A SPATIAL ANALYSIS OF DEMOGRAPHIC AND CURRICULAR INFLUENCES ON SECONDARY EDUCATION IN SLOVAKIA

Marcela KÁČEROVÁ[A*], Slavomír ONDOŠ[B], Dagmar KUSENDOVÁ[C]

Received: October 11, 2024 | Revised: November 24, 2024 | Accepted: December 11, 2024
Paper No. 24-66/2-730

A* Comenius University in Bratislava, Bratislava, Slovakia
https://orcid.org/0000-0003-2423-8251, marcela.kacerova@uniba.sk (corresponding author)

B Creative Industry Košice, Košice , Slovakia
https://orcid.org/ 0000-0002-0847-1208, slavomir.ondos@cike.sk

C Comenius University in Bratislava, Bratislava, Slovakia
https://orcid.org/0000-0002-6040-9743, dagmar.kusendova@uniba.sk

Citation: KÁČEROVÁ, M., ONDOŠ, S., KUSENDOVÁ, D. 2024. A Spatial Analysis of Demographic and Curricular Influences on Secondary Education in Slovakia. *Folia Geographica* 66(2), 36-57.

Abstract
Regional disparities in secondary education present significant obstacles to equitable human capital development, particularly in areas where demographic decline and resource imbalances exacerbate the issue. This study examines the spatial and structural dynamics of secondary education enrollment in Slovakia, focusing on demographic and curricular factors. Using a random-effects spatial error model, we analyze panel data from districts over two decades (2003-2023). The model accounts for spatial interdependencies while addressing unobservable district-level heterogeneity. Specification tests confirm the model's validity, demonstrating strong spatial autocorrelation in outcomes but minimal residual dependencies. The results indicate that secondary school enrollment clusters around urban districts, which consistently outperform rural areas. Youth and population density are the strongest predictors of enrollment, while curricular specialization also plays a critical role. Technical and medical programs positively impact enrollment, whereas agricultural and artistic programs show weaker effects. Interestingly, a higher proportion of university-educated residents correlates negatively with secondary enrollment, likely reflecting talent migration from rural districts. The results highlight the geographical clustering of high-performing districts in proximity to urban areas, influenced by demographic benefits and educational programs tailored to meet labor market demands. In contrast, remote regions face persistent challenges tied to structural and demographic disadvantages. Addressing these disparities will require strategic investments in digital infrastructure, curriculum modernization, and demographic stabilization policies.

Key words
Demographic shifts, education dynamics, equity, human capital, regional disparities, secondary education, spatial econometrics**.**

INTRODUCTION

In an era of rapid technological progress and shifting demographic trends, education systems play an increasingly pivotal role in driving regional development. Human capital—defined as the skills, knowledge, and capabilities of individuals—has become a base of economic resilience and societal well-being. However, the spatial distribution of educational opportunities remains highly uneven, often mirroring and reinforcing existing socio-economic disparities. These challenges are particularly acute in countries where historical legacies, demographic shifts, and regional inequalities converge to shape the educational landscape. Slovakia's secondary education system operates amid significant demographic pressures, including a declining youth population and migration-driven urbanization. Over the past two decades, the proportion of young people aged 15–19 has declined sharply, with rural areas bearing the burden of these demographic shifts.

This demographic shift exacerbates challenges in peripheral regions, where educational institutions face difficulties maintaining viability and curricular offerings often fail to align with local labor market needs. These trends highlight the importance of understanding the geographic and structural dynamics of secondary education and their implications for regional development. The geographic dimension of education, frequently overlooked in traditional analyses, provides a valuable perspective for addressing these issues. Spatial education dynamics—including the distribution of schools, accessibility of educational opportunities, and the spatial clustering of outcomes—play a critical role in shaping human capital formation. High-performing regions benefit from concentrated resources and institutional networks, while disadvantaged areas are often trapped in cycles of underinvestment and depopulation. Examining the interplay between these spatial factors and human capital theory offers a robust framework for understanding how education systems can mitigate regional disparities and promote equitable development.

This study examines secondary education system within a broader theoretical framework, addressing two central questions. First, how do demographic and spatial factors shape the distribution and accessibility of secondary education across regions? Second, to what extent do curricular offerings align with regional economic needs, and how do specialized programs influence educational outcomes? These questions are particularly relevant as Slovakia continues its transition to a knowledge-based economy, where aligning education with labor market demands is essential for regional competitiveness. To explore these issues, the study employs a spatial econometric approach, using panel data on secondary school enrollment, demographic trends, and economic conditions across Slovakia's districts. A spatial autoregressive model is applied to account for both

local determinants and geographic interdependencies, offering deeper insights into the spatial and structural dynamics of secondary education.

By integrating theoretical insights on human capital and spatial education dynamics with empirical analysis, this research aims to advance both understanding and policy discussions on educational equity and regional development. The paper is structured as follows: the introduction is followed by a theoretical framework that explores the concepts of human capital, spatial education dynamics, and their implications for regional development. The methodological section details the spatial econometric approach employed in the analysis, leading to a results section that identifies key patterns and disparities in Slovakia's secondary education system. The discussion situates these findings within broader theoretical and policy contexts, offering recommendations to promote educational equity and strengthen regional resilience. This study addresses the specific challenges confronting Slovakia and contributes to the broader discourse on how education systems can reduce regional disparities amid demographic and economic transformations.

THEORETICAL FRAMEWORK

Human capital, development, and technological change

Human capital, encompassing the collective skills, knowledge, and abilities that drive economic productivity, has been a basis of regional development theory. Since its formalization in economic studies, the concept has evolved to include spatial dimensions, its integration with technological change, and its potential to address socio-economic inequalities. Piketty and Saez (2014) highlight the influence of wealth and human capital disparities on regional economic paths and their implications for development policies. More recently, Yang (2023) introduced the concept of human capital space, emphasizing its critical role in fostering dynamic capabilities within cities and regions. The foundational works of Becker (1964) and Schultz (1961) framed human capital as a determinant of both individual and societal economic outcomes, arguing that investments in education and training yield significant returns in productivity, earnings, and growth. Building on this foundation, Lucas (1988) highlighted the externalities of human capital, proposing that an educated workforce enhances individual productivity and generates spillover effects that benefit entire regions.

Contemporary scholarship has expanded and critiqued foundational theories of human capital. Sen (1997) reframed the concept beyond its economic utility, highlighting its role in enhancing individual freedoms and societal well-being. This perspective emphasizes equitable access to education as essential for addressing broader socio-economic inequalities. Recent research has highlighted the importance of the spatial distribution of human capital as a significant factor

contributing to regional disparities (Moretti, 2012). Areas with a higher density of educated individuals are more likely to draw investment, promote innovation, and exhibit enhanced economic resilience. In contrast, regions with low human capital often experience stagnation and depopulation, perpetuating cycles of underdevelopment (Rodríguez-Pose and Tselios, 2011; Strielkowski et al., 2013). Glaeser et al. (2011) argue that cities function as talent magnets, facilitating knowledge exchange and innovation. This dynamic is further reinforced by Florida's (2002) creative class thesis, which proposes that regions attracting skilled and creative workers are more likely to thrive in the knowledge economy. Additionally, Bowles et al. (2001) highlight the importance of non-cognitive skills and personality traits in enhancing the economic returns of human capital, reshaping traditional understandings of education and productivity.

Agglomeration effects, while fostering growth in urban centers, can exacerbate regional inequalities by concentrating resources and opportunities in cities at the expense of rural areas. Peripheral regions often face human capital traps, where limited educational and economic prospects drive young, educated individuals to migrate in search of better opportunities (Bahna, 2013). This phenomenon erodes the socio-economic fabric of these regions and hinders their recovery from economic downturns (Novotný, 2016). Recent studies (Barzotto, 2024) emphasize the need for policy interventions to retain talent in lagging regions, such as improving local education systems and aligning curricula with regional labor market demands. Another line of research explores the spatial mismatch between human capital and labor market demand. Sutton (2017) highlights that regions with an oversupply of educated individuals but insufficient job opportunities face underemployment, diminishing the returns on human capital investments. This issue is particularly acute in Slovakia, where regional disparities in industrial structure and economic activity limit the effective use of local talent. Rodríguez-Pose (2018) contends that areas labeled as "places that don't matter" frequently face economic stagnation and political instability, highlighting the necessity for human capital development strategies that are specifically tailored to these regions.

The advent of Industry 4.0 has fundamentally altered the nature of work and the skills required in the labor market. Automation, digitalization, and artificial intelligence are reshaping industries, increasing demand for high-skilled labor while reducing opportunities for low-skilled workers (Grenčíková et al., 2021; Mocák et al., 2022). This shift has significant implications for regional development, as areas with inadequate educational infrastructure struggle to keep pace with these changes. Technological advancements have led to skill polarization, with high-skilled jobs on the rise and middle-skilled jobs declining (Popjaková and Mintálová, 2019; Nurković, 2020). Kovács and Domonkos (2024) argue that this trend exacerbates regional inequalities, as urban centers are better equipped to

provide advanced training and attract high-skilled industries, leaving rural regions further behind. In response to these challenges, policymakers have stressed the importance of lifelong learning and reskilling programs to prepare workers for the evolving labor market. Rusnák et al. (2024) suggest that aligning the supply of secondary vocational graduates with labor market demands, particularly through an industrial structure of related variety, is essential for addressing skill gaps. Grenčíková et al. (2021) highlight that regions investing in continuous education and training exhibit higher adaptability and economic resilience, making such programs a critical element of regional development strategies. Additionally, Autor and Salomons (2018) provide evidence that while automation displaces certain job segments, it has also contributed to net employment growth in other sectors.

Demographic transitions and education dynamics

Demographic trends, such as aging populations and declining birth rates, present significant challenges to the sustainability of human capital. Auerbach and Lee (2010) stress that regions facing population decline must focus on the efficient allocation of educational resources to maximize the potential of a shrinking youth cohort. In Slovakia, the demographic changes have highlighted the necessity for focused initiatives aimed at tackling regional inequalities in both educational access and quality (Szabo and Bleha, 2018). Migration patterns play a crucial role in shaping the spatial distribution of human capital. While urban centers benefit from an influx of young, educated individuals, rural areas often face depopulation and workforce shortages. Bahna (2013) observes that international migration exacerbates these challenges, as highly skilled Slovaks seek opportunities abroad, leaving a gap in the local talent pool. Rees et al. (2016) highlight how internal migration influences regional population distributions, shaping the availability and accessibility of educational resources.

Emerging research also highlights the role of gender in shaping human capital dynamics. Vidyattama et al. (2019) contend that addressing gender disparities in education and labor market participation can unlock untapped potential, fostering regional growth. Klasen and Lamanna (2009) emphasize that reducing gender disparities in education and employment yields substantial positive effects on both economic growth and regional equity. In Slovakia, policies promoting gender equity in education and employment could play a key role in reducing regional disparities. Demographic trends significantly influence the demand for and supply of education. Over the past two decades, Slovakia has seen a decline in its youth population, shifting public policy from expansion to consolidation in the education sector (Auerbach and Lee, 2010). However, this transition has not been uniform across regions, leading to divergent educational outcomes. Theories of educational

equity assert that equal access to quality education is crucial for reducing regional disparities and promoting socio-economic mobility (Brown et al., 2013). Factors such as population density, age distribution, and migration patterns affect the spatial distribution of educational resources (Gibbons and Vignoles, 2012).

The historical legacy of centralized education under socialism has resulted in an uneven distribution of secondary schools, particularly in rural areas. While post-1990s decentralization efforts aimed to address these imbalances, they have not fully mitigated regional inequalities (Haratyak, 2013; Luczaj and Bahna, 2018). The spatial dynamics of education systems include the geographic distribution of institutions, access to quality education, and the outcomes these factors generate. These dynamics are shaped by socio-economic, political, and cultural influences, often reflecting and reinforcing broader regional inequalities (Katrňák et al., 2006; Baláž, 2007). Theoretical progress in the field of spatial education research highlights the significance of geographic location, spatial clustering, and the distinctions between urban and rural areas in influencing educational accessibility and its effects on regional development. Chetty et al. (2014) demonstrate how geographic disparities in intergenerational mobility are linked to differences in educational quality and accessibility, highlighting the critical role of equity in promoting social advancement.

Initial research on population migration, conducted by Ravenstein (1889), highlighted the significance of resource accessibility. This idea was subsequently broadened by social geographers to encompass the role of education, as noted by Gibbons and Vignoles (2012). These early theories illustrate the impact of geographical distance and regional infrastructure on educational success. Proximity to schools plays a crucial role in enrollment rates and educational outcomes, especially in rural areas, where limited infrastructure often requires students to travel long distances. Studies (Novotný, 2015) show a strong correlation between proximity to secondary schools and higher enrollment, particularly among low-income households unable to afford private transportation. Recent research, incorporating network theory, examines the interconnections between institutions, communities, and labor markets. This approach reveals that clusters of schools in urban areas create competitive advantages through resource sharing and collaboration, often disadvantaging isolated rural schools (Sykes and Kuyper, 2013).

Table 1: The population variation in the various regions of Slovakia among individuals aged 15-19.

Region	Year	Population		Population change (%)	
		Total (Th.)	15-19 (%)	Total	15-19
Bratislava	2003	599.8	7.5	2.6	-44.0
	2013	615.5	4.1	18.7	21.1
	2023	730.6	4.2	-	-
Trnava	2003	551.3	7.7	1.0	-30.4
	2013	557.1	5.3	1.6	-14.0
	2023	565.8	4.5	-	-
Trenčín	2003	602.7	7.9	-1.6	-33.1
	2013	592.8	5.4	-3.9	-21.4
	2023	569.4	4.4	-	-
Nitra	2003	710.1	7.6	-3.2	-31.6
	2013	687.5	5.4	-2.6	-18.5
	2023	669.5	4.5	-	-
Žilina	2003	693.2	8.2	-0.4	-24.2
	2013	690.3	6.2	-0.4	-19.3
	2023	687.6	5.1	-	-
Banská Bystrica	2003	659.4	7.9	-0.3	-28.7
	2013	657.7	5.6	-6.3	-17.7
	2023	616.1	5.0	-	-
Prešov	2003	794.0	8.8	3.0	-18.5
	2013	818.1	6.9	-1.2	-17.8
	2023	808.5	5.8	-	-
Košice	2003	768.4	8.3	3.4	-22.6
	2013	794.4	6.2	-1.9	-10.3
	2023	779.3	5.7	-	-

The data presented includes the total population figures and the percentage of individuals within the 15-19 age group in each region for the years 2003, 2013, and 2023. This information offers insights into the changes in demographics and the patterns of population increase or decrease witnessed in diverse regions.

Source: Statistical Office of the Slovak Republic (2024a).

Patterns of educational inequality

Educational inequality is often embedded in spatial patterns, reflecting broader socio-economic disparities. These patterns are shaped by factors such as urbanization, regional economic structures, and the historical legacies of policy decisions (Allmendinger, 1989; Douglass, 2010; Brown et al., 2013). Mouw and Kalleberg (2010) explore the structural shifts in the labor market, linking wage

inequality to the evolving educational demands of occupations. Urban centers tend to offer better access to quality education due to higher population densities and more favorable resource allocation. In contrast, rural areas face challenges like teacher shortages, outdated infrastructure, and limited curricular offerings (Mussida et al., 2019). These disparities are particularly pronounced in post-socialist countries, where the transition to market economies disrupted centralized education systems. Spatial segregation in education occurs when socio-economic factors lead to the concentration of disadvantaged or advantaged populations in specific areas. This clustering perpetuates inequality, as schools in wealthier regions benefit from better funding and parental involvement, while schools in poorer areas struggle with resource deficits (Rodríguez-Pose and Tselios, 2011).

Regions experiencing demographic decline often face the consolidation of schools and reduced curricular diversity, further marginalizing students in these areas. Szabo and Bleha (2018) highlight that rural regions are especially vulnerable, as declining youth populations undermine the viability of local schools. Research shows that high-performing schools tend to cluster in urban or economically prosperous areas, creating hubs of educational excellence (Florida et al., 2008). This clustering is tied to broader socio-economic advantages, such as access to skilled teachers, modern facilities, and extracurricular opportunities. Feedback loops between educational outcomes and regional development intensify these disparities. For example, regions with high-performing schools attract families seeking better education, which increases local tax revenues and further enhances school funding (Glaeser et al., 2011). In contrast, low-performing regions are trapped in cycles of depopulation and underinvestment, perpetuating educational disadvantage. The concentration of institutions in cities enables resource sharing, professional development for teachers, and collaboration with industries (Michaels and Stevick, 2009).

However, rapid urbanization can lead to overcrowded schools, competition for resources, and socio-economic segregation. Studies in Slovakia (Pazúr et al., 2017) show that while Bratislava benefits from urban growth, neighboring regions often face negative spillover effects, such as rising housing costs that limit access to urban schools. Effective policy interventions are crucial for addressing spatial disparities in education. International case studies offer valuable lessons in tackling these challenges. While decentralization enables greater local control, it can exacerbate regional inequalities if resources are distributed unevenly. The shift to decentralized education governance has benefited urban centers but left rural areas at a disadvantage. Balancing local autonomy with centralized support is essential for achieving equitable outcomes. Investments in rural education infrastructure, teacher training, and technology are key to bridging the urban-rural divide. For example, Finland's education system prioritizes equity by allocating resources to underserved regions, offering a model to follow (Silliman and Virtanen, 2019).

DATA AND METHODS

This research utilizes a dataset containing the annual count of students enrolled in daytime programs at secondary schools in Slovakia. The data is aggregated at the district level (79 districts) for three-time intervals: 2003, 2013, and 2023. These intervals correspond to the consistent territorial-administrative divisions established in 1996. In addition to student enrollment data, we extract key information on the number of secondary schools, which is crucial for assessing the competitive landscape among educational institutions within each district. The competition is primarily influenced by public stakeholders and self-governing regions, though private entities and church organizations are also becoming more prominent. To facilitate comparisons across districts and time periods, we normalize the data by calculating the number of students and schools per one thousand residents. This approach accounts for demographic changes, offering a clearer understanding of regional educational dynamics.

Within each district, we also calculate the proportion of specialized study programs, which cover areas such as the arts, agricultural sciences, technical sciences, security and military sciences, and medical sciences, alongside the dominant general education. However, practical specializations are often criticized by employers in the context of regional development, particularly in less developed areas. Graduates without specific, regionally applicable skills often pursue higher education outside their home regions and do not return, leading to a depletion of valuable labor resources in local economies. For our statistical model, we use a population framework based on age, with a particular focus on individuals aged 15 to 19. This age group is the primary driver of secondary school demand, with few exceptions. Therefore, our analysis centers on this demographic, examining how the distribution and specialization of secondary education align with the economic needs of different regions.

To further enhance our analysis, we incorporate the population density of these regions. This distinction between densely and sparsely populated areas is crucial as it allows for comparisons between large cities and their surrounding residential zones. In densely populated urban areas, such as the capital and regional centers, demand for education tends to be higher due to the concentration of the population. Conversely, in less densely populated peripheral areas, demand may be lower due to a smaller population, limiting the benefits of economies of scale. To improve the accuracy of our analysis, we replace the overall unemployment rate with a targeted unemployment rate focusing on individuals aged 15-24. This demographic includes those who have completed high school but choose not to pursue further education, often staying in their regions due to various constraints. In contrast, older individuals may relocate in search of employment opportunities, particularly in economically disadvantaged areas.

A key component of our model is measuring the proportion of university graduates in each district, based on census data from 2001, 2011, and 2021. This data helps us understand the educational level within a region, which impacts both local economic development and the labor market's ability to absorb high school graduates. It also reflects the structure of the local economy and influences the academic ambitions of secondary school students. Our analysis further incorporates regional economic data, organized into four sectors: primary (agriculture, forestry, and fishing), secondary (manufacturing, construction), creative (information, scientific, technical, and artistic services), and service (other service sectors). This classification allows us to examine how each sector influences educational outcomes and the local labor market, providing a clearer picture of how economic specialization affects educational needs and the alignment between educational outputs and regional labor market demands.

Econometric panel approach with spatial effects

This study uses a spatial econometric panel data framework to analyze secondary school enrollment in Slovakia's districts over two decades, considering spatial dependencies and unobservable district-level heterogeneity. The spatial error model (Millo and Piras, 2012) is well-suited to contexts with significant regional spillovers, capturing both spatial and temporal dimensions. The general model specification is as follows:

$$y = \lambda(I\mathrm{T} \otimes \mathrm{WN})y + X\beta + u$$
$$u = \lambda(\iota\mathrm{T} \otimes I\mathrm{N})\mu + \varepsilon$$
$$\varepsilon = \rho(I\mathrm{T} \otimes W\mathrm{N})\varepsilon + \nu$$

where y represents the dependent variable (secondary school enrollment per 1,000 residents), X includes the explanatory variables (e.g., demographic factors, curricular specializations, and economic conditions), WN is the spatial weight matrix capturing inter-district interactions, and u denotes unobservable effects. The parameters λ (lambda) and ρ (rho) represent spatial autocorrelation in the dependent variable and residuals, respectively. The spatial weight matrix, based on contiguity, assumes interactions between neighboring districts. The random effects spatial error model explicitly incorporates error correlation across districts, addressing spatial dependence and unobservable district-level characteristics. Additional parameter ϕ (phi) quantifies spatial autocorrelation in enrollment outcomes, while ρ (rho) captures the spatial dependence in residuals. By addressing these dependencies, the model reduces bias and enhances the efficiency of estimates.

To ensure the robustness and validity of our model, we performed specification tests. Lagrange Multiplier (LM) tests revealed significant spatial dependencies.

The LM1 test highlighted strong spatial lag dependence, while the LM2 test identified spatial error dependence. The conditional test for spatial error (CLMμ) confirmed significant error dependence, supporting the inclusion of spatial effects in the residuals. On the other hand, the conditional test for spatial lag (CLMλ) was insignificant, suggesting that spatial lag dependence is adequately captured without adding complexity. The Hausman test validated the use of the random effects specification, indicating that it yields consistent and efficient estimates in contrast to the fixed effects models employed in the initial experiments of this research. This finding strengthens the model's capacity to manage unobserved heterogeneity while preserving simplicity.

Table 2: The distribution of secondary school students in Slovakia.

Variable	Description	Mean level		
		2003	2013	2023
Students	The district's secondary school student population per thousand residents.	58.6	40.2	34.5
Demand side:				
Age 15-19	The percentage of individuals aged 15-19 years in the overall population of the district.	8.0	5.8	5.0
Density	The density of the population in the district, measured as the number of inhabitants per square kilometer.	259.0	252.8	267.5
University	The proportion of individuals with university degrees in the population of the district.	7.3	13.2	17.3
Unemployment	The percentage of individuals aged 15-24 who are registered as job seekers at employment offices, relative to the overall population.	11.2	10.5	4.1
Regional economy				
Sector I	The proportion of the primary sector's contribution to the overall value added in the economic output of the region.	2.4	3.0	2.9
Sector II	The percentage of the industrial sector and construction industry's impact on the region's total value added.	35.5	33.7	34.6
Sector III (Ref.)	The portion of the service sector's involvement in the economic output value of the region.	50.0	46.8	47.2
Sector IV	The allocation of the creative sector's value added to the region's economic production.	12.2	16.5	15.3
Supply side:				
Competition	Mean number of high schools per one thousand residents in the region.	0.2	0.1	0.1

Variable	Description	Mean level		
		2003	2013	2023
Fields of specialisation (%)				
Social (Ref.)	Proportion of students enrolled in broad academic programs as well as in social sciences and humanities.	58.6	63.8	57.9
Artistic	Percentage of students pursuing cultural and artistic studies.	2.1	3.4	3.2
Agricultural	Distribution of students studying agricultural sciences.	5.9	3.4	4.5
Technical	Ratio of students enrolled in technical programs.	31.4	27.1	30.6
Military	Proportion of students pursuing security and military studies.	0.0	0.0	0.5
Medical	Share of students in health and nursing programs.	1.9	2.1	3.3

The table outlines the breakdown for the years 2003, 2013, and 2023. The data is segmented based on educational fields, with explanatory variables representing various factors such as demographics, social aspects, and economic conditions that influence the demand side in statistical analysis.

Source: Slovak Centre of Scientific and Technical Information (2024), Statistical Office of the Slovak Republic (2024a-e)

RESULTS

The random effects spatial error model incorporates two key spatial parameters. The parameter which measures spatial autocorrelation in the dependent variable, is significant, indicating that districts with higher secondary school enrollments tend to cluster spatially. This suggests the presence of regional spillover effects, where high-performing districts influence their neighboring areas, likely due to shared socioeconomic advantages or policy networks. In contrast, spatial dependence in the residuals is insignificant, indicating that once observable factors are accounted for, unobserved spatial correlation in the error terms diminishes. The significance pattern reinforces the robustness of the model, highlighting that regional disparities in educational outcomes are more driven by structural and demographic factors than by unaccounted latent spatial dynamics. This finding supports the model's ability to capture observable regional patterns while minimizing bias from spatial heterogeneity.

This discovery highlights the necessity for specific regional policies that tackle structural inequalities, as opposed to depending on generalized interventions. Table 4 presents the estimated coefficients for demographic, economic, and curricular predictors of secondary school enrollment. As expected, the proportion of youth aged 15-19 and population density emerge as strong positive predictors,

highlighting the importance of demographic and geographic factors. Districts with a higher concentration of youth and greater population density show higher enrollment rates due to economies of scale and better access to educational resources. Conversely, the proportion of university-educated residents negatively correlates with secondary school enrollment, suggesting that districts with higher educational attainment may face talent outmigration or shifts toward higher education pathways outside the region. This trend reflects concerns about rural-to-urban migration or outflow to foreign countries, further deepening regional disparities.

The results confirm that technical and medical specializations are positively associated with secondary school enrollment, reflecting their alignment with labor market demands and the growing emphasis on Industry 4.0 skills. Technical programs, in particular, exhibit the highest marginal effect among curricular tracks, emphasizing their significance for regional economic development. In contrast, agricultural and artistic programs show weaker or insignificant associations, suggesting potential mismatches with contemporary economic needs or limited student interest. These findings underline the need to tailor curricular offerings to

Table 3: Lagrange Multiplier and Hausman tests for spatial linkages and model specification

	Statistic	p	Interpretation
Lagrange Multiplier tests			
LMH	50.346	0.000	Strong evidence of spatial autocorrelation in both the lagged dependent variable and spatial error.
LM1	6.234	0.000	Strong evidence of spatial lag dependence.
LM2	3.388	0.001	Strong evidence of spatial error dependence.
CLMλ	0.005	0.996	No evidence of spatial lag dependence in the random effects model.
CLMμ	6.939	0.000	Strong evidence of spatial error dependence in the random effects model.
Hausman tests			
Lag	2.381	0.999	Random effects model is more efficient for the spatial lag model.
Error	9.117	0.764	Random effects model is more efficient for the spatial error model.
SARAR	18.237	0.149	Random effects model is more efficient for the SARAR model.

This table presents the results of tests used to evaluate geographic linkages and the appropriateness of the random effects spatial error model. The tests reveal significant spatial error dependence and validate the efficiency of the random effects specification over fixed effects models for both spatial lag and spatial error formulations.

regional economic structures. For instance, modernizing agricultural programs to incorporate sustainability and advanced technologies could enhance their appeal and relevance, particularly in rural areas. The choice of a random effects spatial error model effectively captures the interplay between local and regional factors, offering insights into how these influences shape educational outcomes across districts.

By accommodating district-specific effects and recognizing spatial spillovers, this model highlights the importance of localized interventions tailored to both demographic and economic contexts. Economically, the clustering of high-performing districts around urban centers reflects broader agglomeration patterns, where concentrated resources and institutional networks drive superior educational outcomes. In contrast, peripheral districts face challenges linked to demographic decline and economic underdevelopment, as evidenced by weaker enrollment figures and the limited impact of certain specializations. The absence of significant residual spatial correlation further suggests that disparities are

Table 4: Estimated coefficients from the random effects spatial error model on secondary school enrollment.

	Estimate	SE	t	p
Phi (ϕ)	5.467	1.671	3.271	0.001
Rho (ρ)	-0.038	0.174	-0.216	0.829
Intercept	1.949	0.543	3.588	0.000
Age 15-19	0.307	0.083	3.699	0.000
Density	0.212	0.038	5.620	0.000
University	-0.204	0.054	-3.810	0.000
Unemployment	0.019	0.022	0.848	0.396
Sector I	0.008	0.041	0.198	0.843
Sector II	0.041	0.107	0.378	0.705
Sector IV	0.158	0.088	1.799	0.072
Competition	0.540	0.042	12.854	0.000
Artistic	0.026	0.021	1.236	0.217
Agricultural	-0.000	0.014	-0.006	0.995
Technical	0.134	0.025	5.273	0.000
Military	0.025	0.030	0.823	0.411
Medical	0.105	0.027	3.924	0.000

This table presents the estimated coefficients from the random effects spatial error model analyzing secondary school enrollment. Key predictors include demographic, economic, and curricular factors, with spatial autocorrelation (ϕ) significantly influencing enrollment outcomes, while residual spatial dependence (ρ) is found to be negligible.

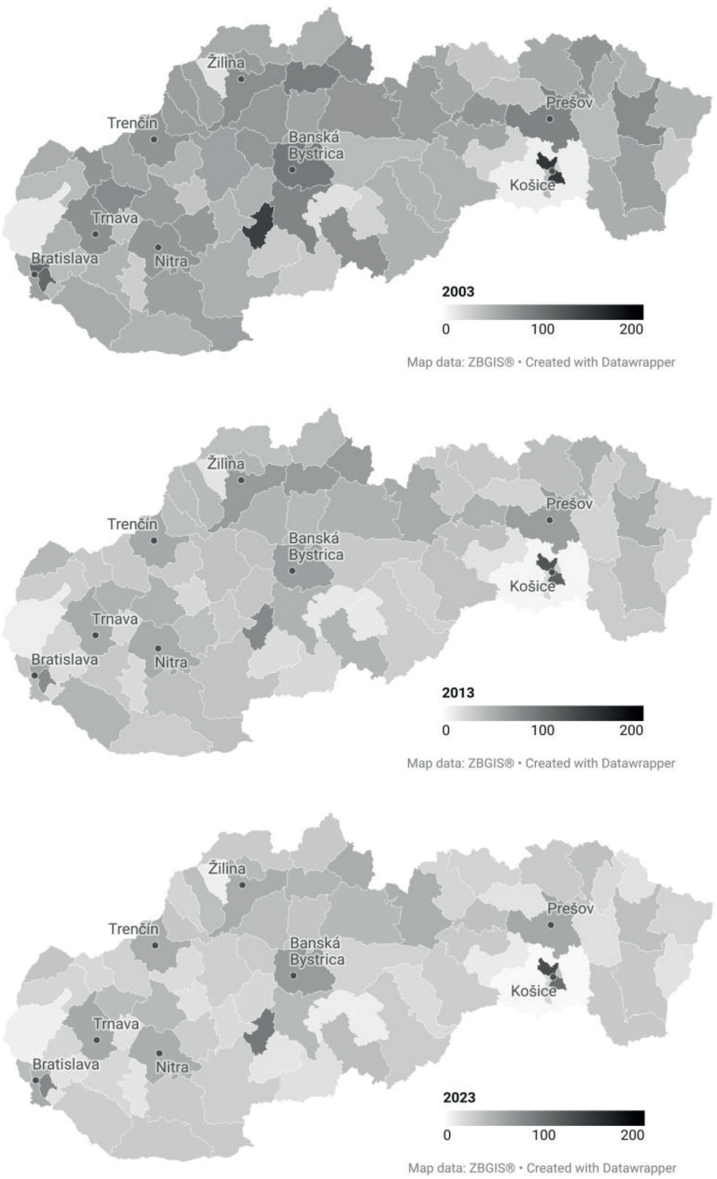

Figure 1: Spatial distribution of secondary school enrollment across Slovak districts (2003-2023)

This figure illustrates the spatial distribution of secondary school enrollment, highlighting a decline in the effectiveness of the education sector and an increasing divide, particularly between urban and rural areas. This trend poses a long-term challenge for regional development across various districts.

Source: Slovak Center of Scientific and Technical Information (2024), Geodetic and Cartographic Institute Bratislava (2024)

primarily driven by observable structural inequalities rather than unmeasured spatial dynamics. This finding emphasizes the need for targeted investments in underperforming districts, such as improving infrastructure, expanding technical and medical programs, and fostering partnerships with local industries to better align educational offerings with regional economic needs.

DISCUSSION

The findings of this study provide insights into the spatial and demographic dynamics of Slovakia's secondary education system, highlighting regional inequalities that reflect broader socio-economic trends. The spatial clustering of high-performing districts, particularly around urban centers like Bratislava, demonstrates the role of resource concentration and institutional networks in fostering educational success. This observation aligns with Glaeser et al. (2011) and Florida et al. (2008), who emphasize the self-reinforcing advantages of urban areas in attracting talent and generating economic resilience. In contrast, rural and peripheral districts continue to grapple with demographic decline and underinvestment, which perpetuate regional disparities. The spatial autocorrelation parameter reveals that well-performing districts have a positive influence on their neighboring areas. However, the insignificance of residual spatial dependence suggests that unobserved factors, such as governance quality or informal networks, are less important than structural and demographic factors in explaining these disparities.

Demographic factors are critical drivers of secondary school enrollment, with population density and the proportion of youth aged 15-19 showing a consistent positive influence. These findings align with Szabo and Bleha (2018), who note how demographic decline in post-socialist countries exacerbates educational disparities, especially in rural areas. The negative correlation between the proportion of university-educated residents and secondary school enrollment is particularly significant. This suggests that districts with higher educational attainment may experience talent outmigration, either to urban centers or abroad, as noted by Bahna (2013). Talent outmigration weakens local labor markets and perpetuates inequalities by depleting already disadvantaged regions of valuable human capital. Addressing these demographic challenges will require targeted policies to encourage population retention in rural areas, such as affordable housing programs, tax incentives for young families, and improved local job opportunities.

Curricular specialization plays a crucial role in shaping enrollment trends. The pronounced positive impact of technical and medical programs illustrates their correspondence with labor market requirements and the transition towards Industry 4.0, as noted by Grenčíková et al. (2021) and Kovács and Domonkos (2024). This highlights the necessity of modifying secondary school curricula to meet

evolving economic demands, thereby equipping students with skills pertinent to rapidly expanding sectors. However, the limited impact of agricultural and artistic programs suggests a disconnect from contemporary economic realities and student interests. To improve their relevance, these programs could be updated to integrate modern advancements, such as sustainable agriculture practices or digital arts. This is especially important for rural regions, where agriculture remains a key economic driver, and adapting these programs could better equip students for future opportunities in these sectors.

The spatial patterns revealed by this study highlight the need for localized policy interventions. The clustering of high-performing districts suggests that targeted investments in infrastructure, teacher recruitment, and curricular modernization could help replicate these successes in underperforming regions. For example, digital education platforms and mobile learning units could bridge access gaps in remote areas, while partnerships between schools and local industries could align curricula with regional labor market demands. These strategies echo recommendations by Sutton (2017) and Silliman and Virtanen (2019), who advocate for stronger connections between education and industry to mitigate regional disparities. By fostering such partnerships, regions can enhance educational outcomes and address labor market mismatches, promoting more equitable development.

The implications of these findings extend beyond education, reflecting broader patterns of urban agglomeration where concentrated resources generate outsized benefits. However, this urban advantage could deepen rural disparities unless counterbalanced by targeted investments in outlying regions. Policymakers should prioritize equity-focused resource allocation to ensure rural schools can provide competitive educational opportunities. Strategies such as expanding transportation networks for better access to schools or subsidizing education costs for rural families could help bridge the urban-rural divide. Additionally, demographic stabilization policies, like offering relocation incentives for skilled teachers to underserved regions, could strengthen local capacities and reduce dependence on urban centers for educational and economic opportunities. These interventions can support a more balanced regional development, fostering economic resilience and equitable access to educational resources.

CONCLUSION

This study emphasizes the pivotal role of education in shaping human capital and addressing regional disparities in Slovakia. By applying a random effects spatial error model, it reveals how demographic, geographic, and curricular factors interact to influence secondary school enrollment. The findings show significant spatial clustering of high-performing districts, especially around Bratislava, driven

by the concentration of resources and institutional networks. In contrast, rural and peripheral districts face ongoing challenges linked to demographic decline and economic underdevelopment. Demographic factors, particularly youth density and population structure, emerge as key drivers of enrollment, highlighting the importance of stabilizing younger populations in rural areas to maintain a robust education system. The positive influence of technical and medical programs emphasizes the need to align curricula with regional labor market demands, while the limited impact of agricultural and artistic programs calls for curricular modernization to address evolving economic needs.

The economic implications of these findings are significant. The clustering of high-performing regions highlights the self-reinforcing nature of urban advantages, where resource concentration and institutional networks create a cycle of success. Rural areas often face significant structural challenges, highlighting the urgent need for specific interventions. Initiatives designed to enhance digital learning access, improve transportation options, and cultivate collaborations between educational institutions and local businesses can effectively address the disparities between urban and rural settings, thereby advancing educational equity. This study ultimately reinforces the idea that education can serve as a powerful tool for economic and social equality. To tackle regional inequalities, it is essential to maintain a long-term dedication to policies that emphasize equity, which includes reallocating resources, updating educational curricula, and focusing on areas that are currently underperforming. By tailoring strategies to local contexts and leveraging spatial dynamics, Slovakia can ensure that all districts contribute to and benefit from national development. As the country transitions to a knowledge-based economy, investments in education will remain key to unlocking its full potential.

Acknowledgement

The paper was written within the projects: APVV-20-043 Suburbanization: Community, identity and everydayness, APVV-23-0062 Depopulation and destabilization? Forecasts and simulations of demographic development in the Slovak Republic until the end of the 21st century and modelling of selected impacts.

REFERENCES

ALLMENDINGER, J. (1989). Educational systems and labor market outcomes. *European Sociological Review*, 5(3), 231-250. https://doi.org/10.1093/oxfordjournals.esr.a036524.

AUERBACH, A., & LEE, R. (2010). *Demographic Change and Fiscal Policy*. Cambridge University Press. https://doi.org/10.1017/cbo9780511528545.

AUTOR, D., & SALOMONS, A. (2018). Is automation labor-displacing? Productivity growth, employment, and the labor share. *Brookings Papers on Economic Activity*, vol 2018(1), 1-87. https://doi.org/10.3386/w24871.

BAHNA, M. (2013). Intra-EU migration from Slovakia. *European Societies*, 15(3), 388-407. https://doi.org/10.1080/14616696.2012.707669.

BALÁŽ, V. (2007). Regional polarization under transition: The case of Slovakia. *European Planning Studies*, 15(5), 587-602. https://doi.org/10.1080/09654310600852639.

BARZOTTO, M. (2024). Educational (mis) match in the context of new manufacturing: A qualitative comparative analysis study in five European countries. *International Journal of Finance & Economics*, 29(2), 2116-2138. https://doi.org/10.1002/ijfe.2767.

BECKER, G. S. (1964). *Human Capital. A theoretical and empirical analysis, with special reference to education*. The University of Chicago Press.

BOWLES, S., GINTIS, H., & OSBORNE, M. (2001). Incentive-enhancing preferences: Personality, behavior, and earnings. *American Economic Review*, 91(2), 155-158. https://doi.org/10.1257/aer.91.2.155.

BROWN, P., REAY, D., & VINCENT, C. (2013). Education and social mobility. *British Journal of Sociology of Education*, 34(5-6), 637-643. https://doi.org/10.1080/01425692.2013.826414.

CHETTY, R., HENDREN, N., KLINE, P., & SAEZ, E. (2014). Where is the land of opportunity? The geography of intergenerational mobility in the United States. *Quarterly Journal of Economics*, 129(4), 1553-1623. https://doi.org/10.1093/qje/qju022.

DOUGLASS, J. (2010). Creating a culture of aspiration: higher education, human capital and social change. *Procedia - Social and Behavioral Sciences*, 2(5), 6981-6995. https://doi.org/10.1016/j.sbspro.2010.05.050.

FLORIDA, R. (2002). The economic geography of talent. *Annals of the Association of American geographers*, 92(4), 743-755. https://doi.org/10.1111/1467-8306.00314.

FLORIDA, R., MELLANDER, C., & STOLARICK, K. (2008). Inside the black box of regional development - human capital, the creative class and tolerance. *Journal of Economic Geography*, 8(5), 615-649. https://doi.org/10.1093/jeg/lbn023.

GEODETIC AND CARTOGRAPHIC INSTITUTE BRATISLAVA (2024). ZBGIS® Administrative boundaries. https://www.geoportal.sk/en/zbgis/download/.

GIBBONS, S., & VIGNOLES, A. (2012). Geography, choice and participation in higher education in England. *Regional Science and Urban Economics*, 42(1-2), 98-113. https://doi.org/10.1016/j.regsciurbeco.2011.07.004.

GLAESER, E., PONZETTO, G., & TOBIO, K. (2011). Cities, skills and regional change. *Regional Studies*, 48(1), 7-43. https://doi.org/10.1080/00343404.2012.674637.

GRENČÍKOVÁ, A., KORDOŠ, M., & NAVICKAS, V. (2021). The impact of Industry 4.0 on education contents. *Business: Theory and Practice*, 22(1), 29-38.

HARATYAK, A. (2013). Regional education in Polish, Czech and Slovakian borderline after 1945. *Czech-Polish Historical and Pedagogical Journal*, 5(1), 44-52. https://doi.org/10.2478/cphpj-2013-0005.

KATRŇÁK, T., KREIDL, M., & FÓNADOVÁ, L. (2006). Trends in educational assortative mating in Central Europe: The Czech Republic, Slovakia, Poland, and Hungary, 1988-2000. *European Sociological Review*, 22(3), 309-322. https://doi.org/10.1093/esr/jci059.

KLASEN, S., & LAMANNA, F. (2009). The impact of gender inequality in education and employment on economic growth: New evidence for a panel of countries. *Feminist Economics*, 15(3), 91-132. https://doi.org/10.1080/13545700902893106.

KOVÁCS, O., & DOMONKOS, E. (2024). Deindustrialisation and reindustrialisation patterns in V4 countries – industry 4.0 as a way forward? *Post-Communist Economies*, 36(4), 432-463. https://doi.org/10.1080/14631377.2024.2323834.

LUCAS, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics*, 22(1), 3-42. https://doi.org/10.1016/0304-3932(88)90168-7.

LUCZAJ, K., & BAHNA, M. (2018). Explaining the role of international scholars in semi-peripheries. Evidence from Slovakia. *Studies in Higher Education*, 45(4), 706-722. https://doi.org/10.1080/03075079.2018.1550744.

MICHAELS, D., & STEVICK, D. (2009). Europeanization in the 'other' Europe: writing the nation into 'Europe' education in Slovakia and Estonia. *Journal of Curriculum Studies*, 41(2), 225-245. https://doi.org/10.1080/00220270802515919.

MILLO, G., & PIRAS, G. (2012). splm: Spatial panel data models in R. *Journal of statistical software*, 47(1), 1-38. https://hdl.handle.net/11564/738096.

MOCÁK, P., MATLOVIČOVÁ, K., MATLOVIČ, R., PÉNZES, J., PACHURA, P., MISHRA, P. K., KOSTILNÍKOVÁ, K., & DEMKOVÁ, M. (2022). 15-minute city concept as a sustainable urban development alternative: A brief outline of conceptual frameworks and Slovak cities as a case. *Folia Geographica*, 64(1), 69-89.

MORETTI, E. (2012). *The New Geography of Jobs*. Houghton Mifflin Harcourt Publishing Company.

MOUW, T., & KALLEBERG, A. L. (2010). Occupations and the structure of wage inequality in the United States, 1980s to 2000s. *American Sociological Review*, 75(3), 402-431. https://doi.org/10.1177/0003122410363564.

MUSSIDA, C., SCIULLI, D., & SIGNORELLI, M. (2019). Secondary school dropout and work outcomes in ten developing countries. *Journal of Policy Modeling*, 41(4), 547-567. https://doi.org/10.1016/j.jpolmod.2018.06.005.

NOVOTNÝ, L. (2015). Processes of spatial redistribution of population and changes in educational structure of population: Case study of the Košice functional urban region. Acta Universitatis Lodziensis. *Folia Geographica Socio-Oeconomica*, 20, 25-44. https://doi.org/10.18778/1508-1117.20.02.

NOVOTNÝ, L. (2016). Urban development and migration processes in the urban region of Bratislava from the post-socialist transformation until the global econo-

mic crisis. *Urban Geography*, 37(7), 1009-1029. https://doi.org/10.1080/02723638.2016.1139413.

NURKOVIĆ, R. (2020). STEM education in teaching geography in Bosnia and Herzegovina. *Folia Geographica*, 62(1), 127-141.

PAZÚR, R., FERANEC, J., ŠTYCH, P., KOPECKÁ, M., & HOLMAN, L. (2017). Changes of urbanised landscape identified and assessed by the Urban Atlas data: Case study of Prague and Bratislava. *Land Use Policy*, 61, 135-146. https://doi.org/10.1016/j.landusepol.2016.11.022.

PIKETTY, T., & SAEZ, E. (2014). Inequality in the long run. *Science*, 344(6186), 838-843. https://doi.org/10.1126/science.1251936.

POPJAKOVÁ, D., & MINTÁLOVÁ, T. (2019). Priemysel 4.0, čo mu predchádzalo a čo ho charakterizuje – geografické súvislosti. *Acta Geographica Universitatis Comenianae*, 63(2), 173-192.

RAVENSTEIN, E. G. (1889). The laws of migration. *Journal of the Royal Statistical Society*, 52(2), 241-305. https://doi.org/10.2307/2979333.

REES, P., BELL, M., KUPISZEWSKI, M., KUPISZEWSKA, D., UEFFING, P., BERNARD, A., CHARLES-EDWARDS, E., & STILLWELL, J. (2016). The impact of internal migration on population redistribution: An international comparison. *Population, Space and Place*, 23(6), e2036. https://doi.org/10.1002/psp.2036.

RODRÍGUEZ-POSE, A. (2018). The revenge of the places that don't matter (and what to do about it). Cambridge Journal of Regions, *Economy and Society*, 11(1), 189-209. https://doi.org/10.1093/cjres/rsx024.

RODRIGUÉZ-POSE, A., & TSELIOS, V. (2011). Mapping the European regional educational distribution. *European Urban and Regional Studies*, 18(4), 358-374. https://doi.org/10.1177/0969776411399345.

RUSNÁK, J., KULLA, M., & HORŇÁK, M. (2024). Related variety, region-specific context, and regional economic performance: Empirical evidence from post-socialist Slovakia. *Norsk Geografisk Tidsskrift – Norwegian Journal of Geography*, 78(1), 20-39. https://doi.org/10.1080/00291951.2024.2322454.

SCHULTZ, T. W. (1961). Investment in human capital. *The American Economic Review*, 51(1), 1-17. https://www.jstor.org/stable/1818907.

SEN, A. (1997). Editorial: Human capital and human capability. *World Development*, 25(12), 1959-1961. https://doi.org/10.1016/s0305-750x(97)10014-6.

SILLIMAN, M., & VIRTANEN, H. (2019). Labor market returns to vocational secondary education. *American Economic Journal: Applied Economics*, 14(1), 197-224. https://doi.org/10.1257/app.20190782.

SLOVAK CENTER OF SCIENTIFIC AND TECHNICAL INFORMATION (2024). The number of students newly admitted to the first year and graduates for the previous school year of gymnasiums, secondary schools and conservatories in full-time study for the years 2003, 2013 and 2023. https://www.cvtisr.sk.

STATISTICAL OFFICE OF THE SLOVAK REPUBLIC (2024a). Age groups, om7007rr. https://datacube.statistics.sk.

STATISTICAL OFFICE OF THE SLOVAK REPUBLIC (2024b). Gross value added at current prices, nu3007rr. https://datacube.statistics.sk.

STATISTICAL OFFICE OF THE SLOVAK REPUBLIC (2024b). Job seekers by gender and age, pr3807rr. https://datacube.statistics.sk.

STATISTICAL OFFICE OF THE SLOVAK REPUBLIC (2024d). Number of inhabitants by highest level of education for the years 2001, 2011 and 2021. https://www.scitanie.sk.

STATISTICAL OFFICE OF THE SLOVAK REPUBLIC (2024e). Population density, om7015rr. https://datacube.statistics.sk.

STRIELKOWSKI, W., FILIPEC, P., ŠTEFÁNIK, M., & KOWALSKA, K. (2013). Outward Labour Migration in the Czech Republic, Poland and Slovakia after the EU Enlargement in 2004. *Czech Economic Review*, 7(1), 42-54.

SUTTON, A. (2017). Preparing for local labor: Curricular stratification across local economies in the United States. *Sociology of Education*, 90(2), 172-196. https://doi.org/10.1177/0038040717703447.

SYKES, B., & KUYPER, H. (2013). School segregation and the secondary-school achievements of youth in the Netherlands. *Journal of Ethnic and Migration Studies*, 39(10), 1699-1716. https://doi.org/10.1080/1369183x.2013.833707.

SZABO, M., & BLEHA, B. (2018). Changing educational pathways and economic activity. Time and space aspects in Slovakia after 1989. *Ekonomický časopis*, 66(10), 1031-1050.

VIDYATTAMA, Y., LI, J., & MIRANTI, R. (2019). Measuring spatial distributions of secondary education achievement in Australia. *Applied Spatial Analysis and Policy*, 12, 493-514. https://doi.org/10.1007/s12061-018-9252-z.

YANG, Z. (2023). Human capital space: A spatial perspective of the dynamics of people and economic relationships. *Humanities and Social Sciences Communications*, 10(1), 1-14. https://doi.org/10.1057/s41599-023-01639-5.