

Typification of Polish regions based on human capital and innovativeness: a cluster analysis approach

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Abstract

Purpose – This study aims to classify Polish regions using measurable indicators of human capital and innovativeness to assess regional disparities and development dynamics. It explores whether Polish regional development trends indicate integration or polarization and how variations in human capital relate to innovation and socioeconomic outcomes, especially after COVID-19, which has redefined regional development dynamics in Poland.

Design/methodology/approach – Hierarchical (Ward's method) and nonhierarchical (k-means) clustering techniques were applied to regional-level data from 2009 to 2023 sourced from Statistics Poland and Eurostat. Eleven human capital indicators and six innovation indicators were selected. Standardization and Euclidean distance were used for robust comparability.

Findings – The analysis reveals significant regional disparities in human capital and innovation, with Mazowieckie voivodeship consistently ranking as the leader due to its capital city advantage. Regions featuring strong urban centers (e.g. Malopolskie and Pomorskie) exhibit higher levels of human capital and innovation, whereas eastern regions (e.g. Podlaskie and Lubelskie) remain in lower-performing clusters. The study confirms the polarization effect, where more developed regions attract greater human capital, thereby exacerbating inequalities.

Research limitations/implications – The study is limited by indicator availability and does not include qualitative factors such as governance quality or informal networks. Future research should incorporate sectoral and spatial dimensions and expand to a European comparative context.

Practical implications – The findings highlight the need for targeted regional policies aimed at reducing development disparities. Policymakers should consider smart specialization strategies, innovation hubs and talent retention programs to support weaker regions, and intensifying university-business cooperation and building multistakeholder partnerships and innovation clusters.

Originality/value – This study updates and deepens the typology of Polish regions by integrating both human capital and innovation dimensions over a longitudinal timespan.

Keywords Regional innovativeness, Human capital, Cluster analysis, Socioeconomic disparities, K-means and Ward's method

Paper type Research paper



1. Introduction

This study begins by emphasizing the centrality of human capital, which is defined by Organisation for Economic Co-operation and Development as the sum of knowledge, competencies, skills and attributes that enhance individual and collective social and economic well-being (Healy and Côté, 2001), is a key determinant of socioeconomic development. Without man's intellect, knowledge, entrepreneurship and willingness to take risks, there would be no progress. Hence, people's creativity entails innovation, which explains the interest in intangible factors within neoclassical growth theory (Solow, 1956; Solow, 1956). The importance of people's factors in research and policies began with the birth of a human capital theory. The main precursors of human capital theory from the 1960s are considered by three authors: Mincer (1984), Schultz (1961) and Becker (1994). Omitting this factor in growth analyses is a significant methodological limitation. Especially since the center of socioeconomic development is supposed to be people, not the increased production of goods and services. Human capital determines innovation, which, in turn, determines socioeconomic development. Whether this development is shared equitably across regions and populations depends on the attitudes, ethics and moral principles of human capital. According to Schultz, an educated society is a productive society (Schultz, 1970). Growth theories predict that increasing enrollment rates will result in higher per capita income. Based on neoclassical growth theory, an increase in educational attainment enhances the standard growth rate. In contrast, endogenous growth theory says that a higher proportion of people entering education leads to an increased steady-state growth rate (Lucas, 1988; Romer, 1990; Diebolt and Hippe, 2019). Concepts that correspond to these theories are innovation institutions and networks (Storper, 1993). Development based on innovation processes enables regions to develop new technologies or create knowledge (Samuelson and Nordhaus, 2009; Jagódka, 2021a, 2021b). There is a positive coupling between human capital and innovation (Baycan *et al.*, 2017; Cinnirella and Streb, 2017; Diebolt and Hippe, 2019; Romão and Nijkamp, 2019; Jagódka and Snarska, 2021).

Today, there is no sustained long-term growth path without significant investment in human capital, technology and research and development (R&D). The starting point for understanding these differences is to study the stimulants and destimulants of innovation processes in the region. The key to innovation in the region is the talent of the population (Gössling and Rutten, 2007), the second most crucial factor in generating innovation processes, just behind technological innovation (Pinto, 2009; Buesa *et al.*, 2010).

In the literature, there is an ongoing discussion on the terminology and the definition of innovation. It is an interdisciplinary category from different disciplines such as economics, management, engineering and sociology. As per Statistics Poland (SP), the capability of businesses to develop and execute innovations, along with the continuous capacity to launch new and improved products and altered or novel technological or organizational processes, is defined as innovation stemming from human capital. This explanation was suggested by an international methodological guideline referred to as the Oslo Manual (OECD/Eurostat, 2019). The role and importance of knowledge assets in shaping competitiveness, productivity and growth rates are often present in the regional and extra-regional literature (Harris, 2011). Innovation is the key to regional development based on productive and cultural traditions, accepting different approaches and social values, and the ability and willingness to accept new solutions and ways of thinking (Nijkamp *et al.*, 2010).

Although economic growth is often analyzed at the national level due to the availability of aggregated data, such an approach may overlook critical regional dynamics. Centrally designed policies may fail to account for the specific conditions and needs of subnational territories, leading to suboptimal outcomes. Importantly, regional development is not a

simple subset of national growth, just as regional human capital is not merely a fraction of the country's total.

Understanding development as a multilayered, socioeconomic process calls for a regional lens – especially in an era of globalization, where regions, not states, increasingly drive growth. This raises a fundamental question:

- Q1. Why do individuals from different regions, even within the same country, achieve different socioeconomic outcomes?

To explore this, it is necessary to analyze phenomena within clearly defined territorial units.

Identifying weaker and better regions in human capital and innovation allows describing leaders and clusters of similar regions. The purpose is to select differentiated development tools in individual units to equalize their level to others. Development must include all entities and not have an island character (Kołodko, 2014; Jagódka, 2019; Jagódka, 2024).

Regional disparities in human capital and innovation performance are key determinants of socioeconomic development, particularly in emerging economies such as Poland. Despite extensive academic debate, relatively few studies have provided a comprehensive typology of Polish regions that integrates both human capital and innovativeness dimensions across a longitudinal timespan.

The integration of Poland into the European Union (EU) and the increasing emphasis on regional cohesion policies make it crucial to understand whether regional development processes are characterized by convergence or polarization. Such understanding is necessary for designing effective policy interventions aimed at supporting lagging regions and promoting balanced development.

This study aims to classify Polish regions based on selected indicators of human capital and innovativeness, using hierarchical (Ward's method) and nonhierarchical (k-means) clustering techniques over a period of 15 years. This study seeks to fill this gap by using a cluster analysis approach to classify Polish voivodeships [1] according to their human capital and innovation profiles over a longitudinal period, offering updated insights into the evolving patterns of regional disparities. The research specifically seeks to answer the following question:

- Q2. How do Polish regions differentiate in terms of human capital and innovativeness and to what extent do these differences contribute to regional polarization or integration?

Unlike prior studies (e.g. Jagódka and Snarska, 2021), it includes updated data and a combination of hierarchical and nonhierarchical clustering techniques.

This paper is structured as follows. Section 2 reviews the relevant theoretical and empirical literature on human capital, innovation and regional disparities. Section 3 describes the research methodology and data sources. Section 4 presents and discusses the findings from the cluster analysis. Section 5 concludes with policy recommendations and suggestions for future research.

2. Literature review

2.1 Theoretical foundations – human capital and innovations in regional growth models – growth through polarization or inclusion?

Innovation does not always bring positive social effects. Sometimes, it leads to increased social inequalities and excessive accumulation of human capital in big cities at the expense of economically weaker regions (Dmitriev *et al.*, 2016; Li and Pan, 2016; Zhu *et al.*, 2021).

Not all endogenous growth model assumptions are transferable to the regional level. There is a different relationship between human capital and economic growth rate in regions and the national economy. In the region, as opposed to the national economy, there is a greater degree of openness of borders, allowing free movement of production factors, especially workers with their human capital. They move between different areas within the same country. The degree of migration depends precisely on the level of human capital. The higher its quality, the greater the geographical mobility of an individual. A net inflow of human capital is in regions with higher wages offered ([Ritsilä and Ovaskainen, 2001](#)). It is associated with creating positive externalities resulting from population growth, knowledge inputs and labor productivity. In areas where there is an outflow of human capital, the opposite process can be observed, caused by the region's material losses due to the loss of educated people ([Faggian et al., 2019](#)).

Decentralized development combines the concept of endogenous and exogenous development, indicating the complementary actions of demand stimulation, public intervention and external factors. According to the theory of uneven development by [Hirschman \(1958\)](#), development processes in space do not proceed evenly. The mechanism of the economy of scale and agglomeration benefits enterprises in the most important centers and their surroundings. The author noted the psychological dimension of economic development, considering the local community's pro-development mentality as a critical factor in developing regions.

Friedman's core and periphery model is related to the theory of polarized income. According to this model, the concentration of development processes occurs in core (central) areas, manifesting a high capacity to attract, create and maintain appropriate human capital resources. Many authors point out that the level of real wages plays an important role ([Fujita et al., 1999](#)). In his work, Friedman treats as determinants of regional development and noneconomic factors – sociological, psychological and political the sphere is closely related to human activity. According to the author's view, the regions' processes result from human activities and social interactions. A higher development rate occurs in regions with a friendly environment for the absorption and diffusion of innovation. However, innovation is not possible without knowledge and human capital ([Friedmann, 1972](#)).

According to Myrdal's theory of cumulative causation (1957), areas with better development conditions, e.g. infrastructure or an adequate level of human capital, achieve a higher development rate. This is because growth is conditioned by positive changes and processes in the region. Simultaneously, stagnation results from negative changes that cause an effect, as described by Myrdal, of washing out resources from underdeveloped regions. This process contributes to the differentiation of development in space, which increases the disproportion between growth centers and peripheral areas.

The product life cycle theory describes the individual phases of development. From the point of view of human capital, it is worth explaining the specific dependencies described in this theory. The transition to the next phase occurs in the spatial concentration of production around a given product change, which often results in the gradual relocation of plants to regions with lower wage expectations of workers. Some authors consider the spatial division of labor theory to complement this concept ([Malizia and Feser, 1999](#); [Bajerski, 2013](#)).

Storper's theory of learning regions ([Storper, 1995](#)) assumes that the crucial stimulators of competitiveness of the regions are the population's interpersonal skills and cultural climate. Using them, we can distinguish creativity, knowledge, communication skills and the ability to learn, i.e. those factors that support the generation of novelty.

It is worth mentioning the triple helix theory of [Etzkowitz and Leydesdorff \(1998\)](#), which emphasizes the close role of human and social capital in regional development. The authors

emphasize the role of dialogue between key players concerning stimulating economic development. They also emphasize the benefits of cooperation between enterprises, universities, R&D units, business environment units and public administration (Etzkowitz and Leydesdorff, 1998; Etzkowitz and Zhou, 2018).

From the perspective of regional disparities, it is essential to highlight the developmental gap between rural and urban areas. Florida's (2002) concept of creative capital emphasizes the central role of cities in economic development, driven by the concentration of the "creative class" – a group comprising scientists, engineers, academics, designers and professionals in high-tech, legal and financial sectors. According to Florida, regional growth is driven by three interrelated factors: technology, talent and tolerance. These create favorable conditions for attracting and retaining human capital, particularly in urban centers.

This urban-centric concentration aligns with Porter's (1990) theory of industrial clusters, where geographic proximity of related firms fosters both competition and cooperation, enhancing productivity and innovation. Clustering not only strengthens labor markets but also contributes to the formation of "human capital clusters," particularly in metropolitan areas (Klaciak *et al.*, 2008; Bode and Villar, 2017). These clusters reflect the spatial concentration of creative and highly skilled labor, which plays a critical role in shaping regional competitiveness.

Jaźwiński (2017) argues that such human capital clusters are among the most decisive factors for regional socioeconomic development, as they reinforce innovation, trust and knowledge exchange. However, this process can also lead to polarization, with human capital increasingly concentrated in urban growth poles (Jagódka and Snarska, 2023a, 2023b). As innovation tends to flourish in cities, regional inequalities may intensify. While highly qualified workers benefit from urban amenities and labor market opportunities (Cooper and Florida, 2005), some low-skilled workers may also gain employment within the innovative ecosystem in supporting roles (David and Dorn, 2013).

2.2 Empirical evidence – Poland and other European countries

In the context of the EU, regional innovation capital varies significantly across member states and their subnational regions. This variation is influenced by a complex interplay of factors, including R&D investments, human capital, institutional quality and regional collaboration. Understanding these dynamics is essential for policymakers aiming to foster innovation and reduce regional disparities. Implementing initiatives based on networking, increasing R&D spending or enhancing digital competencies and those related to artificial intelligence are examples of strategies to increase regional innovation used by many countries, especially the EU in recent years (Grigorescu *et al.*, 2021; Noni *et al.*, 2018). Many studies are proving that investing in human capital and innovation can reduce regional disparities (Brodny and Tutak, 2024; Bürscher and Scherngell, 2024; Filippopoulos and Fotopoulos, 2022; Tijanic and Obadic, 2015; Zarębski *et al.*, 2022).

In the Polish context, regional disparities have been a persistent feature of the post-transition economy, with the Mazowieckie region, driven by the capital city of Warsaw, consistently outperforming peripheral eastern regions (Golejewska, 2013; Jagódka and Snarska, 2023a). Studies have highlighted how historical legacies, infrastructure deficiencies and limited access to higher education institutions have contributed to the persistent developmental gap between Western and Eastern Poland (Laskowska and Dańska-Borsiak, 2016). The developmental disparities seen in various Polish regions can be attributed in part to their historical and geographical backgrounds. Research focusing on the distribution of wealth, poverty levels, voting tendencies and ideological perspectives (whether conservative or liberal) has revealed a clear distinction between the more affluent Western Poland, often

referred to as Poland A and the less affluent Eastern Poland, labeled as Poland B. Factors such as the framework of democracy, the standard of education and the effectiveness of public institutions significantly influence the nation's progression. Unfortunately, due to the frailty of these elements, Poland fell into decline by the late 18th century, resulting in a loss of autonomy for 123 years (1795–1918) (Backhaus, 2019). The territories were occupied by three powers: Russia controlled Eastern Poland, Prussia dominated the West, and Austria–Hungary held sway over the South. The marks of this division remain visible today in the spatial variance of socioeconomic development and educational outcomes (Bukowski, 2019; Churski *et al.*, 2021; Grosfeld and Zhuravskaya, 2015). Moreover, the conflicts during the Second World War, along with the forced migrations that occurred during or after the conflict, had a particularly significant impact on Poland. For instance, the Western regions of the nation have seen a greater focus on investing in intangible resources like education, owing mainly to the influx of immigrants from the eastern territories known as Kresy Wschodnie (areas that Poland lost after the Second World War) (Becker *et al.*, 2020). Research frequently makes a distinction between the development experiences of both Western and Eastern Poland. Certain regions, such as Mazowieckie, have consistently shown impressive innovation rates, while several other areas, especially in the eastern sector of the country, struggle despite having similar amounts of human capital (Czyż and Hauke, 2011; Gorzelak, 2006; Gurgul and Łach, 2019; Opilowska, 2019; Wielki *et al.*, 2018). Beyond historical factors, structural causes of regional disparities include inadequate infrastructure, labor market segmentation, limited access to R&D facilities and the outmigration of highly skilled workers (brain drain) from peripheral regions. These systemic issues exacerbate the polarization dynamics observed in Poland and are consistent with broader patterns documented in Central and Eastern Europe (Pater and Lewandowska, 2015).

Several studies on EU regional policy effectiveness suggest that investment in human capital and innovation capacity can mitigate polarization trends by empowering lagging regions to participate in knowledge-based economic growth (Rodríguez-Pose and Wilkie, 2017). However, the success of such interventions depends on the absorptive capacities of regions and their institutional quality.

The role of the EU cohesion policy in addressing regional inequalities has been increasingly emphasized, particularly in the 2021–2027 programming period. The European Regional Development Fund and the Cohesion Fund prioritize investments in smart specialization, research and innovation, digital skills and human capital development, aiming to reduce territorial disparities and modernize economies (European Commission, 2020). These policy frameworks underscore the need for integrated strategies linking education, innovation support and regional economic planning. The Lisbon and Europe 2020 Strategies of Smart Growth emphasized the importance of balancing higher education and R&D priorities to improve regional productivity and facilitate catching up. Concepts such as regional innovation systems (RIS) have been explored to understand and foster innovation in different regional contexts, including less innovative or peripheral regions. These systems involve networks of firms, research institutions and universities, and their effectiveness can be compromised by institutional deficits such as low administrative quality (Bürscher and Scherngell, 2024).

Furthermore, the significance of knowledge absorption and innovation capability in driving technological change and economic growth in EU regions has been highlighted. Empirical studies suggest that absorptive capacity at the firm level is a major determinant of regional variations in innovation performance. Policies aimed at improving the quality of government and social capital have also been considered as drivers of regional diversification and innovation in Europe. Spatial econometric perspectives have explored

how features of regional knowledge bases, such as technological relatedness and complementarity among neighboring regions and those connected in R&D networks, can influence regional innovation and potentially reduce inequalities. Illustrative convergence scenarios suggest that increasing relatedness and complementarity can indeed have the potential to reduce disparities in European innovation capabilities. Despite significant EU funding aimed at modernizing the economy and developing human capital, which included substantial allocations to research and technological development, innovation, entrepreneurship and human capital, a fundamental shift toward significantly increased competitiveness and innovation has been slow (Lewandowska, 2016).

Recent empirical work on regional disparities increasingly advocates for the integration of qualitative factors, such as university-business collaboration and the quality of local governance, into the analysis of RIS (Bukhari *et al.*, 2021; Marra *et al.*, 2022; Noor *et al.*, 2023). The impact of human capital and innovation on economic growth in European regions demonstrated by many other authors (Fagerberg *et al.*, 1997; Golejewska, 2013; Buendía Azorín and Sánchez de la Vega, 2015; Laskowska and Dańska-Borsiak, 2016). However, the current study extends earlier research by Jagódka and Snarska (2021) by applying both hierarchical and nonhierarchical clustering techniques to updated data (2009–2023), which incorporates the effects of post-COVID dynamics. Nevertheless, robust, quantitative typifications of regions based on human capital and innovativeness remain relatively scarce, particularly in postsocialist countries like Poland. It contributes to the broader discourse on regional convergence and divergence in postsocialist economies.

3. Materials and methods

The data set used in the analysis covers the years 2009 to 2023 and includes regional-level indicators sourced from SP and Eurostat based on 11 variables describing human capital and 6 variables measuring innovation in Polish regions. The year 2009, as the beginning year of the study, has been established in consideration of data availability, as not all indicators were reported prior to this period. The 15-year period takes into account the first EU financial perspective (during 2009–2013), the second 2014–2021 and the post-COVID times. Selected indicators representing human capital include tertiary education attainment rates, economic activity rates and participation in lifelong learning programs. Innovation indicators comprise patent applications, R&D expenditure per capita and the share of enterprises engaging in innovative activities. These variables reflect a narrow definition of both human capital and innovation (see Tables 1 and 2).

The use of both hierarchical (Ward's method) and nonhierarchical (k-means) clustering techniques allows for cross-validation of results, ensuring the robustness of regional groupings. Ward's method provides an initial hierarchical structure, while k-means refines cluster membership based on minimizing within-cluster variance. Ward's method minimizes the total within-cluster variance at each step, producing a dendrogram that visually represents the agglomerative clustering process. The choice of Ward's method was motivated by its proven efficiency in creating clusters with relatively balanced sizes and high internal homogeneity (Everitt *et al.*, 2011). Following the hierarchical phase, the k-means clustering algorithm was applied to refine cluster membership based on the preliminary number of clusters suggested by the dendrogram analysis. The k-means method optimizes cluster allocation by minimizing the within-cluster sum of squares through iterative reassignment of observations (Kodinariya and Makwana, 2013). The use of k-means in combination with Ward's method serves to validate the cluster solution and ensure greater stability of results. The combination of hierarchical and k-means clustering offers several advantages. Hierarchical clustering provides a visual representation of the data structure,

Table 1. Human capital variables

X1	University students per 10,000 population
X2	Tertiary education graduates per 10,000 population
X3	Technical and natural science students to the total number of students
X4	Matriculation exam pass rate in relation to the national average
X5	Economic activity rates
X6	Registered unemployment
X7	Average monthly gross wages and salaries in relation to the national average (Poland = 100)
X8	Participation rate in education and training (past four weeks) by NUTS 2 region
X9	Life expectancy in health – men
X10	Life expectancy in health – women
X11	Older age dependency ratios

Source(s): Created by author

Table 2. List of innovativeness variables

Y1	R&D per capita
Y2	Share of net revenue from sales of innovative products in total net revenue from sales in the pretransformation period
Y3	Average share of innovative enterprises in the total number of enterprises
Y4	Share of net revenue from sales of products of entities classified as high and medium-high technology in net revenue from sales of products of entities classified in the section manufacturing
Y5	Patents granted by the Patent Office of the Republic of Poland per 100,000 inhabitants
Y6	Protection rights granted by the Patent Office of the Republic of Poland per 100,000 inhabitants

Source(s): Created by author

making it easier to identify the optimal number of clusters. K-means clustering, on the other hand, is computationally efficient and can handle large data sets. By using the hierarchical method to determine the number of clusters and then applying k-means to refine the cluster membership, researchers can achieve high-quality clustering results (Lee *et al.*, 2008).

Before the clustering analysis, multicollinearity between the variables was assessed using the Pearson correlation matrix. Variables exhibiting strong correlations ($r > 0.7$) were identified, indicating potential redundancy. Although some variables are moderately to strongly correlated, all were initially retained to preserve their interpretive value. The clustering results were reviewed for consistency, and the inclusion of correlated variables did not distort the overall classification.

Before clustering based on hierarchical and nonhierarchical methods, variables need to be normalized to bring them into a comparable form. The method used in the study to transform a destimulant into a stimulant for one variable (registered unemployment) was to multiply the original values by -1 . Normalization of the variables was carried out using standardization, which is expressed by the formula below:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{\sigma_j}, \quad (1)$$

where z_{ij} – standardized value of feature j for object i , x_{ij} – the actual value of feature j for object i (if the variable was previously transformed from a destimulant to a stimulant, the

transformed variable values are substituted for x_{ij} , $\bar{x}_j$ – mean value of variable j and σ_j – standard deviation of variable j .

The standardization ensures comparability across indicators and reduces bias in the clustering process.

3.1 *Methods of distinguishing voivodeships based on intangible assets: clustering based on hierarchical methods*

In the next stage of the procedure, the distances between groups of similar objects are determined, i.e. within provinces A and the newly formed cluster of provinces B. The paper uses the average merging, otherwise known as the average neighborhood method, where the distances are determined according to the formula:

$$d(A, B) = \frac{1}{|A| \cdot |B|} \sum_{a \in A} \sum_{b \in B} d_E(a, b), \quad (2)$$

Furthermore, Ward's method of minimizing the within-group variance:

$$d(A, B) = \frac{|C| + |B|}{|C| + |B| + |D|} d(C, B) + \frac{|D| + |B|}{|C| + |B| + |D|} d(D, B) - \frac{|B|}{|C| + |B| + |D|} d(C, D), \quad (3)$$

while attaching, that $|\cdot|$ is the number of objects in the class. Combining objects C and D creates a set A, and the entire dimension of the object space decreases by 1.

3.2 *Nonhierarchical grouping*

To determine the similarity of individual groups of voivodeships to the level of human capital development and innovativeness altogether, we used nonhierarchical groupings. The proximity of voivodeships was described using the Euclidean distance. The clusters around which the voivodships were grouped were additionally presented in the space of two dimensions, based on static indices of human capital and innovation in selected reference years. The criterion adopted is a natural division into voivodships with above average human capital and innovation, voivodships with average innovation and above average human capital, regions with above average innovation and average human capital and voivodships with below average human capital and innovation. It should be explained here that the adopted division is subjective, and depending on the adopted measure and method of representation, the delimitation of regions may look different. The typing procedure applied was the k-means algorithm, Euclidean measure and the furthest neighborhood method (Ahmad and Dey, 2007).

The goal is to minimize the total within-cluster variance, which is calculated using the following formula (Kassambara, 2017):

$$\text{tot.withinss} = \sum_{x_i \in C_k} (x_i - \mu_k)^2 \quad (4)$$

where:

tot.withinss – total within-cluster variance;

x_i – the value of variable X for an object belonging to cluster C_k ;

μ_k – the mean value of the variables for objects in cluster C_k ; and

k – the number of clusters.

In k-means methods, dividing voivodeships into a predetermined number of classes is carried out similarly to the hierarchical methods. The distinguished subgroups are corrected by moving some voivodeships to other classes to minimize intragroup variance in the next stage. The algorithm used is to ensure the similarity of objects within a single cluster with the maximum possible variation between clusters simultaneously. It is necessary to select the centers of classes. These so-called centroids are done after determining the number of classes, e.g. by randomly selecting classes, ensuring maximal distance of individual clusters. In a further procedure, objects are assigned to the nearest centroids so that a given province is closest to a given centroid. The similarity is determined by the square of the Euclidean distance of a given province from the class center. Then, new class centers are determined, whose coordinates are the arithmetic mean of the provinces belonging to the given cluster. These steps are repeated until the criterion of convergence is reached, i.e. the affiliation of voivodeships to the developed classes does not change (Jain, 2010; Ikotun *et al.*, 2023).

4. Results

The clustering of provinces into four clusters was conducted separately for indicators describing human capital and innovativeness. This analysis was performed for both the initial period (2009) and the final period (2023) to examine how cluster membership changed over time.

To enhance the objectivity of the results, both Ward's hierarchical method and the nonhierarchical k-means method were applied. Graphical results for Ward's method are presented in Figures 1–4, while the overall clustering results for human capital and innovativeness, based on both Ward's method and k-means clustering, are summarized in Tables 3 and 4 and Figures 5 and 6. Regions are grouped into four clusters using Ward's method. The x-axis represents the linkage distance between merged clusters. The connecting lines indicate groups of similar voivodeships. The smaller the boxes formed by these connections, the greater the similarity between the regions. The red line marks the cutoff point selected to distinguish four main regional clusters. The y-axis represents the positions of the 16 voivodeships within the cluster structure. The number assigned to each region corresponds to the identifiers provided in Tables 3 and 4.

Observing Figure 1 shows that in 2009, the highest human capital level was registered in the Mazowieckie voivodeship (nr 7 on the OY axis), likely due to the concentration of educational institutions, research centers and economic opportunities in Warsaw. Other voivodeships appear grouped into separate clusters, with some regions lagging significantly behind in human capital indicators. Opolskie (8), Podlaskie (10), Podkarpackie (9), Kujawsko-Pomorskie (2), Lubelskie (3) and Łódzkie (5) are in the same cluster. The highest level of human capital in the 2023 year is noted in the group consisting of four regions: Mazowieckie (7), Małopolskie (6), Pomorskie (11) and Dolnośląskie (1). These urban regions host major metropolitan centers such as Warsaw, Krakow, Gdansk and Wrocław. The East Poland regions remain in the same cluster: Kujawsko-Pomorskie, Lubelskie, Podkarpackie, Podlaskie and Świętokrzyskie (Figure 2).

As far as the similarity within innovativeness, some other than human capital clusters appeared in 2009. Mazowieckie (7) remains separate, showing its continued dominance in innovations, and then three other groups are formed (Figure 3).

In 2023 year, Mazowieckie became similar to Pomorskie within the innovation level. Podkarpackie shows similarity to regions Łódzkie and Wielkopolskie, which are generally better developed (Figure 4).

Ward's Method and k-means for the 2009 year produced similar classifications, with Mazowieckie consistently in the highest cluster. Other developed regions, such as

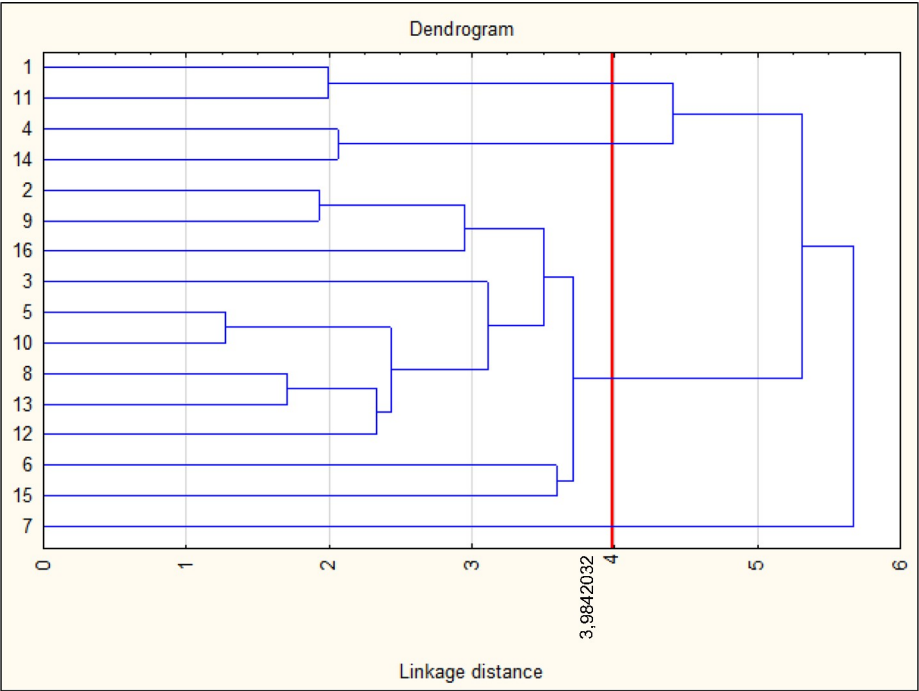


Figure 1. Similarities of voivodeships in terms of human capital in 2009 according to Ward algorithm
Source: Created by author in Statistica program

Małopolskie, Śląskie and Pomorskie, were also grouped similarly. Less developed voivodeships (e.g. Lubuskie, Świętokrzyskie and Podlaskie) were placed in lower clusters in both methods.

The overall cluster structure in the year 2023 remained stable, but some voivodeships changed groups, indicating slight shifts in human capital levels. Some inconsistencies between the methods appeared, particularly for Lubelskie, Łódzkie and Opolskie, which moved to different clusters depending on the method used. The main difference between Ward's and k-means was in borderline regions, where small variations in data affected cluster assignment.

Results from Ward's method and k-means are largely consistent, particularly in distinguishing leading and lagging regions. The biggest differences are seen in middle-tier voivodeships, which sometimes switch clusters depending on the method.

While Mazowieckie consistently ranks as the top-performing region in both Ward's and k-means clustering, regional disparities remain visible. The persistence of underperforming regions – such as Podlaskie, Lubuskie and Świętokrzyskie – across both methods highlights the structural nature of these inequalities. Only minor shifts in cluster membership occurred between 2009 and 2023, indicating limited regional mobility. The convergence of results across both techniques confirms the robustness of the findings and underscores the urgent need for differentiated, place-based policy interventions.

The cluster analysis revealed persistent and significant regional disparities in human capital and innovativeness across Polish voivodeships between 2009 and 2023. Based on

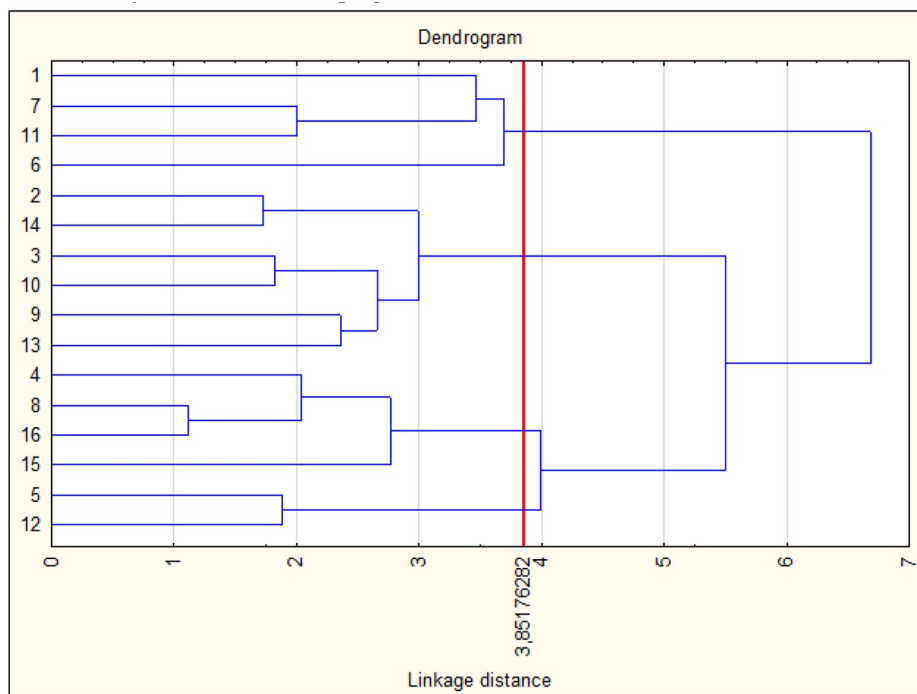


Figure 2. Similarities of voivodeships in terms of human capital in 2023 according to Ward algorithm
Source: Created by author in Statistica program

Ward's method and subsequently validated through k-means clustering, four distinct regional clusters were identified.

Over the 2009–2023 period, while some regions exhibited minor improvements, the overall clustering pattern remained relatively stable, suggesting entrenched developmental inequalities. The persistence of an East–West divide reflects not only historical legacies but also differences in investment attractiveness, public infrastructure development and participation in European funding programs. The results corroborate earlier findings (Jagódka and Snarska, 2023b; Golejewska, 2013) that identify Warsaw and western urban centers as growth poles, while eastern regions continue to struggle with innovation diffusion and human capital retention (Czyż and Hauke, 2011; Gorzelak, 2006; Gurgul and Łach, 2019; Opilowska, 2019; Wielki *et al.*, 2018). Furthermore, the analysis confirms the polarization effect: more developed regions increasingly attract skilled labor and investment, reinforcing their competitive advantage at the expense of peripheral areas.

In addition to structural factors, qualitative aspects such as the intensity of university-business collaboration, local governance quality and strategic utilization of EU Cohesion Funds likely contribute to regional disparities in innovation and human capital development.

Forced resettlement caused a shift in investment preferences from tangible to intangible goods. As a result of weak roots in the new territories and high uncertainty about the future, the Recovered Territories' immigrant population began to invest in children, just as the Jews had done for centuries (Becker *et al.*, 2020). It contributed to expanding human capital

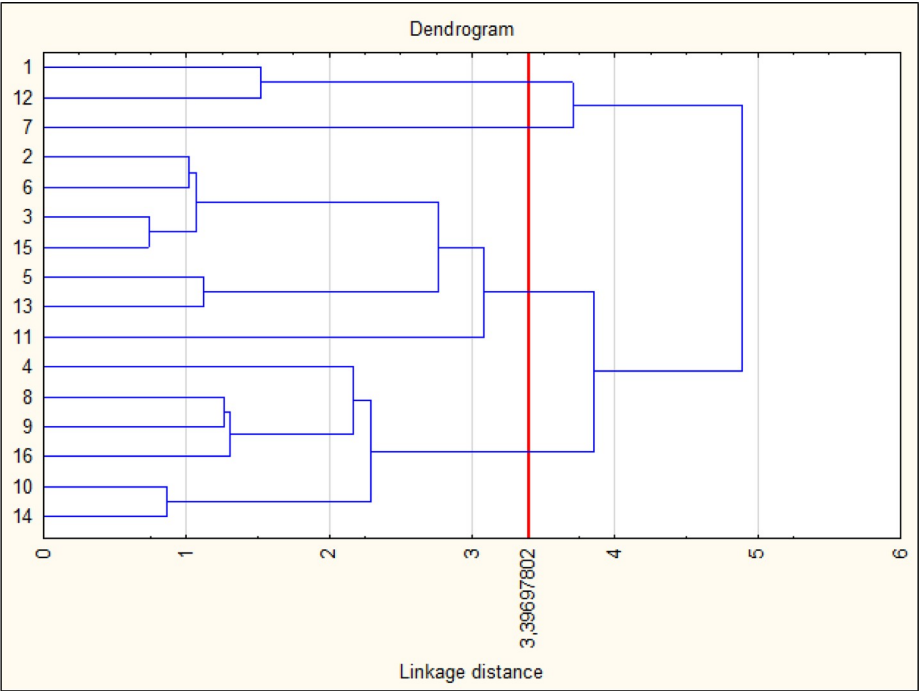


Figure 3. Similarities of voivodeships in terms of innovativeness in 2009, according to Ward algorithm
Source: Created by author in Statistica program

through education, as evidenced by the education indicators for these regions and the relatively high human capital and innovation indicators (Lower Silesian, Pomeranian and West Pomeranian). This finding supports the hypothesis about the correlation between human capital development and innovativeness again.

5. Discussion

5.1 Relating the results to previous studies

The results confirm theoretical expectations: persistent regional disparities align with [Myrdal's \(1957\)](#) theory of cumulative causation and [Friedman's \(1972\)](#) core-periphery model, where capital and talent concentrate in already advantaged areas like Mazowieckie. This supports the notion of increasing spatial divergence, in which strong regions grow stronger while weaker regions face stagnation. Cluster stability over time supports the idea of path dependency in regional development. Mazowieckie's dominance reflects the urban concentration predicted by [Florida \(2002\)](#) and the growth poles of [Perroux \(1950\)](#). Florida's theory of the creative class, where large urban centers concentrate high levels of talent, technology and tolerance. Second, the persistent lag of eastern regions such as Podkarpackie, Lubelskie and Podlaskie reflects the continued East–West developmental divide, described in terms of “Poland A vs. Poland B” (e.g. [Backhaus, 2019](#); [Bukowski, 2019](#); [Churski et al., 2021](#)). The clustering results reinforce the conclusions of [Laskowska and Dańska-Borsiak \(2016\)](#), who found that educational access and labor market indicators remain weaker in the eastern voivodeships, in part due to historical

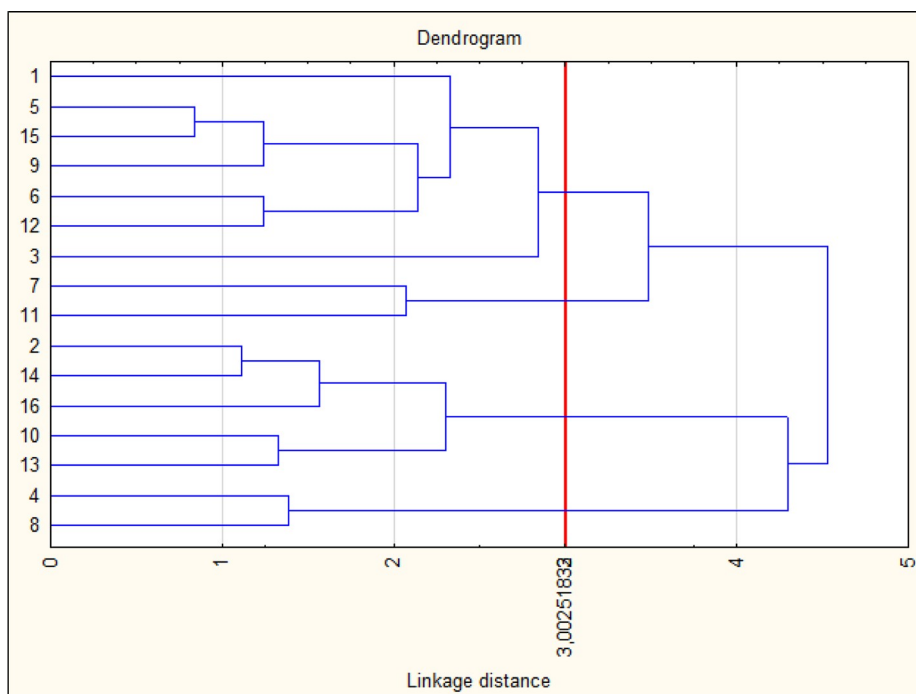


Figure 4. Similarities of voivodeships in terms of innovativeness in 2023 according to Ward algorithm
Source: Created by author in Statistica program

legacies. The presence of mid-tier clusters, where regions such as Śląskie, Wielkopolskie and Pomorskie occasionally shift positions depending on the method used, reflects transitional dynamics. This supports the hypothesis of [Pater and Lewandowska \(2015\)](#), who emphasized the role of institutional and infrastructural modernization in enabling regional mobility within innovation systems. These regions may also reflect the RIS model discussed by [Bukhari *et al.* \(2021\)](#) and [Bürscher and Scherngell \(2024\)](#) – regions with functional networks but differentiated performance due to varying administrative or coordination capacities. Finally, the results can be viewed in light of [Lewandowska \(2016\)](#) and [Filippopoulos and Fotopoulos \(2022\)](#), who argue that human capital and innovation do not automatically produce convergence unless they are embedded in cohesive, high-quality governance structures. The current clustering patterns imply that regional disparities in Poland are deeply rooted in structural conditions and require differentiated, place-based policy responses. The concentration of high-quality human capital in large urban centers confirms the process of brain drain, which disadvantages weaker regions ([Faggian *et al.*, 2019](#)).

5.2 Future policy directions

The policy should focus on tailored interventions: talent vouchers, innovation hubs and improved infrastructure. Results confirm theoretical expectations: persistent regional disparities align with core-periphery and cumulative causation theories. Regions like

Table 3. Summary of affiliation of Polish voivodeships to four individual clusters within human capital in 2009 and 2023 according to Ward’s and k-means methods

Voivodeship	Ordinal ID	2009		2023	
		Ward	k-means	Ward	k-means
		Cluster membership			
Dolnośląskie	1	1	3	1	1
Kujawsko-Pomorskie	2	2	4	2	3
Lubelskie	3	2	3	2	3
Lubuskie	4	3	4	3	4
Łódzkie	5	2	3	4	3
Małopolskie	6	2	2	1	2
Mazowieckie	7	4	1	1	2
Opolskie	8	2	3	3	4
Podkarpackie	9	2	4	2	3
Podlaskie	10	2	3	2	3
Pomorskie	11	1	3	1	2
Śląskie	12	2	2	4	3
Świętokrzyskie	13	2	3	2	3
Warmińsko-mazurskie	14	3	4	2	3
Wielkopolskie	15	2	2	3	4
Zachodniopomorskie	16	2	4	3	4

Source(s): Author’s own creation based on the results in Statistica

Table 4. Summary of affiliation of Polish voivodeships to four individual clusters within innovativeness in 2009 and 2023 according to Ward’s and k-means methods

Voivodeship	Ordinal ID	2009		2023	
		Ward	k-means	Ward	k-means
		Cluster membership			
Dolnośląskie	1	1	1	1	1
Kujawsko-Pomorskie	2	2	3	2	2
Lubelskie	3	2	4	1	2
Lubuskie	4	3	4	3	4
Łódzkie	5	2	4	1	2
Małopolskie	6	2	1	1	1
Mazowieckie	7	4	2	4	3
Opolskie	8	3	1	3	4
Podkarpackie	9	3	4	1	1
Podlaskie	10	3	4	2	2
Pomorskie	11	2	3	4	3
Śląskie	12	1	1	1	1
Świętokrzyskie	13	2	4	2	2
Warmińsko-mazurskie	14	3	3	2	2
Wielkopolskie	15	2	1	1	1
Zachodniopomorskie	16	3	4	2	2

Source(s): Author’s own creation based on the results in Statistica

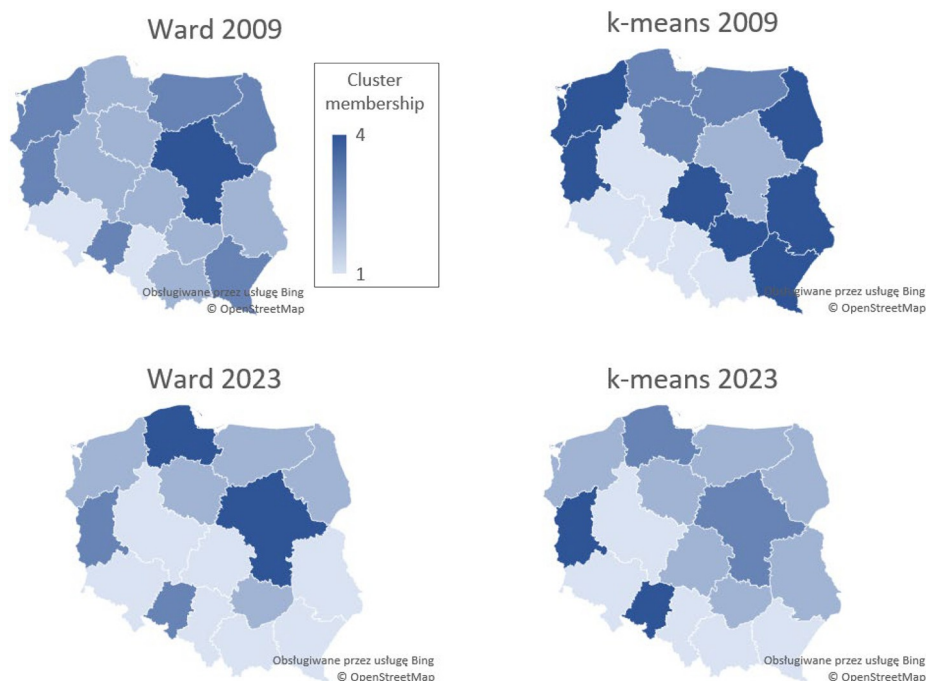


Figure 5. Classification of provinces by four clusters in terms of innovation status in 2009 and 2023 – k-means and Ward's method

Source: Author's own creation in Excel based on the results

Mazowieckie benefit from capital city effects, while eastern regions face ongoing disadvantages.

Polish regional inequalities are largely due to historical and cultural factors, which have been described by many researchers. History alone, however, does not explain everything. After the political transformation, many enterprises went bankrupt, which contributed to an exponential increase in unemployment and socioeconomic inequality. Admittedly, Poland experienced a big leap in higher education enrolment, but this was mainly a quantitative and qualitative change. The massification of higher education reduced its quality. Today, there is still a shortage of students in mathematics and science. The state and the regions should support the idea of “demand-driven” degrees, i.e. degrees that are relevant to the current and future labor market. The link between universities and business is also weak. Collaborative centers should be created, for example, by allowing companies to participate in creating a course of study and taking on students for placements (e.g. as part of dual degree programs). Because of current technological and digital megatrends, it is necessary to pay more attention to digital skills not only among students of formal education but also among adults, enabling them to adapt more quickly to new conditions in the labor market. Both digital competencies and those related to artificial intelligence are developed mainly in large urban centers with strong academic centers. There is also a need to focus on less developed regions. In addition, Poland unfortunately still invests little in R&D. First and foremost, companies need to increase their spending on this, as they are the biggest beneficiaries. A barrier, however, is the

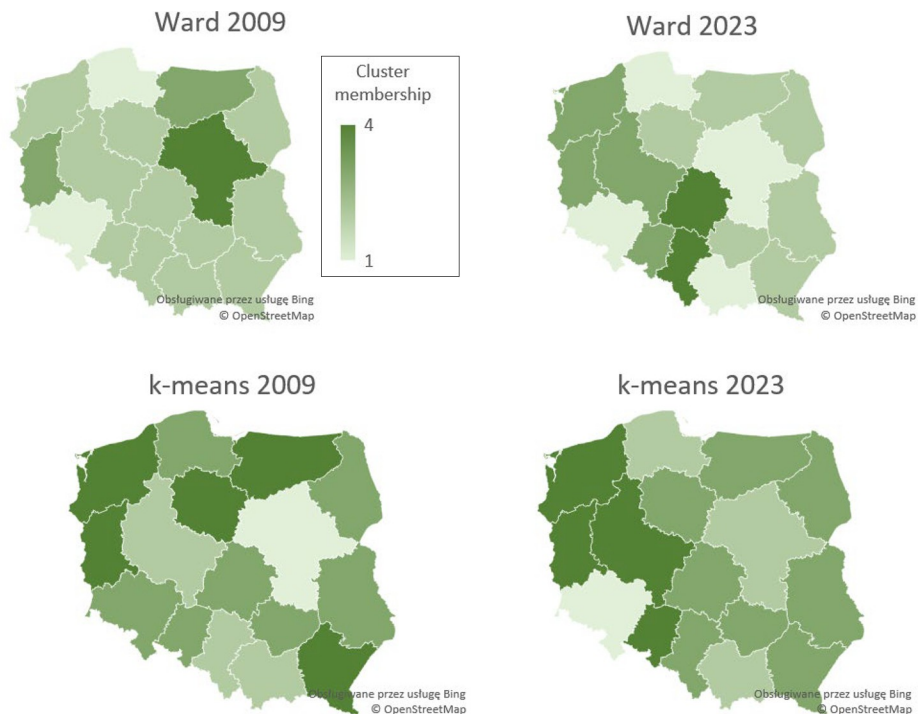


Figure 6. Classification of provinces by four clusters in terms of human capital status in 2009 and 2023 – k-means and Ward's method

Source: Author's own creation in Excel based on the results

high fragmentation of companies in Poland and the predominance of micro-, small- and medium-sized enterprises, which do not create the right critical mass to invest in R&D. Hence, the state must provide some incentives. For example, the possibility of deducting R&D expenses, the IP Box or the Estonian tax has been introduced. However, there is a lack of initiatives that will help accumulate the capital necessary for high-risk ventures. The Polish Development Fund was supposed to play such a role, but its functions have been significantly transformed as a result of the COVID-19 pandemic and the refocusing of its objectives on *ad hoc* assistance to enterprises. It is necessary to return to its original purpose. Regional policy must confront the brain drain. It might be worth thinking about financial vouchers for students graduating from university to take up employment in their place of origin. It may also be worthwhile to develop vocational and technical education, which has lost ground in the surge of interest in general secondary schools and universities. The working model is changing. An opportunity for lagging regions may be the development of remote working. We should work on legal solutions that will develop this model.

The lack of convergence contradicts EU cohesion goals and suggests the need for policy redesign. Support from the cohesion policy should be much greater, but this needs the agreement of the old EU countries. It should be emphasized that they, too, are beneficiaries of such support, as raising the standard of living of citizens in developing countries consequently expands developed countries' markets. The EU emphasizes innovation, smart

specialization and digital development. Research support programs such as Horizon Europe and Digital Europe have emerged. The evaluation of universities should take into account the successful application of such programs. A certain challenge of Polish regions in leveling regional disproportions is the system transformation, which requires uncommonly high resources. The EU should allocate more funds for this purpose, especially for the old EU countries. EU policies have partially mitigated disparities, but structural issues (e.g. weak university-business ties, small medium-sized Enterprise fragmentation and low R&D spending) persist. The policy should focus on tailored interventions: talent vouchers, innovation hubs and improved infrastructure.

A separate sphere of regulation is the protection of intellectual property. An entity that has taken on increased business risk must have adequate protection in the area of profiting from the sale of the products of its work. However, in the context of rapidly changing conditions and progressing processes of the fourth industrial revolution, the idea of intellectual property protection needs to be restructured. Indeed, it is economically inefficient for a large corporation to bombard the patent offices with a huge number of applications, patenting the smallest aspect of its activities. This restricts the access of certain groups of people to certain types of goods and services, which further encourages monopolization processes.

Regional disparities are the result, among other things, of differences in transport infrastructure (rail, road and motorway networks). It is immediately apparent that Poland's eastern regions have a lot of catching up to do in this area. Hence, projects such as the via Carpathian – a motorway running from the south to the north of the eastern provinces – should be considered appropriate. The new rail network as part of the central transport hub project may provide an opportunity to make up for the infrastructural differences of the more backward regions.

5.3 Limitations of the research

The clustering methods (Ward's hierarchical and k-means) are sensitive to the selection of initial parameters and distance metrics. Different methodological choices might yield slightly different results. The choice of four clusters is somewhat subjective; different numbers of clusters could lead to alternative classifications. The study is based on available statistical indicators, which may not fully capture the complexity of human capital and innovativeness. Some qualitative aspects, such as entrepreneurship culture or informal knowledge networks, are difficult to quantify. The study does not differentiate between sectors (e.g. high-tech vs low-tech industries), which could affect innovation patterns. Urban vs rural differences are not explicitly addressed, even though they play a crucial role in human capital accumulation and innovation diffusion. Taking the above constraints into consideration, future research should address the gaps and weaknesses of the current study.

6. Conclusions

This study examined the typology of Polish regions based on indicators of human capital and innovativeness using both Ward's hierarchical clustering and the k-means method over the period 2009–2023. The results consistently show persistent regional inequalities, with Mazowieckie maintaining its leading position, while eastern voivodeships such as Podlaskie, Lubelskie and Świętokrzyskie remain in the weakest clusters. The similarity of outcomes across both methods supports the robustness of the findings and highlights the structural nature of these disparities.

The results align with core-periphery models (Friedmann, 1972), cumulative causation (Myrdal, 1957) and the creative class theory (Florida, 2002), all of which suggest that economic advantages tend to reinforce themselves in already developed regions. Limited

changes in cluster positions over the 15 years reflect the inertia of regional development processes and the insufficient impact of cohesion policy to date.

The findings underscore the importance of systemic factors – including infrastructure quality, access to higher education, innovation ecosystems and historical legacies – in shaping regional trajectories. While historical accumulation of human capital plays a role, it does not fully determine future development. If it did, there would be no justification for policy intervention. Instead, well-designed public policy – especially smart specialization and support for endogenous growth factors – can mitigate divergence and support lagging regions.

From a policy perspective, the study highlights the urgent need for differentiated regional strategies. One-size-fits-all approaches have proven inadequate. Weaker regions would benefit from targeted support for innovation hubs, university-business cooperation, talent retention programs and digital skill development. Enhancing regional absorptive capacity is crucial to ensure the effective use of national and EU funds.

Additionally, the issue of economic emigration remains a significant concern. Although outmigration has slowed compared to the postaccession period, it still threatens the retention of human capital. Measures such as employment vouchers for returning migrants or partial reimbursement of public education costs in case of permanent emigration may warrant discussion – while preserving the principle of free movement.

This study contributes to the literature by offering a longitudinal, data-driven classification of Polish regions based on dual dimensions of development. However, it has limitations: it focuses solely on quantitative indicators and omits qualitative aspects such as governance quality, social capital or institutional effectiveness. It also does not account for sectoral differentiation or internal migration flows.

Future research should expand the analysis by incorporating qualitative variables – such as innovation networks, local governance and spatial planning quality – and by comparing regional dynamics across Central and Eastern European countries. Such an approach would help better understand how human capital and innovation interact in diverse institutional contexts. Further analysis of the drivers behind convergence or divergence would support more evidence-based policymaking.

In sum, regional inequalities in Poland remain pronounced and resistant to change. Addressing them requires both structural investment and a shift toward more adaptive, regionally tailored policy frameworks.

Note

1. Voivodships are administrative regions in POLAND (16 regions).

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