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Regional Innovation Systems in Poland: How to classify them? [1]

The literature emphasises the role of regional and local innovation environment. Regional Innovation Systems show differences in innovation outputs determined by different inputs. Understanding these relationships can have important implications for regional and innovation policy. The research aims to classify Regional Innovation Systems in Poland according to their innovation capacity and performance. The analysis covers 72 subregions (classified as NUTS 3 in the Nomenclature of Territorial Units for Statistics) in 2004–2016. Classes of Regional Innovation Systems in Poland were identified based on a combination of linear and functional approaches and data from published and unpublished sources. It was assumed that innovation systems in Poland differ due to their location in metropolitan and non-metropolitan regions, thus, the Eurostat NUTS 3 metro/non-metro typology was applied for this purpose. Panel data regressions as models with individual random effects were estimated separately for metropolitan and non-metropolitan groups of subregions. The study identified common determinants of innovation outputs in both NUTS 3 types: share of innovative industrial enterprises, industry share, unemployment rate, and employment in research and development. Next, NUTS 3 were classified within each of two analysed types in line with output- and input-indices, the latter being calculated as non-weighted average of significant inputs. Last, the subregions were clustered based on individual inputs to enable a more detailed assessment of their innovation potential. The cluster analysis using k-means method with maximum cluster distance was applied. The results showed that the composition of the classes identified within metropolitan and non-metropolitan systems in 2004–2016 remains unstable, similarly to the composition of clusters identified by inputs. The latter confirms the changes in components of the capacity within both Regional Innovation System types. The observed situation allows us to assume that Regional Innovation Systems in Poland are evolving. In further research, the efficiency of Regional Innovation Systems should be assessed, taking into account the differences between metropolitan and non-metropolitan regions as well as other environmental factors that may determine the efficiency of innovative processes.

Keywords: regional economics, Regional Innovation System, innovation inputs, innovation outputs, metropolitan NUTS 3, non-metropolitan NUTS 3, classification, panel data, cluster analysis, Poland

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ИССЛЕДОВАТЕЛЬСКАЯ СТАТЬЯ

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Классификация региональных инновационных систем Польши

Современная научная литература подчеркивает значение региональной и местной инновационной среды. Поскольку производительность региональных инновационных систем может существенно различаться в зависимости от особенностей ресурсов и инфраструктуры, понимание подобных отношений может иметь важные последствия для региональной и инновационной политики. Цель исследования — классификация региональных инновационных систем в Польше в соответствии с их инновационными потенциалом и эффективностью. Проведенный анализ охватывает 72 субрегиона Польши (классифицированных как NUTS 3 в Номенклатуре территориальных единиц статистики) в 2004–2016 гг. Классы региональных инновационных систем определены на основе комбинации линейного и функционального подходов, а также данных из опубликованных и неопубликованных источников. Ввиду различий инновационных систем по географическому положению субрегионы NUTS 3 поделены в зависимости от их нахождения в пределах или за пределами метрополии. Модели панельных данных со случайными эффектами проанализированы отдельно для этих двух групп. В исследовании определены общие детерминанты инновационной производительности для обоих типов NUTS 3: доля инновационных промышленных предприятий, доля промышленности, уровень безработицы и занятость в НИОКР. Затем субрегионы были отнесены к каждому из двух проанализированных типов в соответствии с индексами выходных и входных данных, причем последний был рассчитан как невзвешенное среднее значение. Наконец, субрегионы были сгруппированы на основе индивидуальных данных для детальной оценки их инновационного потенциала. Для этой цели был применен кластерный анализ с использованием метода k-средних с максимальным кластерным расстоянием. Результаты показали, что состав классов (нахождение в пределах/за пределами метрополии) в 2004–2016 гг. остается нестабильным, как и состав кластеров, определенных входными данными, что подтверждает изменения потенциала в обоих типах региональных инновационных систем. Исходя из этого, можно предположить, что региональные инновационные системы в Польше находятся в процессе развития. В дальнейших исследованиях следует оценить эффективность региональных инновационных систем, учитывая как различия между двумя группами субрегионов, так и другие внешние факторы, определяющие эффективность инновационных процессов.

Ключевые слова: региональная экономика, региональная инновационная система, инновационные ресурсы, инновационные результаты, NUTS 3 в пределах метрополии, NUTS 3 за пределами метрополии, классификация, панельные данные, кластерный анализ, Польша

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Introduction

In today's global economy, one of the most exposed features of innovation processes is their systemic nature [1]. The growing interest in the Regional Innovation System (RIS) concept largely results from an increase in competitive pressure on the global market, the awareness of limitations of traditional regional development models and examples of effective collaboration in clusters. All the factors have caused the rediscovery of regional scale importance and specific regional assets in stimulation of innovative potential and competitiveness of firms as well as the whole territory. The concept of RIS, seen as an analytical tool of innovation process in regional economy, became the subject of interest of scientists and politicians [2, 3]. There are numerous examples of empirical studies on RIS sources in the literature, most of them focusing on individual systems. However, it would be difficult to assess application of the concept without providing a comparative analysis. Research on the systems is constantly evolving and two development paths can be distinguished. Proponents of the first one analyse RIS

in the framework of innovation inputs and outputs. These studies are focused on the assessment of components, which transform a region into RIS. In the second approach, it is assumed that every region, regardless of its innovation level, has its own innovation system. In this case, Regional Innovation Systems differ in quality and type. The latter approach has been implemented in the presented study.

Despite rich scientific achievements in RIS issues, it seems that these systems in Poland have not been sufficiently examined, which might be the result of only "fledgling" regional innovation policy [4]. The presented research aims to fill this gap. The paper examines RISs in Poland in 2004–2016 and, as a result, classifies them according to their innovation capacity and innovation performance. The analysis covers 72 NUTS 3 subregions[1]. The assumption is that RISs in Poland differ due to their metropolisation level, thus, we decided to apply the Eurostat metro/non-metro typology of NUTS 3. The following specific objectives were pursued: a review of the literature on RIS and the RIS typology; a review of empirical research on the potential and effects of innovative RIS in Poland; and conclusions.

Literature Review and Research Hypotheses

The literature often emphasises the importance of regions, geographical proximity and localised knowledge flows in innovation processes [5]. There is a number of concepts derived from political science, economic geography or business economics underscoring the localisation of innovative activities within limited territory. These include among others the concepts of learning region [6, 7, 8], innovative milieu [9], industrial district [10, 11], local productive system [12], cluster [13], technopole [14, 15] and Regional Innovation Systems [16, 17, 18, 19, 20, 21].

The concept of Regional Innovation Systems has been the subject of increased attention since the early 1990s. However, there is no universal, widely accepted definition of RIS. Cooke [17] describes it as a cooperation network of regional organisations and institutions that aim at fostering innovation potential of enterprises. Furthermore, RIS is a result of territorially embedded institutional infrastructure and production system [22]. In accordance with another definition, that has been quite well accepted in the literature, RIS is understood as "a set of interacting private and public interests, formal institutions and other organisations that function according to organisational and institutional arrangements and relationships conducive to the generation, use and dissemination of knowledge." [23, 134–135]. On the other hand, Asheim and Isaksen [19] define RIS as regional clusters supported by surrounding organisations. In line with the holistic approach, RIS includes all important determinants of innovations [24]. Then, defining RIS, three core dimensions of the term have to be taken into consideration: central role of innovation (1) created and diffused within a geographical locally defined system (2) in which enterprises play a key role (3). A system can be recognised as "appropriate" resulting from interactions of all the three dimensions, integrated in National Innovation System, linked to other RISs and containing technological and sectoral systems [25, 26]. At present, RIS is increasingly being recognised as an important factor in economic development affecting the type of regional policy [3, 27].

The concept has enabled a better understanding of the uneven geography of innovation. Based initially on "success stories" of some industrial clusters and agglomerations [28, 29], it is currently being verified on the basis of empirical research. The first group of empirical research papers focuses on the key elements of RIS, which are institutional entities and companies, and aims to define the main innovative profile of the region using indicators, such as education, technological bases and outputs. Their results help local and government authorities to define components crucial for the transformation of the region into RIS. In the second group of the studies, it is assumed that RIS can be found anywhere including not only best performing regions but also old industrial regions [30], peripheral regions [31], rural regions [32] and regions in transition [33]. In this approach, RISs are ranked from weak to strong, as well as characterised by various types [23].

Typologies of RIS have been developed according to various dimensions. They focus on a) level of metropolisation [34, 35, 36, 37], b) strengths in radical and incremental innovations [38], c) key actors and modes of governance [39, 40, 41, 19], d) RIS failures [42, 43]. The differences between metropolitan (commonly referred to as global cities, world cities, metropolitan areas) and peripheral (lagging, remote) regions are often emphasised in the literature [5]. Both types of regions may differ in many aspects, such as endowment with knowledge [35], concentration of talent [44] and high qualified labour force; concentration of production [45]; density of corporate headquarters, multinational enterprises, main administrative bod-

[1] According to the European Nomenclature of Territorial Units for Statistics.

ies, major suppliers and dedicated research organisations; and finally ease of access to knowledge sources outside of the region [37]. Firms located in cities should differ from firms in lagging areas [46]. First, if we treat innovation as an open and social process — all else being equal — cities have more potential to deliver innovation, knowledge and partnerships. Second, even if firms in peripheral areas innovate, why do these areas tend to decline, at least over the last 30–40 years. It is worth noting that the behaviour of innovative firms in lagging regions differs from that of innovators in industrial clusters or cities. While the latter may innovate in the same way as the former if they choose so, the reverse may not necessarily be the case, as lagging areas do not have access to rapidly changing market information [46, 5]. However, the results from the existing empirical research on the relationship between metropolitan location and innovation are ambiguous [47, 48, 49, 50, 51, 52, 53]. Based on the studies, the role of knowledge networks and technological spillovers in innovative clusters may be overrated [52]; the probability of linkages is not necessarily higher in cities if the open innovation model is taken into account [54]; knowledge-intensive firms suffer from negative externalities as sources of knowledge spillovers [50]; finally, fragmented or incomplete RISs are also present in metropolitan areas [55].

Slightly different concept, although linked to previously discussed classifications, was presented by Rypestøl and Aarstad [56]. The authors distinguish between thick and thin RIS. First type of RIS is mainly located in urbanised areas, characterised by high density of high schools and environment supporting research and development (R&D). Its activity is based on analytical knowledge and well-educated workers. All this enables direct interactions as a result of workforce mobility and acquisition of scientific knowledge [57]. Thin RISs are based on synthetic experience-based and non-codified knowledge, which — contrary to thick RISs — results rather in incremental than radical innovations.

Both types of RIS, metropolitan or peripheral, may experience some failures [42, 43]. A distinction was made between metropolitan agglomerations, peripheral regions and old industrial regions. Agglomerations should be well equipped with different types of knowledge, thereby, be innovative. However, a typical failure of systems located in agglomerations is a fragmentation resulting from a lack of cooperation and knowledge exchange [47]. This means that the sub-systems generating and implementing knowledge operate there separately. Consequently, development of new technologies is below expectations. Meanwhile, in peripheral regions, low level of R&D activity leads to limited absorption of innovative potential of local firms. There is a lack of learning opportunities, so these regions depend on external networks. Therefore, one more RIS group is identified, consisting of regions where, despite signs of improvement, innovations are not sufficient. They face serious problems connected with too strong clustering in mature and declining industries. Another problem is the "lock-in" effect limiting their growth potential.

The purpose of the presented study was to identify RIS in Polish NUTS 3 regions. In the face of so many different RIS concepts and classification methods, the task turned out to be not so easy. It is not only about classifying individual regions into given categories, but also about indicating the differences that can be observed between these categories. Based on the literature review along with our earlier studies, the main hypothesis was set: innovation systems in Poland differ due to their location in metropolitan and non-metropolitan regions. In addition, the following auxiliary hypotheses were adopted:

H1: RIS in metropolitan and non-metropolitan subregions show differences in terms of innovative outputs;

H2: the determinants of innovation outputs in metropolitan and non-metropolitan subregions are not identical;

H2: the composition of RIS classes identified within metropolitan and non-metropolitan subregions remains not stable.

Different authors of empirical research on RIS use various methods and consequently obtain different results [58]. In general, two approaches can be found in the literature. In the first, called "linear" approach, used by the European Commission in Regional Innovation Scoreboard, the division into input and output indicators is applied. In the second, more dynamic, "functional" approach, functions of RIS are emphasised, including the creation of knowledge, diffusion of knowledge, absorption capacity, activities of local authorities, externalities of agglomeration, demand, regional accessibility etc. [59,60]. However, it should be noted that studies of RIS hardly ever deal with the question of how the systems transform over time being mostly snapshots [61].

There are numerous studies on innovativeness of Polish regions with only few focused on RIS. Examples of analysis devoted to single RIS are works of Świadek et al. [62], Gust-Bardon and Niedzielski [63] or Mamica [64]. Quite a small group are interregional studies. Plawgo et al. [65] con-

firm positive relationship between innovativeness of RIS in Poland and willingness of regional authorities to undertake actions strengthening their elements. Świadek et al. [66] prove that innovative activity of industrial systems in Poland depends on inter-industrial links. According to Kondratiuk-Nierodzińska [60], the higher value of regional innovativeness index means better performance of RIS functions and thereby higher effectiveness of the whole system. Finally, Golejewska [58] considers a lack of cooperation as a significant limitation to effectiveness of Polish RISs causing their fragmentation.

Data and Methodology

In the analysis, we assumed that RIS can be found in every region. A combination of two approaches — "linear" and "functional" — was applied. In the proposed research method, we speculate that in metropolitan and non-metropolitan regions, the level of innovation output is influenced by various factors representing innovative inputs. Therefore, the set of input variables that were taken into account when creating synthetic indicators was different in both types of regions. Significant factors for each group were selected using regression analysis of panel data. With synthetic measures reflecting both output innovation and input innovation, we classified the Polish NUTS 3 regions into groups: low-input & low-output; low-input & high-output; high-input & high-output; high-input & low-output. Having data for 2004, 2010 and 2016, we analysed the changes that occurred in this classification over a 12-year period. The results showed that the positions of individual regions in the classification are not constant and unchanging.

In our study, we employed the Eurostat metro/non-metro typology of NUTS 3.[1] The analysis was based on data from various sources: published (Eurostat, PATSTAT database, Statistics Poland: Local Data Bank) and unpublished (see Table 1). The analysis covered subregions in Poland at the NUTS 3 level (72 units according to the territorial division as of 1 January 2015). The non-public data include: the share of enterprises that incurred expenditure on innovative activities; the share of enterprises that implemented process or product innovations; the share of cooperating enterprises; and the share of new or modernised products in total production sold. The data concern industrial enterprises with more than 49 employees, based on reports on innovation in industry (PNT-02). Due to the lack of data at the NUTS 3 level, it became necessary to supplement it with data at the NUTS 2 level. In order to examine changes in the RIS features, the analysis was carried out separately for three selected years: 2004 — the year of Poland's accession to the European Union, 2010 — crisis period, 2016 — time of a fairly good economic situation.

In the first step, a synthetic assessment of innovation performance in individual regions was carried out. In constructing the final "innovation output" variable, the unweighted average of four variables was used. These include: the share of industrial enterprises that have introduced process and product innovations; the share of production of new or modernised products; the number of patent applications to the EPO and the number of Community Designs (all variables were standardised using min/max procedure). In the second step, upon a thorough review of the literature, we took into account a number of inputs [67, 68 69, 70, 71]. Since the assessment of innovation in a given region (e.g. the number of innovative companies) largely depends on the number of all companies in this region, the relative values of output variables were determined. We calculated them as multiplication of the share of innovative companies in the number of all companies in the region and the share of the number of companies in the region in the number of all companies in Poland. Appropriate calculation were performed for the output variable relating to production.

Then, regression analysis was applied in order to examine which variables reflecting the innovation capacity affects the innovation output in a statistically significant way. The regressions were estimated separately for groups of metropolitan and non-metropolitan NUTS 3 subregions, using panel data models with individual random effects that proved to be appropriate by the Hausman test.

In the next step, we classified NUTS 3 within each of two analysed types in line with output- and input-indices, the latter being calculated as non-weighted average of significant inputs. The criteria for classification constitute the average values of both indices. In the last step, NUTS 3 subregions were clustered based on individual inputs to enable a more detailed assessment of their innovation potential. The cluster analysis using k-means method with maximum cluster distance was adopted. In case of metropolitan NUTS 3 subregions including an outlier — the capital city — four clusters have been identified (the first was only the capital city). In non-metropolitan NUTS 3, three separate clusters were distinguished.

[1] OECD. (2011, June). OECD Regional Typology. Directorate for Public Governance and Territorial Development, Eurostat. Retrieved from: https://ec.europa.eu/eurostat/web/metropolitan-regions/background (Data of access: 20.10.2019).

Table 1

Variable definitions and data sources

NUTS 3 level		
variables	Description	data source
innov_share	share of innovative industrial enterprises	Statistics Poland, Szczecin
coop_share	cooperation, share of industrial enterprises	Statistics Poland, Szczecin
ppinov_share	process and product innovations, share of enterprises	Statistics Poland, Szczecin
nmproduct_share	new/modernised products, share of production	Statistics Poland, Szczecin
epopat_number	number of EPO patent applications	PATSTAT database
cd_number	Community Designs, number	Eurostat, Regional Statistics
gdp_pc	GDP per capita, PLN, current prices	Local Data Bank, Statistics Poland
gdp_total	GDP total, Mln PLN, current prices	Local Data Bank, Statistics Poland
VA _pc	Value Added per capita, PLN, current prices	Local Data Bank, Statistics Poland
VA_total	Value Added total, Mln PLN, current prices	Local Data Bank, Statistics Poland
highschools_number	number of high schools	Local Data Bank, Statistics Poland
industry_share	industry share in total VA of NUTS 3	Local Data Bank, Statistics Poland
unem_rate	registered unemployment, percentage of active population	Local Data Bank, Statistics Poland
wages	PLN	Local Data Bank, Statistics Poland
pop_ density	population density, population per km2	Local Data Bank, Statistics Poland
crime_share	crimes per 1000 inhabitants	Local Data Bank, Statistics Poland
divorces_share	divorces per 1000 inhabitants	Local Data Bank, Statistics Poland
NUTS 2 level		
Railway	density, km per 100 km2	Local Data Bank, Statistics Poland
Roads	density, km per 100 km2	Local Data Bank, Statistics Poland
Highway	density, km per 1000 km2	Local Data Bank, Statistics Poland
tertiary_share	levels 5–8, percentage, 25–64 years	Eurostat
postphd	post-graduate and doctoral students per 1000 inhabitants	Local Data Bank, Statistics Poland
no_life_learn_share	young people neither in employment nor in education and training	Eurostat
empl_rd_share	employed in R&D in total employment, percentage	Eurostat
rd_pc	internal expenditure on research and development, per capita	Local Data Bank, Statistics Poland
rd_percgdp	internal expenditure on research and development, percentage of GDP	Local Data Bank, Statistics Poland

Source: Prepared by the Authors.

Findings

Fig. 1 and Fig. 2 show the diversification of values of output indices in 2004 and 2016. In 2004, the highest values were recorded, apart from such cities as Warsaw, Krakow, Wroclaw, Poznan and Lodz, for most of the subregions of Silesian conurbation, Starogardzki (PL638), Bydgosko-Torunski (PL613), Legnicko-Glogowski (PL516) and Krosnienski (PL323) subregions. After twelve years, there occurred significant changes in the composition of the best performing class. Half of the subregions, mostly of Silesian conurbation, were replaced by Tricity (PL633), Poznanski (PL418), Kaliski (PL416), Czestochowski (PL224), Lubelski (PL314), Radomski (PL128) and Warszawski Zachodni (PL12A). The weakest class in both analysed years included Swiecki (PL618), Ciechanowski (PL12C) and subregions of Eastern Poland such as Elcki (PL623), Suwalski (PL345), Łomzynski (PL344), Bialski (PL311) and Pulawski (PL315).

The estimation results of panel regressions identified significant inputs in each subregion type. For both metropolitan and non-metropolitan groups of subregions, the four variables were statistically significant: share of innovative industrial enterprises, unemployment rate, industry share and employment in R&D. The share of crime and the number of high schools were significant for metropolitan RIS while cooperation share and lack of "lifelong learning" were important for non-metropolitan RIS. The estimation results are presented in Table 2 and Table 3.

According to the Eurostat classification, the group of metropolitan subregions in Poland consists of 28 NUTS 3 with half of them located in three provinces: Slaskie (7), Mazowieckie (4) and Malopolskie (3). The results of the analysis confirm that in the examined NUTS 3 type, the most numerous are systems with low inputs and low outputs, which proves high disparities in the

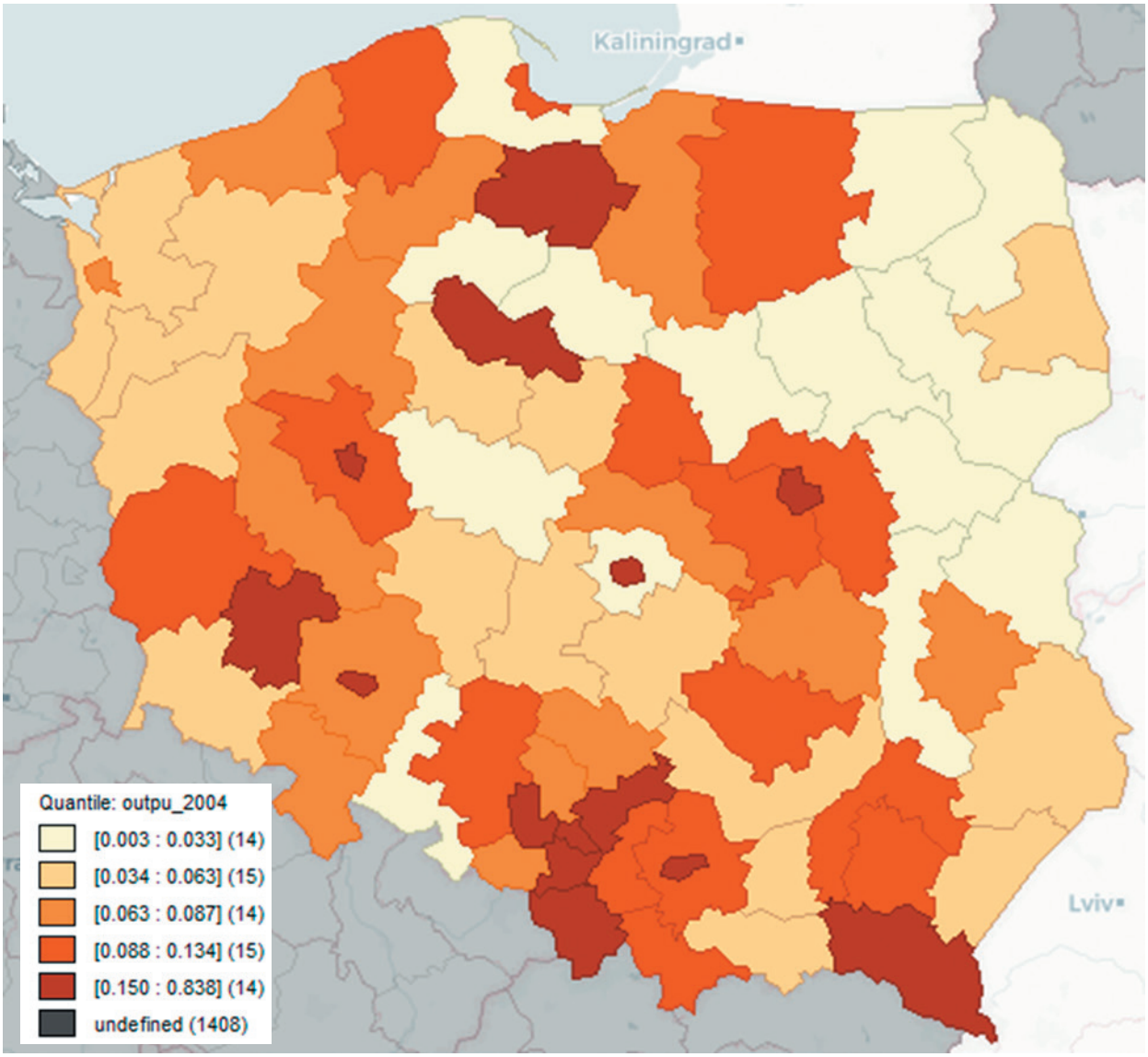


Fig. 1. *Output index in 2004 — regions divided into equal groups*
Source: Authors' calculations

group (see Table 4). There are only three subregions remaining in the high input/high output class throughout the period. These are the city of Kraków (PL213), Bielsko-Biała (PL225) and the city of Warsaw (PL127). In 2004–2016, six subregions improved their performance moving to the class with high outputs. These include: Tricity (PL633), City of Lodz (PL113), Czestochowski (PL224), Lubelski (PL314), Radomski (PL128) and Poznanski (PL418). Apart from the above mentioned, four other subregions recorded an above average increase in outputs. These were Bialostocki (PL343), Lodzki (PL114), City of Szczecin (PL424) and City of Wroclaw (PL514) (see Fig. 3). Three subregions, all located in Slaskie, moved in the opposite direction: Katowicki (PL22A), Sosnowiecki (PL22B) and Tyski (PL22C).

In the last examined year, the least favourable class, in which high inputs were transformed into low outputs consisted of such subregions as Krakowski (PL214), Tyski (PL22C), city of Poznan (PL415), Rzeszowski (PL325), Warszawski Wschodni (PL129) and Warszawski Zachodni (12A). There were six RIS with above-average input changes being transformed into below-average output changes, which are Kielecki (PL331), City of Poznan (PL415), Gliwicki (PL229), Bydgosko-Torunski (PL613), Rzeszowski (PL325) and Krakowski (PL214).

The results of cluster analysis based on individual inputs confirms that the composition of identified clusters remains unstable. Separate cluster consists of one NUTS 3 — city of Warsaw (PL127), with the highest number of high schools and highest employment in R&D, as well as the lowest industry share (see Table 5 and Table 6).

In 2016, the most numerous fourth cluster was very similar in characteristics to the third one

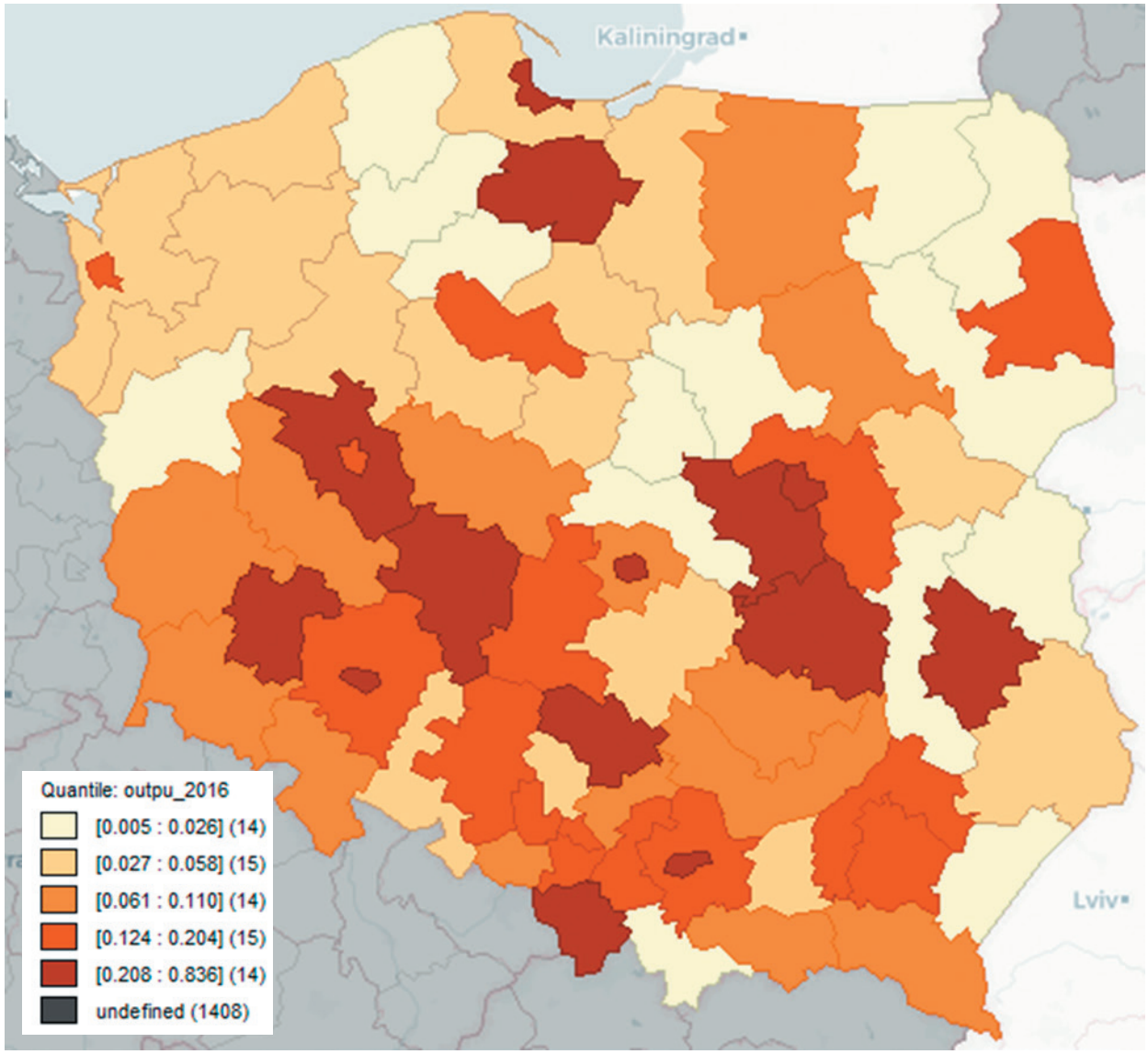


Fig. 2. *Output index in 2016 — regions divided into equal groups*
Source: Authors' calculations

Table 2

Panel regression estimates for metropolitan NUTS 3

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	**Dependent variable: innovation output**						
innov_share	0.001***	0.001***	0.001***	0.001***	0.001***	0.002***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
coop_share	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log_gdp_pc	0.017	—	—	—	0.041	0.050*	0.041
	(0.020)				(0.033)	(0.026)	(0.033)
unem_rate	−0.003**	−0.002*	−0.003**	−0.003**	−0.003*	−0.004**	−0.003*
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
crime_share	−0.001**	−0.001**	−0.001***	−0.002***	−0.002***	−0.000	−0.002***
	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
divorces_share	−0.009	−0.008	−0.010	−0.012	−0.006	−0.005	−0.006
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
industry_share	0.326***	0.316***	0.345***	0.350***	0.352***	0.198**	0.352***
	(0.110)	(0.106)	(0.110)	(0.113)	(0.119)	(0.100)	(0.119)

Окончание табл. 2

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	**Dependent variable: innovation output**						
highschools_number	0.005***	0.005***	0.006***	0.005***	0.006***	—	0.006***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)		(0.002)
Railway	—	—	—	—	−0.000	—	−0.000
					(0.002)		(0.002)
tertiary_share	—	—	—	—	−0.002	—	−0.002
					(0.002)		(0.002)
no_life_learn_share	—	—	—	—	0.001	0.002	0.001
					(0.002)	(0.002)	(0.002)
empl_rd_share	—	—	—	—	0.077**	0.003	0.077**
					(0.031)	(0.029)	(0.031)
rd_percgdp	—	–	—	—	−0.025	—	−0.025
					(0.027)		(0.027)
log_gdp_total	—	0.031*	—	—	—	—	—
		(0.018)					
log_wages	—	—	−0.006	—	—	—	—
			(0.024)				
pop_density	—	–	–	0.000	–	–	–
				(0.000)			
Roads	—	—	—	—	—	−0.000	—
						(0.000)	
Highway	—	—	—	—	—	−0.001	—
						(0.001)	
postphd	—	—	—	—	—	0.002	—
						(0.004)	
rd_pc	—	—	—	—	—	0.000	—
						(0.000)	
Constant	−0.128	−0.257	0.110	0.052	−0.386	−0.443	−0.386
	(0.223)	(0.183)	(0.215)	(0.043)	(0.315)	(0.286)	(0.315)
Observations	344	344	344	344	343	343	343
Number of NUTS 3	28	28	28	28	28	28	28
R^2	0.847	0.850	0.845	0.845	0.858	0.850	0.858

Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations.

Table 3

Panel regression estimates for non-metropolitan NUTS 3

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	**Dependent variable: innovation output**						
innov_share	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
coop_share	0.001*	0.001***	0.001	0.001***	0.001	0.001**	0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log_gdp_pc	−0.027*	—	—	—	−0.018	−0.010	−0.018
	(0.016)				(0.024)	(0.019)	(0.024)
unem_rate	−0.002***	−0.002***	−0.002***	−0.002***	−0.002**	−0.001	−0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
crime_share	−0.000	0.000	−0.000	0.000	−0.000	0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
divorces_share	0.010	0.007	0.010	0.007	0.011*	0.007	0.011*
	(0.007)	(0.007)	(0.007)	(0.006)	(0.007)	(0.007)	(0.007)

Окончание табл. на след. стр.

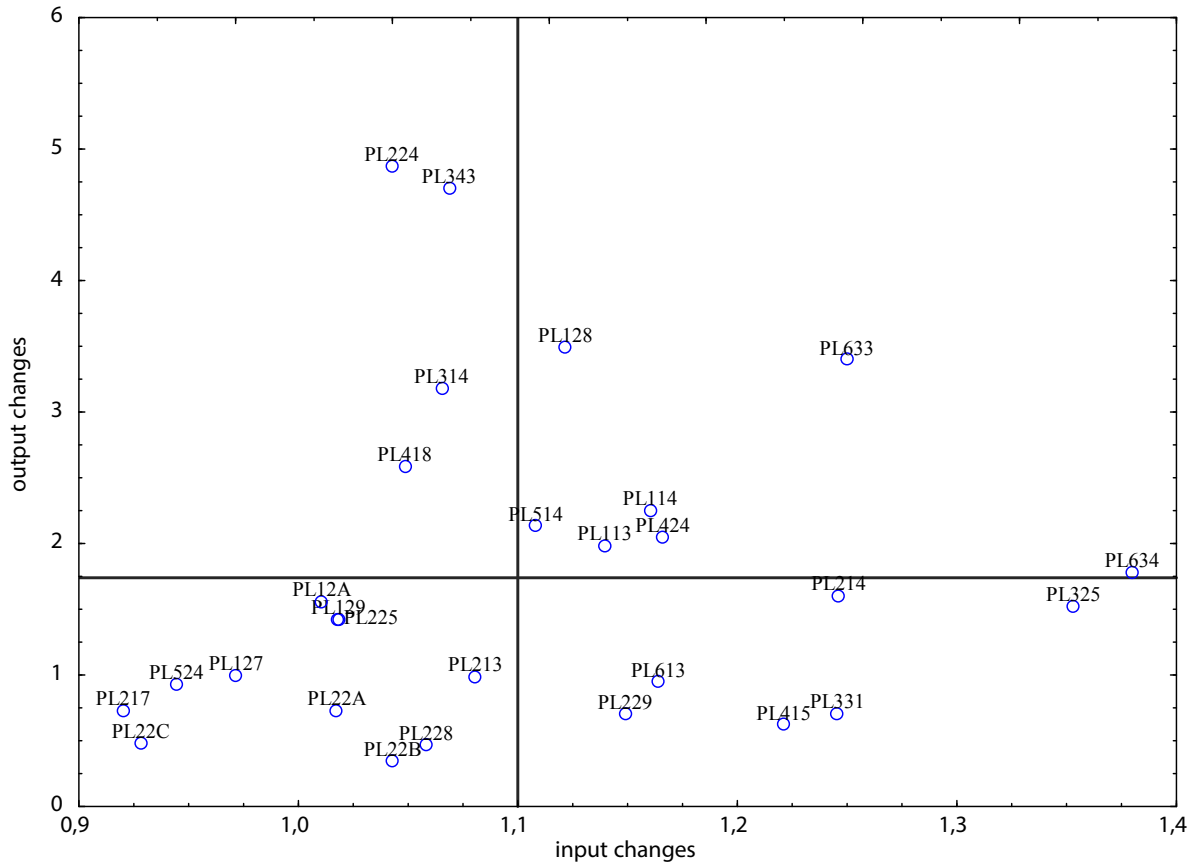
Окончание табл. 3

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	**Dependent variable: innovation output**						
industry_share	0.130**	0.058	0.114**	0.057	0.121**	0.118**	0.121**
	(0.055)	(0.046)	(0.045)	(0.041)	(0.061)	(0.056)	(0.061)
highschools_ number	–0.002	–0.003	–0.002	–0.003	–0.002	—	–0.002
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)		(0.002)
Railway	—	—	—	—	–0.001	—	–0.001
					(0.002)		(0.002)
tertiary_share	—	—	—	—	–0.001	—	–0.001
					(0.001)		(0.001)
no_l_learn_share	—	—	—	—	–0.001	–0.002**	–0.001
					(0.001)	(0.001)	(0.001)
empl_rd_share	—	—	—	—	0.037***	0.051***	0.037***
					(0.014)	(0.013)	(0.014)
rd_percgdp	—	—	—	—	–0.018	—	–0.018
					(0.013)		(0.013)
log_gdp_total	—	0.001	—	—	–	—	—
		(0.010)					
log_wages	—	—	–0.035**	—	–	—	—
			(0.016)				
pop_density	—	—	—	0.000	–	—	—
				(0.000)			
Roads	—	—	—	—	–	–0.000	—
						(0.000)	
Highway	—	—	—	—	–	0.000	—
						(0.001)	
postphd	—	—	—	—	–	–0.004**	—
						(0.002)	
rd_pc	—	—	—	—	–	–0.000	—
						(0.000)	
constant	0.282*	0.004	0.290**	0.015	0.205	0.126	0.205
	(0.156)	(0.089)	(0.131)	(0.017)	(0.214)	(0.188)	(0.214)
Observations	527	527	527	527	524	550	524
Number of NUTS 3	42	42	42	42	42	44	42
R^2	0.351	0.355	0.364	0.352	0.372	0.389	0.372

Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' calculations.

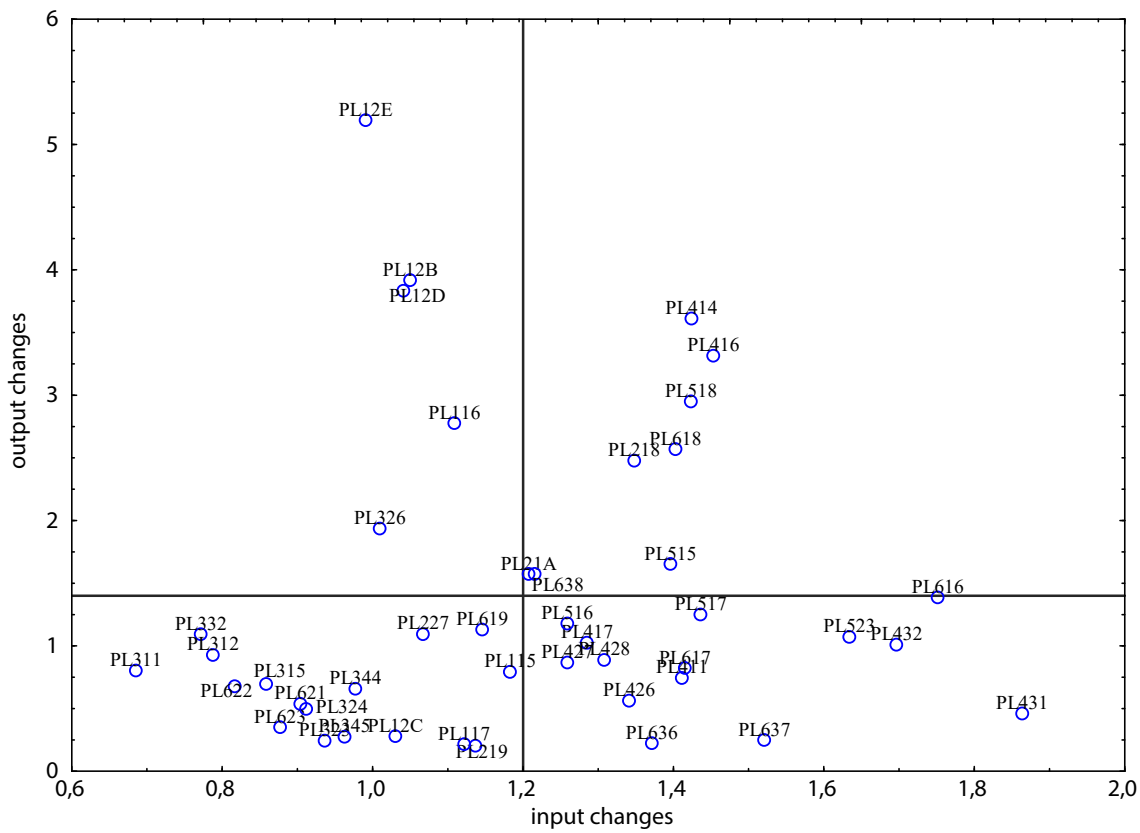
apart from R&D employment share, higher in the latter. Both clusters were characterised by the lowest share of innovative enterprises and number of high schools and the highest industry share. The second cluster, of relatively stable composition and average input values, was distinguished by the lowest values of crime. Most of the subregions with high outputs belong to the second and four cluster and the majority of least effective (high input/low output) NUTS 3 units are included in the third cluster. Thereby, it could be assumed that employment in R&D had a relatively low impact on outputs in the latter class.

The second type includes 44 non-metropolitan NUTS 3, of which most are subregions with low outputs. In 2010 and 2016, the most numerous were NUTS 3, in which low inputs were transformed into low outputs, half of them located in three provinces: Kujawsko-Pomorskie (PL616, PL617, PL618, PL619), Zachodniopomorskie (PL426, PL427, PL428) and Lubelskie (PL311, PL312, PL315). In 2004–2016, seven RIS moved to high-output classes. These were Jeleniogorski (PL515), Legnicko-Głogowski (PL516), Wroclawski (PL518), Koninski (PL414), Kaliski (PL416), Nowosadecki (PL218), Sieradzki (PL116) subregions. 13 subregions recorded an above average increase in outputs. The highest positive changes in outputs were observed in three Mazowian subregions: Ciechanowski (PL12B),



Source: Authors' calculations.

Fig. 3. *Metropolitan NUTS 3, changes in inputs and outputs 2004–2016*



Source: Authors' calculations.

Fig. 4. *Non-metropolitan NUTS 3, changes in inputs and outputs 2004–2016*

Table 4

Input-output classifications of RIS in Poland

2004_2010				2016							
low input/ low output	**low input/ high output**	**high input /high output**	**high input/ low output**	**low input/ low output**	**low input/ high output**	**high input/ high output**	**high input/ low output**	**low input/ low output**	**low input/ high output**	**high input/ high output**	**high input/ low output**
Metropolitan											
PL228 PL424 PL524 PL634 PL633 PL114 PL113 PL331 PL314 PL325 PL343 PL128	PL229 PL22A PL22B PL415 PL514 PL613	PL213 PL225 PL22C PL127	PL214 PL217 PL224 PL418 PL129 PL12A	PL228 PL224 PL229 PL22A PL22B PL424 PL524 PL634 PL114 PL331 PL314 PL325 PL343 PL128	PL415 PL514 PL613 PL113	PL213 PL225 PL633 PL127 PL12A	PL214 PL217 PL22C PL418 PL129	PL217 PL228 PL229 PL22A PL22B PL424 PL524 PL613 PL634 PL114 PL331 PL343	PL224 PL514 PL113 PL314 PL128	PL213 PL225 PL418 PL633 PL127	PL214 PL22C PL415 PL325 PL129 PL12A
non-metropolitan											
PL431 PL426 PL427 PL428 PL515 PL523 PL616 PL619 PL617 PL618 PL623 PL332 PL324	PL432 PL517 PL636 PL637 PL621 PL622 PL323	PL21A PL219 PL227 PL417 PL516 PL638 PL117 PL326 PL12C	PL218 PL416 PL414 PL411 PL518 PL115 PL116 PL311 PL312 PL315 PL344 PL345 PL12B PL12D PL12E	PL636 PL637 PL621 PL431 PL426 PL427 PL428 PL523 PL616 PL619 PL617 PL618 PL623 PL332 PL324 PL311	PL432 PL517 PL622 PL323 PL515 PL326	PL21A PL227 PL417 PL638 PL218 PL416 PL414 PL518 PL116	PL219 PL516 PL117 PL12C PL411 PL115 PL312 PL315 PL344 PL345 PL12B PL12D PL12E	PL622 PL621 PL431 PL426 PL427 PL428 PL523 PL616 PL619 PL617 PL618 PL623 PL332 PL324 PL311 PL312 PL315 PL344 PL345	PL432 PL323 PL326	PL517 PL515 PL21A PL227 PL417 PL638 PL218 PL416 PL414 PL518 PL116 PL516	PL636 PL637 PL219 PL117 PL12C PL411 PL115 PL12B PL12D PL12E

Source: Authors' calculations.

Ostrolecki (PL12D) and Siedlecki (PL12E) and two subregions of Wielkopolskie: Kononski (PL414) and Kaliski (PL416) (see Fig. 4). The classes with low outputs were joined by Slupski (PL636), Chojnicki (PL637), Elblaski (PL621), Skierniewicki (PL117), Nowotarski (PL219) and Plocki (PL12C). Throughout the whole time period, in the class of the least effective RIS remain Pilski (PL411), Piotrkowski (PL115) and three subregions of Mazowieckie, such as Ciechanowski (PL12B), Ostrolecki (PL12D) and Siedlecki (PL12E).

In addition, in this case, the composition of groups by significant inputs remains unstable. The biggest differences among clusters can be recognised in two inputs: young people neither in employment nor in education and training and R&D employment. There are almost no differences in share of innovative and cooperating enterprises. The first cluster is characterised by the highest unemployment rate and the highest share of no-lifelong learning. The second cluster has the lowest values of all variables, both stimulants and destimulants and the third one has the highest industry share and R&D employment. Although in 2004, the most effective RIS (low-input & high-output) belonged to all the identified clusters, in 2010 and 2016, all of them were included in the second cluster. The least effec-

Table 5

Metropolitan sub-regions, results of cluster analysis by inputs

Metropolitan											
1	2	3	4	1	2	3	4	1	2	3	4
2004				2010				2016			
PL127	PL213 PL22A PL415 PL424 PL514 PL613 PL633 PL113	PL214 PL217 PL634 PL128	PL225 PL228 PL224 PL229 PL22B PL22C PL418 PL524 PL114 PL331 PL314 PL325 PL343	PL127	PL213 PL22A PL415 PL514 PL633	PL214 PL217 PL418 PL634 PL325 PL128	PL225 PL228 PL224 PL229 PL22B PL22C PL524 PL613 PL114 PL113 PL331 PL314 PL343	PL127	PL213 PL22A PL415 PL424 PL514 PL633	PL214 PL217 PL418 PL325 PL129 PL12A PL128	PL225 PL228 PL224 PL229 PL22B PL22C PL524 PL613 PL634 PL114 PL113 PL331 PL314 PL343

Source: Authors' calculations.

Table 6

Non-metropolitan sub-regions, results of cluster analysis by inputs

non-metropolitan								
2004			2010			2016		
1	2	3	1	2	3	1	2	3
PL115 PL116 PL117 PL332 PL312 PL315 PL323 PL324 PL326 PL344 PL345	PL431 PL432 PL426 PL427 PL428 PL523 PL616 PL619 PL617 PL618 PL621 PL623 PL622	PL218 PL21A PL219 PL227 PL416 PL414 PL417 PL411 PL515 PL516 PL517 PL518 PL636 PL638 PL637 PL12B PL12D PL12C	PL218 PL21A PL219 PL414 PL411 PL636 PL637 PL115 PL116 PL117 PL311 PL312 PL315 PL344 PL345 PL12B PL12D PL12C	PL431 PL432 PL515 PL517 PL523 PL616 PL619 PL617 PL618 PL621 PL623 PL622 PL332 PL323 PL324 PL326	PL227 PL416 PL417 PL516 PL518 PL638	PL227 PL416 PL414 PL417 PL411 PL515 PL516 PL517 PL518 PL523 PL618 PL636 PL638 PL115 PL116 PL117 PL311 PL312 PL315 PL344 PL345	PL431 PL432 PL426 PL427 PL428 PL619 PL617 PL621 PL623 PL622 PL332 PL323 PL324 PL326	PL218 PL21A PL219 PL12B PL12D PL12C PL12E

Source: Authors' calculations.

tive systems — only in one year, 2010 — belonged clearly to the first cluster.

Discussion and Conclusions

We would like to emphasise that there is no dominance of a single core region in Poland. It is characterised less by Krugman's NEG [72] than by the polycentric nature [73]. The aim of our study was to classify RIS in Poland taking into account the aspect of metropolisation. We have shown that the determinants of innovation outputs in metropolitan and non-metropolitan subregions are not identical. The results confirm that the composition of RIS classes identified within metropolitan and non-metropolitan RIS in 2004–2016 remains unstable. Not stable is also the composition of clusters identified by inputs, which confirms changes in components of the capacity

within both RIS types. This allows us to assume that Regional Innovation Systems are evolving. Important factors affecting changes in the identified classes may be also different reactions of RIS to the EU accession, crisis and recovery phase. The most numerous in metropolitan and non-metropolitan RIS are unfortunately subregions with low outputs; this fact indicates high disparities within different RIS types. The smallest differences between metropolitan RIS are in the share of innovative enterprises and unemployment rate. Non-metropolitan RIS differ the least in terms of the share of innovative and cooperating enterprises. Low level of cooperation may cause fragmentation of both metropolitan and non-metropolitan RIS. The results suggest relatively low impact of employment in R&D on the least effective metropolitan RIS. In conclusion, the results confirmed the need for differentiated public support, which should be offered to metropolitan and non-metropolitan regions. The factors conditioning the innovativeness of both types of systems are different, so it is difficult to speak of a unified policy benchmark. The policy, like the systems themselves, should evolve.

We would like to admit that our analysis has several limitations, first and foremost, due to the scope of the available data at NUTS 3 level. As an extension of the conducted research, it could be interesting to identify effective RIS in Poland using Data Envelopment Analysis (DEA). It shall allow us to find out the features of RIS that are important for the efficiency of creating innovations in subregions. Efficient NUTS 3 with high could be considered as strong systems. Further research should be devoted to this issue.

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