 34(1):1–19
Feser EJ, Luger MI (2003) Cluster analysis as a mode of inquiry: its use in science and technology policymaking in North Carolina. Eur Plan Stud 11(1):11–24
Finne H et al (1995) Trailing research. A model for useful program evaluation, Evaluation 1(1):11–31
Fiala P, Jablonsky J, Manas M (1997) Multicriterial decision making. VSE, Praha (in Czech)
Fischer MM, Diez JR, Snickars F (2001) Systems of innovation: an attractive conceptual framework for comparative innovation research. In: Metropolitan innovation systems. Springer, Berlin, Heidelberg, pp 1–21
Fritsch M (2001) Co-operation in regional innovation systems. Reg Stud 35(4):297–307
Fritsch M, Kauffeld-Monz M (2010) The impact of network structure on knowledge transfer: an application of social network analysis in the context of regional innovation networks. Ann Reg Sci 44(1):21–38
Fritsch M, Schwirten C (1999) Enterprise-university co-operation and the role of public research institutions in regional innovation systems. Ind Innov 6(1):69–83
Gertler M (2003) Tacit knowledge and the economic geography of context of the undefinable tacitness of being (there). J Econ Geogr 3(1):75–99

Gower JC (1967) A comparison of some methods of cluster analysis. Biometrics 23:623–637
Guan J, Chen K (2012) Modeling the relative efficiency of national innovation systems. Res Policy 41(1):102–115
Guan JC, Liu SZ (2003) The study on impact of institutions on innovation efficiency in regional innovation systems. Stud Sci Sci 2:020
Guan JC, Yam RC, Mok CK, Ma N (2006) A study of the relationship between competitiveness and technological innovation capability based on DEA models. Eur J Oper Res 170(3):971–986
Haythornthwaite C (1996) Social network analysis: an approach and technique for the study of information exchange. Libr Inf Sci Res 18(4):323–342
Howells J (1999) Regional systems of innovation? In: Archibugi D, Howells J, Michie J (eds) Innovation policy in a global economy. Cambridge University Press, Cambridge, pp 67–93
Howells J (2002) Tacit knowledge, innovation and economic geography. Urban Stud 39(5–6):871–884
Hsieh HF, Shannon SE (2005) Three approaches to qualitative content analysis. Qual Health Res 15(9):1277–1288
Hudec O (2007) Regional innovation systems – strategic planning and forecasting. TUKE, EF, Košice (in Slovak)
Huggins R, Prokop D, Johnston A, Steffenson R, Clifton N (2011, July) Small firm-university knowledge networks: evidence from the UK and the US. In: Triple helix IX conference. Stanford University, California, pp 11–14
Isaksen A, Karlsen J (2010) Different modes of innovation and the challenge of connecting universities and industry: case studies of two regional industries in Norway. Eur Plan Stud 18(12):1993–2008
Kao C, Liu ST (2000) Fuzzy efficiency measures in data envelopment analysis. Fuzzy Set Syst 113 (3):427–437
Ketchen DJ, Shook CL (1996) The application of cluster analysis in strategic management research: an analysis and critique. Strateg Manag J 17(6):441–458
Koschatzky K, Sternberg R (2000) R&D cooperation in innovation systems—some lessons from the European Regional Innovation Survey (ERIS). Eur Plan Stud 8(4):487–501
Krätke S (2002) Network analysis of production clusters: the Potsdam/Babelsberg film industry as an example. Eur Plan Stud 10(1):27–54
Krebs VE (2002) Mapping networks of terrorist cells. Connections 24(3):43–52
Kronthaler F (2005) Economic capability of East German regions: results of a cluster analysis. Reg Stud 39(6):739–750
Kuhlmann S (1998) Moderation of policy-making? Science and technology policy evaluation beyond impact measurement—the case of Germany. Evaluation 4(2):130–148
Kutvonen A (2007) Ranking regional innovation policies: DEA-based benchmarking in an European setting. Lappeenranta University of Technology, Lappeenranta
Lee S, Park G, Yoon B, Park J (2010) Open innovation in SMEs—an intermediated network model. Res Policy 39(2):290–300
Lertworasirikul S, Fang SC, Joines JA, Nuttle HL (2003) Fuzzy data envelopment analysis (DEA): a possibility approach. Fuzzy Set Syst 139(2):379–394
Leydesdorff L (2012) The triple helix, quadruple helix,..., and an N-tuple of helices: explanatory models for analyzing the knowledge-based economy? J Knowl Econ 3(1):25–35
Leydesdorff L, Etzkowitz H (1996) Emergence of a Triple Helix of university–industry–government relations. Sci Public Policy 23(5):279–286
Leydesdorff L, Fritsch M (2006) Measuring the knowledge base of regional innovation systems in Germany in terms of a Triple Helix dynamics. Res Policy 35(10):1538–1553
Liu JS, Lu WM (2010) DEA and ranking with the network-based approach: a case of R&D performance. Omega 38(6):453–464
Love JH, Roper S (2001) Location and network effects on innovation success: evidence for UK, German and Irish manufacturing plants. Res Policy 30(4):643–661
Lyasnikov NVE, Dudin MN, Sekerin VD, Veselovsky MY, Aleksakhina VG (2014) The national innovation system: the conditions of its making and factors in its development. Life Sci J 11(6):535–538
Maťátková K, Stejskal J (2011a) Characteristics of regional innovation systems. Sci Pap Univ Pardubice Ser D 20(22):134–142

Matatkova, K., & Stejskal, J. (2011b). The analysis of the regional innovation systems–Czech Case. In Materials of 51st ERSA 2011 Congress (30.08–3.09. 2011, Barcelona).–12 p.
Matatkova K, Stejskal J (2013) Descriptive analysis of regional innovation system – novel method for public administration authorities. Transylvanian Rev Adm Sci 39:91–107
Morgan K (2007) The learning region: institutions, innovation and regional renewal. Reg Stud 41(S1):147–159
Mosteller F, Tukey JW (1977) Data analysis and regression. Addison-Wesley, Menlo Park
Nekolova K, Rouag A, Stejskal J (2015) The use of the weighted sum method to determine the level of development in regional innovation systems – using Czech regions as examples. Ekonomický Časopis 63(3):239–258
Nowak A, Simiński R, Wakulicz-Deja A (2008) Knowledge representation for composited knowledge bases. Intell Inf Syst 405–414
OECD (2001) http://www.oecd-ilibrary.org/science-and-technology/innovative-clusters_9789264193383-en
Oliver RL (2014) Satisfaction: a behavioral perspective on the consumer. Routledge, Abingdon
Paci R, Usai S (2000) Technological enclaves and industrial districts: an analysis of the regional distribution of innovative activity in Europe. Reg Stud 34(2):97–114
Polanyi M (1966) The tacit dimension. Routledge, London
Poledníková E (2014) Regional classification: the case of the Visegrad Four. Ekonomická Revue Cent Eur Rev Econ Issues 14:25–37
Punj G, Stewart DW (1983) Cluster analysis in marketing research: review and suggestions for application. J Market Res 20:134–148
Robson C (2002) The analysis of qualtative data. In: Robson C (ed) Real world research: a resource for social scientists and practitioner researchers. Blackwell Publishers, Oxford, pp 455–499
Roelandt TJ, Den Hertog P (1999) Cluster analysis and cluster-based policy making in OECD countries: an introduction to the theme. In: Boosting innovation: the cluster approach. OECD, Paris, pp 9–23
Romesburg C (2004) Cluster analysis for researchers. Lulu Press, North Carolina
Romijn H, Albaladejo M (2002) Determinants of innovation capability in small electronics and software firms in southeast England. Res Policy 31(7):1053–1067
Rouvinen P, Ylä-Antilla P (1999) Finnish cluster studies and new industrial policy making. In: Proceedings OECD: boosting innovation. The cluster approach. pp 361–380
Schneider J, Khemani R, Grushkin C, Bart R (2010) Serum creatinine as stratified in the RIFLE score for acute kidney injury is associated with mortality and length of stay for children in the pediatric intensive care unit. Crit Care Med 38(3):933–939
Scott J (1991) Social network analysis. Sage Publications Ltd., London
Seiford LM, Thrall RM (1990) Recent developments in DEA: the mathematical programming approach to frontier analysis. J Econ 46(1–2):7–38
Shapira P, Youtie J, Yogeesvaran K, Jaafar Z (2006) Knowledge economy measurement: methods, results and insights from the Malaysian knowledge content study. Res Policy 35(10):1522–1537
Shavelson RJ, Towne L (eds) (2002) Scientific research in education. National Academies Press, Washington, DC
Siegel DS, Westhead P, Wright M (2003) Science parks and the performance of new technology-based firms: a review of recent UK evidence and an agenda for future research. Small Bus Econ 20(2):177–184
Skokan K (2010) Innovation paradox and regional innovation strategies. J Compet 2(2):30–46
Stejskal J, Hajek P (2012) Competitive advantage analysis: a novel method for industrial clusters identification. J Bus Econ Manag 13(3):344–365
Stejskal J, Hajek P (2015) Modelling knowledge spillover effects using moderated and mediation analysis – the case of Czech high-tech industries. In: 10th international conference on knowledge management in organizations. KMO, Maribor, Slovenia

Sternberg R (2000) Innovation networks and regional development—evidence from the European Regional Innovation Survey (ERIS): theoretical concepts, methodological approach, empirical basis and introduction to the theme issue. Eur Plan Stud 8(4):389–407
Sternberg R, Arndt O (2001) The firm or the region: what determines the innovation behavior of European firms? Econ Geogr 77(4):364–382
Storper M, Scott AJ (1995) The wealth of regions: market forces and policy imperatives in local and global context. Futures 27(5):505–526
Subrt T et al (2011) Mathematical methods in economics. Aleš Čeněk Publishing House, Plzeň
Suorsa K (2014) The concept of 'region'in research on regional innovation systems. Norsk Geografisk Tidsskrift Nor J Geogr 68(4):207–215
Sykes AO (1993) An introduction to regression analysis (Coase-Sandor Institute for Law and Economics working paper No. 20)
Ter Wal AL, Boschma RA (2009) Applying social network analysis in economic geography: framing some key analytic issues. Ann Reg Sci 43(3):739–756
Tödtling F, Trippl M (2005) One size fits all? Towards a differentiated regional innovation policy approach. Res Policy 34(8):1203–1219
Vaivode I (2015) Triple Helix model of university–industry–government cooperation in the context of uncertainties. Proc Soc Behav Sci 213:1063–1067
Wasserman S, Faust K (1994) Social network analysis: methods and applications. Cambridge University Press, Cambridge
Yin R (2003) Case study methodology. Sage Publishing Ltd., Beverly Hills
Zabala-Iturriagagoitia JM, Voigt P, Gutiérrez-Gracia A, Jiménez-Sáez F (2007) Regional innovation systems: how to assess performance. Reg Stud 41(5):661–672
Zhang Y, Tan YW, Stormer HL, Kim P (2005) Experimental observation of the quantum Hall effect and Berry's phase in graphene. Nature 438(7065):201–204
Zhang J, Fu X (2008) FDI and environmental regulations in China. J Asia Pac Econ 13(3):332–353
Zhou P, Ang BW, Poh KL (2008) Measuring environmental performance under different environmental DEA technologies. Energy Econ 30(1):1–14
Zhong W, Yuan W, Li SX, Huang Z (2011) The performance evaluation of regional R&D investments in China: an application of DEA based on the first official China economic census data. Omega 39(4):447–455
Zhu J (2001) Super-efficiency and DEA sensitivity analysis. Eur J Oper Res 129(2):443–455