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Identification of Intellectual Capital Performance Using Data Envelopment Analysis

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Abstract Our research approach is based on the belief that intangible factors (especially intellectual capital) are involved in the processes of territorial development as well as we express our conviction on the need to improve research tools for comprehensive public policy evaluation. The popular concept of intellectual capital (IC) has recently become a common performance measure both for organizations as well as for countries and regions. The authors have used specific approach—Data Envelopment Analysis (DEA) to evaluate intellectual capital in the Polish and Slovak NUTS 2 regions. The analysis aims to present the efficiency of chosen components of regional intellectual capital (IC). To verify the models, data on the Polish and Slovak regions are used for a dynamic comparison of their IC performance in 2011. The efficiency scores obtained show that the regions are significantly diverse in terms of their use of intellectual capital. Even though it is important to point out that the DEA methodology used for this evaluation still needs development, it is nonetheless very promising as a tool for measuring the efficiency of regional intellectual capital. This chapter attempts to contribute to the scientific discussion on methodology development in research on regional development factors. The practical dimension of this text may be to enrich the analytical implications for the paradigm of the public policies evaluation.

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1 Introduction: Conceptual and Methodological Background

The development of the world based on the use of knowledge and innovation requires continuous and consistent empirical and conceptual research. At the same time, one of the basic dimensions of the knowledge in development processes are social and intelectual capital (IC). The importance of these dimensions of capitals has been broadly analyzed in the perspective of the organization and its resources, in this case intangible. However, the relationship between the level of intellectual capital and the development of territories is also a growing area of research (Bradley 1997).

In the first period of IC concept development in the 1990s, the focus was mainly on microscale studies (Bontis 2004). At the beginning of the twenty-first century, the period of research extention into geographic spaces, as cities, regions or states began (Ståhle 2008; Cooke et al. 2005). Most often, this area of scientific interest involves the use of the regional endogenous potential and the pursuit of competitive advantages (Shiuma et al. 2008; Malhotra 2000). The classical definition of Bontis intellectual capital is interpreted as "hidden values of individuals, enterprises, institutions, communities and regions that are the current and potential sources of value creation" (Bontis 2004, p. 14). Simultaneously, from the point of view of the relationship between IC and the development of territories, Ståhle and Ståhle (2006) emphasizes that there are direct assembling and interdependence.

In addition, studies on the relationship between IC and socio-economic transformations in regions using different methodologies are relatively well developed in recent years (Etzkowitz and Klofsten 2005; Lerro and Schiuma 2008; Užienė 2014). The measurement and components of the intellectual capital in the territorial perspective were developed by the following authors, such as: Y. Malhotra—"Skandia Model" (2000), N. Bontis—"National Intellectual Capital Index" (2004), Stam and Andriessen—"Intellectual Capital Monitor" (2009), Lerro, Carlucci, Schiuma—"Knowledge Tree" (2008). At the same time, as noted by Ståhle, "intellectual capital is an abstract and complex concept that is difficult to identify and operationalize" (2008, p. 95). There are many approaches to the selection of variables in the creation of interpretative models for assessing intellectual capital. For example, public policy approaches such as the EU or the UN can be identified (Bontis 2004; Rodriguez and Martí 2006; Schiuma et al. 2008).This article contributes to the discussion of methods for measuring intellectual capital in the context of regional development.

The chapter presents a benchmarking study of selected components of regional intellectual capital using data for the Polish and Slovak regions (the EU's NUTS 2 level units) as an example. A linear programming based method, data envelopment analysis, is used to evaluate the regions' potential for development. The paper's main focus is to introduce the methodological aspects of using DEA and decomposition models to evaluate intellectual capital in regions. The analysis that was conducted aims to illustrate the efficiency of how IC components are used in regions and to point out the regions with the best IC performance. The foundation of the

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process of building knowledge in a region is the evaluation of its endoge-nous growth potential. National and regional growth potential is based on intangi-ble assets and special skills—just as it is for business entities. The primary objec-tive of our research is to work out a reliable method for evaluating knowledge assets that makes it possible to understand the cause and effect relationships between intellectual capital and both regional economic growth and the reasons why it differs between regions (Matlovičová and Matlovič 2005; Matlovič and Matlovičová 2011). This is a topical issue for interdisciplinary research, especially when it concerns economic and geographic boundaries (Matlovič and Matlovičová 2012).

Methods that are based on linear programming use Farrell's efficiency measures (Farrell 1957). According to these measures, enterprise efficiency is based on two components: technical efficiency, representing an enterprise's ability to maximize its outputs using the given inputs, and allocative efficiency, representing the enterprise's ability to use its inputs optimally given their prices and production technology (Nitkiewicz et al. 2014). These two measures are very often used together to evaluate overall economic efficiency (Coelli et al. 2001). Economic efficiency measures compare the results of enterprise activities to the optimal achievable results when given specific objectives (Cherchye 2001). Efficiency measures can be output oriented, defining the maximum level of output that could be achieved by a decision-making unit (DMU) with the given input. Input oriented measures provide us with the minimum level of input that is absolutely necessary to reach the given output. A DMU is inefficient if its inputs and/or output are below the best practice frontier. Nonparametric efficiency analysis using Farrell's measures has become popular due to the development of data envelopment analysis. DEA provides a number of research opportunities for use in the socioeconomic environment (Cooper et al. 2001). It includes other possibilities for cooperation among analysts and decision-makers—from cooperation on the choice of the inputs and outputs to be used to choosing the types of "what-if" questions to be addressed. Such ways of cooperation extend to benchmarking the "what-if" behaviors of competitors and include identifying potential (new) competitors that may emerge for consideration within some of the scenarios that might be generated.

2 Data Envelopment Analysis as a Method for Evaluating IC

Leitner et al. (2005) were among the first to use DEA to evaluate intellectual capital. He used units of higher education, namely the faculties and departments of Austrian universities, as the subject of his research. Afterward, DEA was used to evaluate IC, knowledge management practices, and the overall performance of higher education units by Giambona et al. (2011) at the national level and Kuah and Wong (2011) for single academic units. This approach is complemented by the additional use of Monte Carlo simulation with a genetic algorithm by Kuah et al. (2012). Leitner et al. (2005)

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proved DEA's capability for evaluating intellectual capital and its elements for more than just the higher education sector. This approach was further developed by Nowicka-Skowron et al. (2006), Pachura and Nitwiewicz (2008) and Pachura and Nowicka-Skowron (2010). The use of DEA to evaluate different regional and local issues is quite widespread; it is also used in the context of the operation of business units. Stancu and Lupu (2011) built standard DEA models to evaluate IC in Romania's regions. Wang and Huang (2007) focus on environmental factors in R&D activities while Campisi and Costa (2008) have developed a DEA-based approach to identify and quantify the cause and effect relationship between IC management and improving business performance. Lu et al. (2010) used the DEA approach in order to introduce IC capability and IC efficiency measures, making it possible to assess company IC performance. IC efficiency and productivity is further explored by Costa (2012). Guan and Chen (2010) compiled DEA-based unit assessments to perform a cross-regional empirical study. Lin et al. (2011) combined DEA with the analytic hierarchy process in order to evaluate the economic performance of local governments.

3 Research Field and Method

The issue of socio-economic development at regional level in the countries of Central and Eastern Europe (CEE) began to develop dynamically after 1989, especially in the pre-accession period associated with the preparations for accession to the European Union. Subsequently, after the accession to the EU, academic research on regional development has accelerated considerably. This situation was in fact related to the adoption of European standards for regional development programming and strategic planning. The scientific community of these countries has been trying to undertake research inspired mainly by the work of scientists from Western Europe, and especially as it seems from Scandinavian countries. This has led to a large concentration of research on phenomena related to the role of intangible factors in socio-economic development processes. At the same time, there are many attempts in Central and Eastern European scientific community to develop their own research concepts and methodological approaches. The following representatives are deserving of attention: V. Baláž, J. Blažek, J., Buček, B. Domański, Z. Gal, P. Hájek, O. Hudec, E. Kiss, R. Matlovič, P. Pavlínek, J. Stejskal, L. Sýkora, and many other. Thus, staying in the mainstream of research on regional development issues in relations with aspects of intangible regional developmental factors, the authors wish to propose in this chapter a contribution to scientific discussion based on the adoption of set out above the DEA methodology.

Data Envelopment Analysis was used in this study for the purpose of evaluating intellectual capital in the Polish and Slovak regions. The choice of variables was determined by commonly accepted classification systems for intellectual capital that are suitable for regions. These variables are limited to ones measured in physical units. Determining inputs and outputs is the decisive first step in conducting a DEA.

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Choosing the indicators to be classified as inputs or outputs can be quite difficult. Inputs are characterized by the fact that it is better for their quantities to be smaller (e.g., expenditures on R&D in a region), involving lower costs, whereas outputs are characterized by the fact it is better for their quantities to be larger (e.g., more patents in a region). This study's objective is to evaluate the efficiency of selected areas of intellectual capital at the regional level. Therefore, regions are used as the DMUs. At the NUTS 2 level, these are called voivodeships in Poland and regions in Slovakia. It can be argued that voivodeships/regions are not a good match for DEA analysis, because they do not meet the basic precondition for sound DEA analysis—simply because the area to be evaluated is not sufficiently homogeneous. On the other hand, the production possibility set, in this case for regional intellectual capital use, cannot be precisely defined. Another reason in support of the analysis's validity is connected to the data used as input/output variables. All the variables have been chosen rather intuitively; though their influence on shaping a region's intellectual capital is known and confirmed, it has never been explicitly described. Some assumptions have been made regarding all the concerns presented above (Nitkiewicz et al. 2014):

- The relationships between the given IC inputs and outputs were identified on the basis of common knowledge,
- The efficiency of transforming inputs into outputs was evaluated according to the relationships identified above,
- The models presented made it possible to evaluate partial efficiency because only some of the variables describing IC in regions were used in constructing them, and
- The variables used to construct the DEA models do not completely describe regional IC.

The first of these assumptions is connected with the incomplete knowledge of IC at the regional level and the many factors influencing it. Only the factors connected by an obvious or commonly acknowledged link are used in the study. The study undertaken here is experimental and may help identify similar relationships that have not yet been observed. The second assumption is a direct result of the first one, only the context of evaluating efficiency has been added and made the main research objective. Some important variables were purposefully eliminated in the efficiency evaluation to keep the focus on the relationship identified in the first step. This kind of treatment allows for a more detailed description of the given relationships but does not place them in the broader context of overall IC efficiency. The third assumption results from the specific nature of DEA analysis and its vulnerability with respect to the size of the sample and the number of variables. The number of DMUs could not be increased, because there are only 16 voivodeships in Poland and 4 regions in Slovakia at the NUTS 2 level (Nitkiewicz et al. 2014). If the number of DMUs is only 20, then the number of variables should be kept low enough to ensure

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Table 1 Characteristics of the distance functions used for regional IC

Distance function	Input variables	Output variables	Special input variables
DiA	Population turnover	GDP GVA	
DiICA1	Population turnover	GDP GVA	Total intramural R&D expenditure
DiICA2	Population turnover	GDP GVA	Human Resources in Science and Technology
DiICA3	Population turnover	GDP GVA	Total R&D personnel and researchers
DiICA4	Population turnover	GDP GVA	Second stage of tertiary education
DiICA5	Population turnover	GDP GVA	Patent applications to the EPO

Source: Authors' own compilation

reliable results (Leitner et al. 2005). Statistical data on regional performance for 2011 is used, including the following variables[1] to construct distance functions:

- Inputs
  (1) Population
  (2) Turnover in industry (in millions of Euros)
- Outputs
  (3) GDP at current market prices (in millions of euros)
  (4) Gross value added at basic prices (in millions of euros)
- Special inputs
  (5) Total intramural R&D expenditure (in millions of euros)
  (6) Human resources in science and technology (in thousands)
  (7) Total R&D personnel and researchers (% of active population)
  (8) Second stage of tertiary education (number of students)
  (9) Patent applications to the EPO (number of applications)

The above set does not encompass all the factors shaping IC in regions and is limited to variables accessible in both countries. However, it is complete enough for the purposes of our research considering the assumptions that have been made. Data concerning the variables is presented in the appendix (Table 3). One basic distant function (*DiA* in Table 1) is used to decompose the efficiency of certain factors on the basis of five supporting functions (*DiICA1*, *DiICA2*, *DiICA3*, *DiICA4*, and

[1]All the data used in the research comes from the official websites of Eurostat (http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes), the Polish Central Statistical Office (www.stat.gov.pl), and the Statistical Office of the Slovak Republic (por-tal.statistics.sk).

Pachura P., Nitkiewicz T., Matlovičová K., Matlovič R. (2018): **Identification of Intellectual Capital Performance Using Data Envelopment Analysis**. Part II., s. 115-130. In: Stejskal J., Hajek P., Hudec O. (eds, 2018): *Knowledge Spillovers in Regional Innovation Systems. A Case Study of CEE Regions.* Https:l/doi.orgll0.loo7/978-3-319-67029-4, SPRINGER 286 s.

Table 2 Efficiency scores for the Polish and Slovak NUTS 2 regions

Region	Code (NUTS 2)	DiICA1	DiICA2	DiICA3	DiICA4	DiICA5
Lódzkie	PL11	0.9977	0.8635	0.9864	0.9025	0.9975
Mazowieckie	PL12	1.0000	1.0000	1.0000	1.0000	1.0000
Malopolskie	PL21	0.9695	0.8754	0.9731	0.9955	0.8754
Slaskie	PL22	0.8461	0.9294	0.6582	0.8380	0.6636
Lubelskie	PL31	1.0000	1.0000	1.0000	1.0000	1.0000
Podkarpackie	PL32	0.9371	0.9993	0.9668	0.9991	0.8797
Swietokrzyskie	PL33	0.9998	0.9810	0.8980	0.9625	0.8830
Podlaskie	PL34	0.9724	0.9661	0.9480	0.9992	0.9480
Wielkopolskie	PL41	0.9840	0.9958	0.9734	0.9976	0.9178
Zachodniopomorskie	PL42	1.0000	1.0000	1.0000	1.0000	1.0000
Lubuskie	PL43	0.7961	0.9071	0.9998	0.9944	0.7961
Dolnoslaskie	PL51	0.9771	0.9861	0.9882	0.9975	0.9964
Opolskie	PL52	0.8956	0.9465	0.9373	0.9999	0.9355
Kujawsko-Pomorskie	PL61	0.9033	0.9639	0.9994	0.9990	0.9663
Warminsko-Mazurskie	PL62	0.9990	0.8567	0.9992	0.9989	0.9303
Pomorskie	PL63	0.9995	0.9703	0.9025	0.9751	0.9724
Bratislavský Region	SK01	1.0000	1.0000	1.0000	1.0000	1.0000
Západné Slovensko	SK02	1.0000	1.0000	1.0000	1.0000	1.0000
Stredné Slovensko	SK03	0.8826	0.6975	0.8688	0.9933	0.9410
Východné Slovensko	SK04	0.9935	0.9865	0.8910	0.9828	0.8744

Source: Authors' own compilation

DiICA5). In fact, Models 2 and 3 should be treated interchangeably since they deal with similar variables (employment in the R&D sector).

The scores obtained for the efficiency indicators are presented in Table 2 and Figs. 1, 2, 3, 4 and 5.

4 Closing Remarks

This proposition of intellectual capital performance identification using Data Envelopment Analysis has the value, rather as the technical analysis of the research tools rather than conceptual design. Nevertheless, it seems that the presented concept may contribute to the research tools development in the field of analysis of socio-economic evolution of space systems. As mentioned at the beginning of this text, the issue of intellectual capital is quite difficult to operationalize due to its multidimensional nature.

The efficiency scores, as shown in Table 2, present the overall assessment of IC performance in the analyzed regions with regard to certain aspects of IC. The efficiency scores that were obtained show significant diversity in intellectual capital use for the Polish and Slovak regions (five regions were fully efficient). Some

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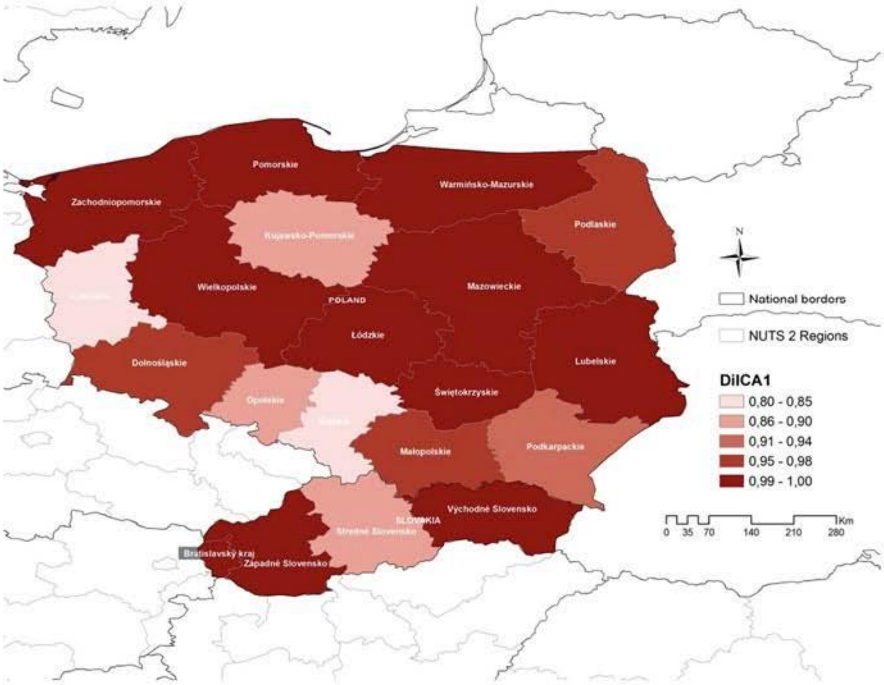

Fig. 1 Efficiency scores DilCA1. Data source: own elaboration. Administrative boundaries: © EuroGeographics, UN-FAO, Turkstat. Bace map source: GISCO Eurostat (European Commission). GCS_ETRS_1989

regions were obviously dominant and fully efficient in all categories, but there also were some highly inefficient ones. The important trend shown in the results is related to the fact that certain variables' levels were exceptional. Therefore, some of the regions that showed variables with extreme values (having the highest out-put or lowest input level) automatically achieved full efficiency (see the Mazowieckie or

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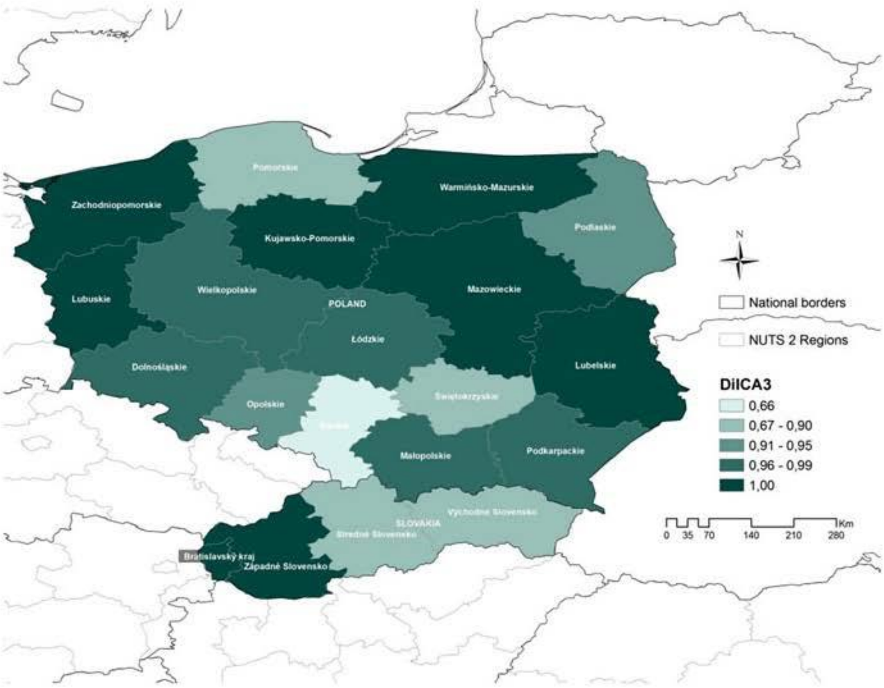

Fig. 3 Efficiency scores DilCA3. Data source: own elaboration. Administrative boundaries: © EuroGeographics, UN-FAO, Turkstat. Bace map source: GISCO Eurostat (European Commission). GCS_ETRS_1989

scientific literature. On the other hand, the effectiveness of research tools is at a stage of development, improvement and continuous modification. The DEA methodology that has been used in this evaluation, it is important to point out that it still needs development; it is nonetheless very promising as a tool for measuring the efficiency of regional intellectual capital. The general conclusion of our research is that Data Envelopment Analysis can be adopted as a method for evaluating intellectual capital in regions. The solution presented here—decomposition models—is quite suitable

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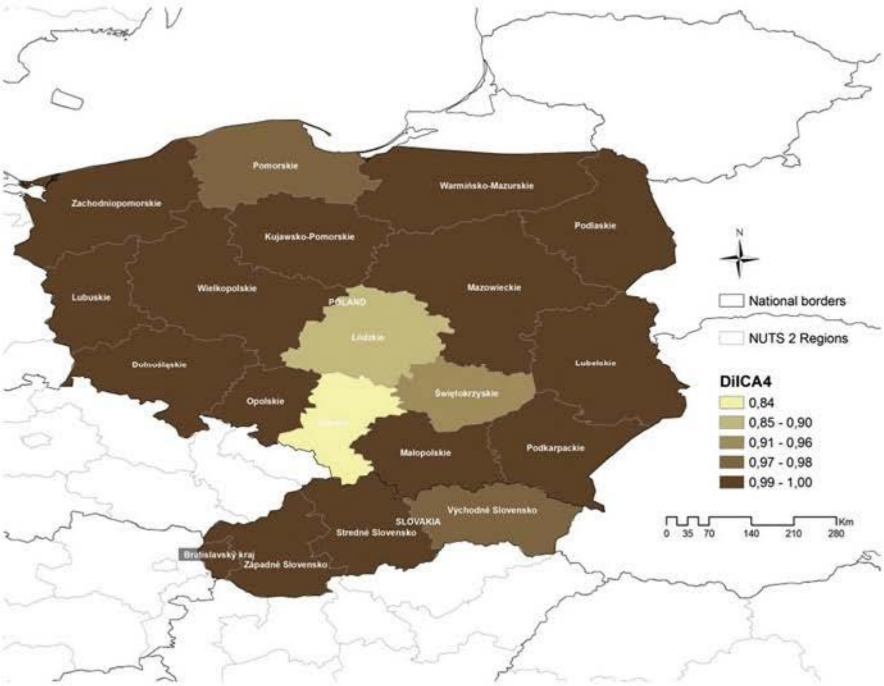

Fig. 4 Efficiency scores DiICA4. Data source: own elaboration. Administrative boundaries: © EuroGeographics, UN-FAO, Turkstat. Bace map source: GISCO Eurostat (European Commission). GCS_ETRS_1989

for this objective. Of course, it is important to bear in mind certain limitations when using DEA, such as the need for reliable data and numerous DMUs for analysis. Nonetheless, it is possible to use it to describe regional IC. Thanks to its flexibility, this DEA methodology can significantly contribute to evaluating the efficiency of processes involving IC. The calculated efficiency scores cannot be treated as measures of absolute efficiency, but they could constitute a significant information base within the process of regional socioeconomic development based on knowledge

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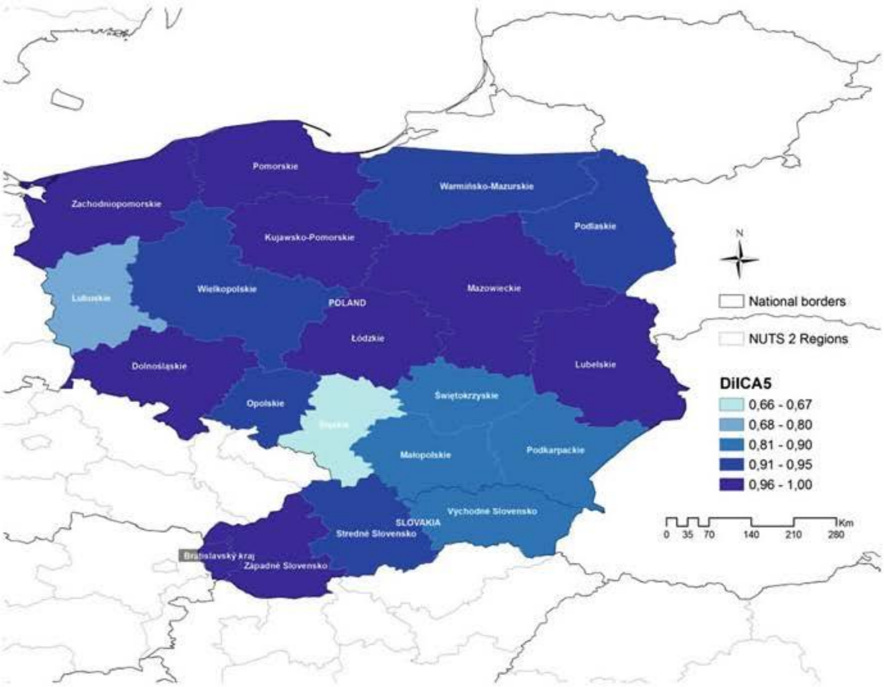

Fig. 5 Efficiency scores DilCA5. Data source: own elaboration. Administrative boundaries: © EuroGeographics, UN-FAO, Turkstat. Bace map source: GISCO Eurostat (European Commission). GCS_ETRS_1989

factors at the regional level. It should be noted that this approach requires further research, their aim could be to develop more effective tools for public administration, whose task is to analyze the effectiveness of public policy and strategic programs implementation.

Pachura P., Nitkiewicz T., Matlovičová K., Matlovič R. (2018): **Identification of Intellectual Capital Performance Using Data Envelopment Analysis**. Part II., s. 115-130. In: Stejskal J., Hajek P., Hudec O. (eds, 2018): *Knowledge Spillovers in Regional Innovation Systems. A Case Study of CEE Regions.* Https:l/doi.orgll0.loo7/978-3-319-67029-4, SPRINGER 286 s.

Appendix

Table 3 Values of variables in Polish and Slovakian NUTS 2 regions for decomposing IC efficiency

Region	Code (NUTS 2)	Inputs		Outputs		Special inputs				
		Population	Turnover in industry (millions of euro)	GDP at current market prices[a] (millions of euro)	Gross value added at basic prices[a] (millions of euro)	Total intramural R&D expenditure (millions of euro)	Human Resources in Science and Technology (in thousands)	Second stage of tertiary education (number of students)	Patent applications to the EPO[b] (number of applications)	Total R&D personnel and researchers (% of active population)
Lódzkie	PL11	2,542,436	16,497.6	21,720	19,129.8	140.4	534	2754	34.08	0.56
Mazowieckie	PL12	5,267,072	58,001.7	79,061	69,632.8	1134.7	1382	10,417	48.64	1.38
Malopolskie	PL21	3,336,699	18,858.1	26,057	22,949.4	293.8	595	5342	40.18	1.04
Slaskie	PL22	4,634,935	52,408.5	46,071	40,576.5	250.9	958	3202	23.35	0.59
Lubelskie	PL31	2,178,611	7257.3	13,528	11,915.0	91.7	413	2521	6.42	0.62
Podkarpackie	PL32	2,127,948	8959.9	13,145	11,577.8	131.6	335	370	5.52	0.68
Swietokrzyskie	PL33	1,282,546	6107.4	8932	7866.9	34.7	239	123	5.63	0.22
Podlaskie	PL34	1,203,448	4862.4	8033	7075.1	33.9	213	509	2.65	0.47
Wielkopolskie	PL41	3,446,745	30,433.8	33,015	29,077.8	220.9	580	3107	18.92	0.89
Zachodniopomorskie	PL42	1,723,741	8280.5	13,680	12,048.5	47.7	257	1115	4.45	0.54
Lubuskie	PL43	1,023,215	6501.2	7931	6985.5	13.6	174	116	10.00	0.23
Dolnoslaskie	PL51	2,917,242	25,425.0	30,070	26,483.8	176.0	527	3924	19.83	0.73
Opolskie	PL52	1,017,241	5247.2	7605	6698.1	20.4	141	373	1.71	0.39
Kujawsko-Pomorskie	PL61	2,098,711	12,548.4	16,116	14,194.1	45.5	314	1149	4.25	0.48

(continued)

Pachura P., Nitkiewicz T., Matlovičová K., Matlovič R. (2018): **Identification of Intellectual Capital Performance Using Data Envelopment Analysis**. Part II., s. 115-130. In: Stejskal J., Hajek P., Hudec O. (eds, 2018): *Knowledge Spillovers in Regional Innovation Systems. A Case Study of CEE Regions.* Https:l/doi.orgll0.loo7/978-3-319-67029-4, SPRINGER 286 s.

Table 3 (continued)

Region	Code (NUTS 2)	Inputs		Outputs		Special inputs				
		Population	Turnover in industry (millions of euro)	GDP at current market prices[a] (millions of euro)	Gross value added at basic prices[a] (millions of euro)	Total intramural R&D expenditure (millions of euro)	Human Resources in Science and Technology (in thousands)	Second stage of tertiary education (number of students)	Patent applications to the EPO[b] (number of applications)	Total R&D personnel and researchers (% of active population)
Warminsko-Mazurskie	PL62	1,453,782	6831.2	9731	8570.1	48.8	221	430	0.20	0.39
Pomorskie	PL63	2,275,494	19,722.1	19,921	17,545.0	151.8	396	2040	7.42	0.85
Bratislavský kraj	SK01	599,931	36,792.1	18,297	16,635.3	242.7	235	5647	8.05	4.09
Západné Slovensko	SK02	1,838,786	14,528.1	21,206	19,280.6	81.6	316	2056	7.18	0.48
Stredné Slovensko	SK03	1,349,286	14,372.8	13,357	12,143.7	68.5	235	2009	2.14	0.68
Východné Slovensko	SK04	1,604,443	10,890.7	13,010	11,828.9	75.6	260	2470	5.98	0.66

Source: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes for all variables, stat.gov.pl and portal.statistics.sk for R&D expenditures in Polish and Slovakian regions accordingly

[a] Data for 2010

[b] Data for 2009

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