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DISPARITIES IN INNOVATION CAPITAL OF CITIES IN POLAND

Abstract

Objectives: The aim of the paper is to measure innovation capital of Polish cities and verify whether its dispersion changed.

Material and methods: Data was retrieved from the Local Data Bank provided by Statistics Poland. The sample consists of 18 Polish cities. The research period covers years 2014-2021. The TOPSIS method was applied to build the innovation capital index of cities and sigma convergence of innovation capital was verified.

Results: The findings indicate relatively high cross-sectional disparities in the vast majority of the investigated indicators of cities' innovation capital. The largest disparities were identified for the number of higher education graduates and the new registered enterprises in high-tech services sector. The constructed composite indicator – innovation capital index took the highest average values in the analysed period for Wrocław, Poznań, Kraków, Warszawa, and Lublin, whereas Gorzów Wielkopolski, Zielona Góra, Bydgoszcz, and Białystok achieved the lowest values. The sigma convergence analysis revealed that the differentiation of innovation capital in Polish cities remained at a similar level and there was no convergence in this area.

Conclusions: Innovation capital plays a key role in the development of urban economy. Given the complexity of innovation capital, its measurement should comprise a set of indicators reflecting both output and input dimensions. Identification of spatial patterns of innovation capital distribution should enable to adjust smart specialization strategy to territorial characteristics of a given city.

Keywords: *innovation capital, cities, composite indicator, convergence, knowledge spillovers*

Introduction

Cities create a fertile milieu for innovation as they provide proximity, density and heterogeneity (Athey et al. 2008, p. 156). Urban proximity allows business, people, and knowledge networks to initiate flow of innovative ideas and bringing new solutions to market. Co-location facilitates the establishment of connections with potential partners for collaboration and the easier exchange of knowledge. A key element of physical proximity is the interpersonal interaction between participants in the process of innovation, as it contributes to the efficient sharing of ideas and the dissemination of knowledge as an external factor. Interpersonal interactions possess four primary characteristics: they serve as an effective means of communication, they can aid in the resolution of incentive issues, they can facilitate socialization and learning, and they offer psychological motivation (Kijek et al. 2023, p. 7). Another source of cities' advantage over less densely populated areas is related to agglomeration economies that are a requirement for successful innovation activity. Research, design, and testing of new products and processes take place in clustered environments where industrial actors gather together (Florida et al. 2017, p. 89). The agglomeration effects encompass sharing, matching, and learning effects (Duranton and Puga, 2004, pp. 2063-2065) and capture the benefits derived from co-location (Wixie, 2015, pp. 2054-2055). Agglomeration externalities defined as Marshall-Arrow-Romer (MAR) externalities (Glaeser et al., 1992) are connected with industrial concentration and specialization leading to knowledge spillovers, whereas Jacobs externalities, after Jacobs (1969) emphasizes the significance of economic diversity within firms located in close proximity in innovation processes and city growth.

The importance of the spatial dimension of the city in innovation processes stems from the fact that innovation is a highly localized process. Extensive empirical research has consistently demonstrated that innovative activities tend to exhibit spatial clustering (Crevoisier, 2004, p. 367). Moreover, innovation demonstrates significantly more spatial concentration than traditional production or manufacturing activities (Feldman and Kogler, 2010, 381–410). The relation between innovation and local spaces was initially presented in the theoretical concepts of new industrial districts and innovative milieu. In the former clustering of collaborating firms within a specific geographic area, sharing common resources, knowledge, and skills, results in innovativeness growth of a given space (Sforzi, 2015, pp. 11-29; Becattini, 2002, pp.483-489). In the second concept, the economic space is delineated as a relational space characterized by interdependent and mutually beneficial collective actions that strongly impact the generation and implementation of innovations within a specified geographical area (Camagni and Capello, 2002, pp. 15-45). The spatial dimension of innovation is also demonstrated in the concept of the learning region according to which, these spaces serve as central locations for the creation of knowledge and offer an infrastructure that facilitates the exchange of knowledge (Florida, 1995, pp. 527-536).

Every city possesses a specific combination of resources and competencies, which form its unique identity and its potential capability of providing the conditions for innovation. When analysing various assets of cities that can be critical inputs of the innovation process, Concilio et al. (2019, pp.48-49) pay attention to such factors as: knowledge regarded as the key resource made available in the city, people with their creativity and talent, and research institutions. All these factors may be encompassed and summarized by a concept of innovation capital. In a general, innovation capital of city may be regarded as the pool of localized assets – intangible, human, and creative – that form the innovative potential of a given city. The concept of innovation capital is closely related to the concept of territorial capital (Camagni and Capello 2013, pp. 1386-1390). The latter consists of different categories that include tangible goods (e.g. fixed capital stock), mixed goods (e.g. connectivity agencies for R&D transcoding), and intangible goods (e.g. relational capital). As is the case for territorial capital, innovation capital may be thought of as a new form of the production function approach with heterogeneous assets and therefor can be analysed using an input-output perspective.

From the input perspective innovation capital of city is to a high extent connected with the determinants of knowledge creation. In this dimension a key role is undoubtedly played by universities as they shape innovative performance of cities both directly, through conducting internal R&D activites, and indirectly, through localized knowledge spillovers, by improving R&D activities of firms in geographical proximity to them (Orlando et al. 2019, pp. 407-408). The knowledge diffusions seems to be particularly strong in areas surrounding academic institutions. The positive effects of universities on innovation performance are found to be concentrated in space (Fritsch and Slavtchev 2007, p. 201). The concentration of universities correlate with innovation performance as proximity to universities can affect firms' capability to innovate and the availability of educational opportunities in a given city increases. Strongly connected with academic institutions factor that is regarded as a source of knowledge in the cities is education, and specifically higher education. As Birch et al. (2017, p.744) reveal more talented entrepreneurs tend to be more educated. Moreover, educational level and skills acquired during work are related to innovative performance. (Zwick et al., 2017, pp. 121). Higher education graduates with higher intrapreneurial skills are more involved in innovation (van Wetten et al., 2020, p. 12; Bjornali and Støren (2012, pp. 415-417). The diversity and density of cities create environment for human creativity that is considered to be a significant driver of innovations. The results of empirical analysis indicate that creative industries enterprises improve innovation performance (Lee and Rodríguez-Pose, 2014, p. 1139; Müller et al., 2009, p. 148).

From the output perspective, innovation capital of city can be measured through patents or scientific publications (Florida et al. 2017, p. 89). The former and the latter may be viewed as a measure of an intermediate output of innovation processes. Using patents and publications as indicators of innovation capital has a number of advantages and disadvantages. A main advantage of patents is that gaining a patent needs a certain level of novelty that allows for comparability across cities (Fritsch and Wyrwich, p. 3). On the other hand, peer-reviewed publications provide a wealth of information on research performance and they are commonly used to disseminate knowledge on research results. Unfortunately, both the mentioned indicators focus on the results of R&D activities and not on their applications in new processes or products. It can be assumed that a critical mass of high technology firms must be reached to realise the full potential of patentable and non-patentable inventions and new scientific developments. For example, Anselin et al. (2000) found that there were university research spillovers in the high-tech industries such as Electronics and Instruments. In this situation, entrepreneurship in high-tech and knowledge intensive firms in the urban economy may be a useful proxy for innovation capital.

Given that there is a clear correlation between innovation and economic performance of cities (Athey et al. 2008, p. 157), there are grounds for questioning the dispersion in innovation capital of cities. This question is particularly relevant for Polish cities, since innovation-based potential is regarded as the main determinant of their development (Orankiewicz and Turała, 2019, p. 273). Despite the importance of innovation in ensuring city's competitiveness, studies on innovation capital of Polish cities are rare. The paper tries to fill this gap and seeks the answers to the following research questions:

- What is the level of dispersion in innovation capital of Polish cities?
- Does dispersion in innovation capital of Polish cities change?

The reminder of the paper is structured as follows. The next section presents data and methods. The results and discussion are included in the subsequent section. The last part of the paper concludes.

Data and methods

Our analysis uses data taken from the Local Data Bank provided by Statistics Poland. The sample consists of 18 Polish cities, including: Wrocław, Bydgoszcz, Toruń, Lublin, Gorzów Wielkopolski, Zielona Góra, Łódź, Kraków, Warszawa, Opole, Rzeszów, Białystok, Gdańsk, Katowice, Kielce, Olsztyn, Poznań, Szczecin. The research period covers years 2014-2021.

The multidimensional nature of innovation capital requires the use of appropriate methods for its measurement. For this purpose, we apply the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981). It is a multi-criteria decision analysis method, which is based on the geometric distances from the positive ideal solution (PIS) and from the negative ideal solution (NIS).

To assess innovation capital of cities, we use a composite measure – innovation capital index that combines the values of a set of indicators presented in Table 1.

Table 1. *Innovation capital indicators*

Input of innovation capital of cities	
Higher education institutions/100 thousand inhabitants	UNI
Higher education graduates/100 thousand inhabitants	HEG
Share of creative sector entities in the total number of entities	CRE
Output of innovation capital of cities	
Scopus publications/100 thousand inhabitants	SCP
Patents granted by the Patent Office of the Republic of Poland /100 thousand inhabitants	PAT
New registered enterprises in high-tech and medium high tech industry sectors/100 thousand inhabitants	HTI
New registered enterprises in high-tech services sectors/100 thousand inhabitants	HTS
New registered enterprises in knowledge-based services sectors/100 thousand inhabitants	KBS

Source: own elaboration.

Then the values of indicators are normalised as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{m} x_{kj}^2}},\ i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n,$$

where
x_{ij} – value of indicator j in city i,
r_j – normalised value of indicator j in city i,
m – number of cities,
n – number of indicators.

The normalised indicators are weighted like this:
$z_{ij} = r_{ij} \cdot w_j,\ i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n$

where w_j $(\sum_{k=1}^{n} w_k = 1)$ is the weight given to the indicator j.

For each indicator, the worst value z_{wj} and the best value z_{bj} is determined. For stimulants, z_{wj} is the minimum value and z_{bj} is the maximum value. For destimulants, z_{wj} is the maximum value and z_{bj} is the minimum value. The worst values of indicators create the worst alternative, and the best values of indicators create the best alternative.

In the next step, the distances between cities and the worst and the best alternatives are calculated:

$$d_{iw} = \sqrt{\sum_{j=1}^{n}\left(z_{ij} - z_{wj}\right)^2}, i = 1, 2, \ldots, m,$$

$$d_{ib} = \sqrt{\sum_{j=1}^{n}\left(z_{ij} - z_{bj}\right)^2}, i = 1, 2, \ldots, m.$$

The composite measure, innovation capital index, is calculated as the similarity to the worst condition:

$$s_{iw} = \frac{d_{iw}}{d_{iw}+d_{ib}}, 0 \leq s_{iw} \leq 1, i = 1, 2, \ldots, m.$$

The low (high) value of the index denotes the low (high) level of innovation capital.

The study of innovation capital in Polish cities includes verification of sigma convergence of innovation capital index. The concept of sigma convergence assumes a decrease in the dispersion of the economic variable over time (Kijek et al. 2023). The first step of sigma convergence measurement is the choice of dispersion measure. There are several measures of dispersion, providing a different way to quantify the difference of individual data points from the central tendency (such as the mean or median) of the dataset, The most popular are standard deviation and coefficient of variation. The second step is the assessment of the decrease of dispersion measure over time. The simplest solution is to compare the values of the dispersion measure in two analysis periods, the final and the initial one. Another way is to determine the linear trend equation for the dispersion measure and check the sign of its slope coefficient.

Results and discussion

The descriptive statistics of indicators used to measure innovation capital of city are presented in Table 2.

Table 2. *Descriptive statistics of innovation capital indicators*

Indicator	Mean	Stand. dev.	Coeff. of var	Min	Max
UNI	2,9	0,9	31,0%	0,7	5,0
HEG	3709,5	1617,7	43,6%	433,6	8144,4
CRE	8,2	1,3	16,5%	4,1	11,6
SCO	511,9	262,0	51,2%	1,6	1124,5
PAT	21,0	11,4	54,3%	0,0	64,9
HTI	6,4	2,5	39,7%	0,8	14,1
HTS	110,1	71,6	65,0%	25,0	361,6
KBS	392,9	122,2	31,1%	180,9	813,3

Source: own elaboration.

The data in Table 2 indicate relatively high cross-sectional disparities in the vast majority of the investigated indicators of cities' innovation capital. As regards the proxies of innovation capital input, the largest disparities were identified for the number of higher education graduates per 100 thousand inhabitants (HEG) with the coefficient of variability reaching nearly 44%. The highest level of HEG in the examined period (8,144.4) occurred in Rzeszów in 2014, whereas the lowest one (433.6) was found in Gorzów Wielkopolski in 2019, with the mean value in the sample at about 3,710. Also the number of higher education institutions per 100 thousand inhabitants (UNI) turned out to be strongly diversified (coefficient of variability equal to 31%). In the case of this measure the highest value (5.0) was found in Kielce in 2014, while the lowest one (0.7) in Zielona Góra in 2019 with the sample mean at 2.9. The most uniform distribution among the innovation capital input indicators occurred in the share of creative sector entities in the total number of entities (CRE), as indicated by a relatively low value of the coefficient of variability (16.5%). The highest level of CRE (11.6%) was recorded in Warsaw in 2014, whereas the lowest one (4.1%) was found in Gorzów Wielkopolski in 2019, with the mean in the sample at 8.2%.

Similarly to the indicators of cities' innovation capital input, the investigated measures of output also varied significantly across the examined sample. The largest dispersion was identified in the case of the new registered enterprises in high-tech services sector per 100 thousand inhabitants (HTS) with the coefficient of variability at 65%. The highest value of HTS was found in Warsaw in 2021 (361.6) while the lowest one in Gorzów Wielkopolski in 2014 (25.0), with the mean value in the sample at 110.1. The disparities of similar magnitude were recorded also for two additional indicators, namely the Scopus publications per 100 thousand inhabitants (SCO) and patents granted by the Patent Office of the Republic of Poland per 100 thousand inhabitants (PAT), with the coefficients of variability at 51.2% and 54.3%, respectively. For both indicators, the highest values were found in Lublin in 2021 (nearly 1,125 and 65, respectively), whereas the lowest ones were recorded in Gorzów Wielkopolski (1.6 in 2014 as regards the former indicator and 0.0 in 2016 as regards the second one), with the means at 511.9 and 21.0, respectively. Somewhat lower disparities in the examined sample were identified in the case of the two remaining indicators of cities' innovation capital output, i.e. new registered enterprises in high-tech and medium high tech industry sectors per 100 thousand inhabitants (HTI) and new registered enterprises in knowledge-based services sectors per 100 thousand inhabitants (KBS), with the coefficients of variability at 39.7% and 31.1%, respectively. The lowest values of each indicator were found again in Gorzów Wielkopolski (0.8 in 2016 for the former and 180.9 in 2020 for the second one). As regards the highest values in the sample, for HTI it was recorded in Lublin in 2016 (14.1), whereas for KBS it occurred in the same year in Warsaw (813.3), with the means at 6.4 and 392.9, respectively.

The composite indicator of innovation capital of Polish cities – innovation capital index, assessed with TOPSIS method is presented in Table 3. It includes the values of synthetic measures and the position in ranking for cities in 2014-2021. The innovation capital index took the highest average values in the analysed period for Wrocław, Poznań, Kraków, Warszawa, and Lublin. The top position of Wrocław in the ranking mainly resulted from its relatively high level of technological entrepreneurship and patent propensity. Similar trends in entrepreneurship can be observed as regards Warszawa. For this city, creative industries were of high importance to urban economy. It should be noted that the vital role of creative industries in line with intensive publication activities and a high rate of higher education graduates were observed in Kraków. Poznań, in comparison to other cities, stood out for a high number of higher education institutions and scientific publications. As for Lublin, it has to be recognised that its strengths were patenting and publication activities. Our results are partially consistent with the findings presented by Turała (2019, p. 46), who studied innovation potentials of Polish cities and placed Warszawa, Kraków, and Poznań at the head of his ranking. Our analysis shows that Gorzów Wielkopolski, Zielona Góra, Bydgoszcz, and Białystok were at the other end of the ranking.

Table 3. *Composite measure of innovation capital and its ranking for Polish cities in 2014-2021*

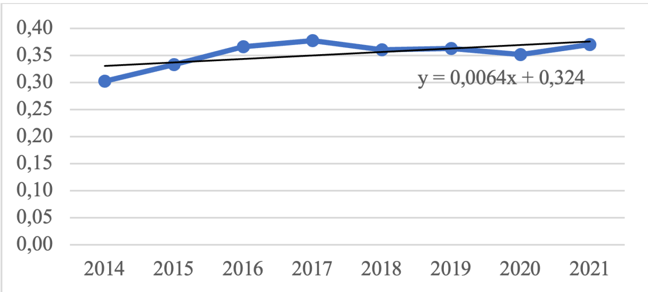
City	2014	2015	2016	2017	2018	2019	2020	2021	2021/ 2014
Wrocław	0.54 (2)	0.54 (2)	0.59 (1)	0.62 (1)	0.59 (2)	0.59 (1)	0.51 (3)	0.66 (1)	22.0%
Bydgoszcz	0.2 (17)	0.23 (17)	0.22 (16)	0.24 (16)	0.19 (16)	0.22 (16)	0.19 (17)	0.23 (16)	14.2%
Toruń	0.31 (13)	0.31 (13)	0.35 (11)	0.27 (15)	0.32 (12)	0.27 (15)	0.26 (15)	0.33 (14)	4.5%
Lublin	0.46 (5)	0.5 (5)	0.54 (5)	0.46 (6)	0.45 (6)	0.58 (2)	0.53 (1)	0.63 (2)	37.0%
Gorzów Wlk.	0.17 (18)	0.09 (18)	0.07 (18)	0.08 (18)	0.12 (18)	0.11 (18)	0.13 (18)	0.12 (18)	-30.1%
Zielona Góra	0.24 (16)	0.3 (14)	0.19 (17)	0.19 (17)	0.19 (17)	0.18 (17)	0.2 (16)	0.19 (17)	-19.4%
Łódź	0.31 (12)	0.3 (15)	0.3 (14)	0.32 (11)	0.32 (13)	0.31 (12)	0.3 (11)	0.39 (9)	22.9%
Kraków	0.49 (3)	0.51 (4)	0.56 (2)	0.57 (2)	0.55 (3)	0.55 (3)	0.49 (5)	0.61 (3)	24.7%
Warszawa	0.49 (4)	0.53 (3)	0.56 (3)	0.54 (4)	0.54 (4)	0.52 (5)	0.46 (7)	0.53 (6)	7.8%
Opole	0.37 (8)	0.4 (7)	0.44 (7)	0.33 (9)	0.32 (11)	0.35 (10)	0.3 (12)	0.36 (11)	-3.8%
Rzeszów	0.45 (6)	0.38 (8)	0.43 (8)	0.49 (5)	0.46 (5)	0.47 (6)	0.52 (2)	0.54 (5)	20.9%
Białystok	0.28 (15)	0.27 (16)	0.26 (15)	0.27 (14)	0.3 (14)	0.3 (14)	0.27 (14)	0.32 (15)	16.2%
Gdańsk	0.37 (9)	0.38 (9)	0.39 (9)	0.41 (8)	0.39 (8)	0.41 (8)	0.38 (8)	0.46 (8)	26.4%
Katowice	0.44 (7)	0.44 (6)	0.46 (6)	0.44 (7)	0.44 (7)	0.46 (7)	0.48 (6)	0.52 (7)	17.6%
Kielce	0.32 (11)	0.34 (10)	0.34 (12)	0.33 (10)	0.3 (15)	0.31 (13)	0.3 (10)	0.34 (13)	6.1%
Olsztyn	0.33 (10)	0.32 (11)	0.35 (10)	0.32 (12)	0.35 (9)	0.35 (11)	0.31 (9)	0.36 (10)	9.2%

Poznań	0.56 (1)	0.61 (1)	0.54 (4)	0.55 (3)	0.6 (1)	0.55 (4)	0.5 (4)	0.61 (4)	8.7%
Szczecin	0.31 (14)	0.31 (12)	0.3 (13)	0.3 (13)	0.33 (10)	0.37 (9)	0.28 (13)	0.34 (12)	10.7%
Mean	**0.37**	**0.38**	**0.38**	**0.37**	**0.38**	**0.38**	**0.36**	**0.42**	**13.5%**
Stand. dev.	**0.11**	**0.13**	**0.14**	**0.14**	**0.14**	**0.14**	**0.13**	**0.15**	**39.0%**
Coeff. of var.	**0.3**	**0.33**	**0.37**	**0.38**	**0.36**	**0.36**	**0.35**	**0.37**	**22.5%**

Note: Positions in the ranking are presented in parentheses ().

Source: own elaboration.

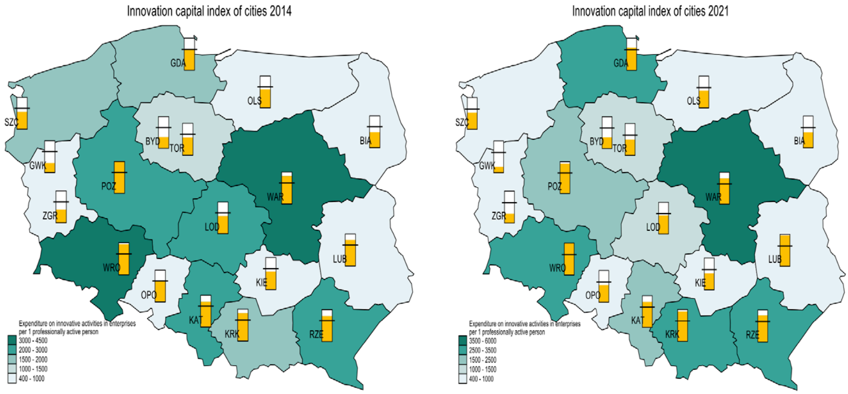
Figure 1. *Coefficient of variation of innovation capital index in 2014-2021*



Source: own elaboration.

Figure 2 presents the spatial distribution of innovation capital index for Polish cities in relation to the expenditures on innovative activities in enterprises per 1 professionally active person in Polish voivodeships in 2014 and 2021. As can be seen, there are not visible tendencies of the spatial clustering of regions with cities with a similar level of innovation capital index. On the other hand, the innovation capital distribution of cities seems to be interrelated with innovation potential of regions. Lublin is an exception in this regard. It should be noted that Lublin, as a strong academic center, is a driver of innovation in the region. The share of universities expenditures in the total value of R&D spending in the region is the highest in Poland (Maliszewski et al., 2021, p. 30).

Figure 2. *Spatial distribution of innovation capital index in years 2014-2021*



Source: own elaboration.

Conclusions

This paper focuses on the concept of innovation capital at the city level. Innovation capital of city may be regarded as the pool of localized assets – intangible, human, and creative – that form the innovative potential of a given city. Using data from the Local Data Bank provided by Statistics Poland for 18 Polish cities, the paper employs the TOPSIS to assess the innovation capital level in years 2014-2021. The results reveal that the innovation capital index took the highest average values in the analysed period for Wrocław, Poznań, Kraków, Warszawa, and Lublin, whereas Gorzów Wielkopolski, Zielona Góra, Bydgoszcz, and Białystok achieved the lowest values. The sigma convergence analysis revealed that the dispersion in innovation capital in Polish cities remained at a similar level and there was no convergence in this area. Identification of the spatial distribution of innovation capital across Polish cities has implication for the local innovation policies and smart specialization strategies development. In particular, these strategies should be based on knowledge assets that constitute the innovation potential of a given city.

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