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Viktoriia Yanovska

National Transport University

Olena Tsvirko

National Transport University

Iryna Udovychenko

hafran@ukr.net

Sumy Regional Institute of Postgraduate Pedagogical Education

Iryna Lomachynska

Odesa I.I. Mechnikov National University

Halyna Kryshtal

Interregional Academy of Personnel Management

Viktoriia Tvoronovich

National Transport University

Article

Keywords: academic human capital, relative concentration, regional inequality, intellectual migration, spatial disparities, Ukraine, risk, external shocks

Posted Date: October 15th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10671973/v1>

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Additional Declarations: No competing interests reported.

Intellectual Migration and the Spatial Redistribution of Academic Human Capital under External Shocks

Viktoriia Yanovska ^{1,2}, Olena Tsvirko ^{1,3}, Iryna Udovychenko ^{4,*}, Iryna Lomachynska ⁵,
Halyna Kryshstal ⁶, Viktoriia Tvoronovich ¹

¹ National Transport University, Ukraine

² SGH Warsaw School of Economics, Poland

³ Western Paraná State University, Brazil

⁴ Sumy Regional Institute of Postgraduate Pedagogical Education, Ukraine

⁵ Odesa I.I. Mechnikov National University, Ukraine

⁶ Interregional Academy of Personnel Management, Kyiv, Ukraine

**Corresponding author: Iryna Udovychenko hafran@ukr.net*

Abstract

This study analyses how a full-scale war is transforming the intellectual landscape of the country (the case of Ukraine). It highlights disturbing trends of increasing regional inequality and concentration of academic human capital in the face of external shocks. The study focuses on the changing intensity and direction of relative concentration, capturing the reconfiguration of the academic system under extreme conditions. Using Lorenz Curves, Gini Coefficients, and Location Quotient (period 2019-2024), the paper identifies a high level of academic personnel concentration in a limited number of regions and its further intensification following the full-scale invasion in 2022. The results reveal a shift from pre-existing unevenness to a more pronounced spatial asymmetry, characterised by increasing divergence between core academic centers and the rest of the country. This spatial deformation is evidenced by the Lorenz Curves flattening at the lower end, where the bottom 12% of regions in 2022-2023 accumulated 0% of teaching staff, and the initial 16% of regions in 2022 recorded zero R&D personnel. Quantifying this trend, Gini Coefficients grew from 0.4653 in 2020–2021 to 0.5475 in 2023-2024 (by 0.0822 points) for teaching staff in higher education institutions and from 0.7679 in 2019 to 0.7909 in 2022 (by 0.0230 points) for R&D personnel. Both systems exhibit rising inequality driven by the displacement of highly skilled personnel. Furthermore, Location Quotients confirm hyperconcentration in traditional hubs such as Kyiv, where teaching staff LQ reached 2.64, and R&D LQ reached 6.41 - alongside the erosion of frontline scientific centres (Kharkiv R&D LQ fell from 1.94 to 1.00) and an increase in junior academic concentration (PhDs) across safer western and central regions. The analysis demonstrates that these changes are accompanied by a redistribution of academic human capital across regions, indirectly reflecting the impact of intellectual migration. The observed spatial patterns indicate deeper structural transformations affecting the national academic system.

Key words: academic human capital; relative concentration; regional inequality; intellectual migration; spatial disparities; Ukraine; risk; external shocks

1. Introduction

Intellectual migration, manifested through transnational and internal mobility of individuals with high cognitive capacities, plays a pivotal role in shaping the global knowledge space. Within the knowledge-economy paradigm, scholars, researchers, innovators, entrepreneurs, and highly skilled professionals act as key carriers of intellectual capital and agents of socio-economic transformation (Tsvirko 2025; Tsvirko et al. 2026). The direction of intellectual migration directly affects the pace and trajectory of modernisation and innovation-driven development at both national and regional levels.

Research on these processes has traditionally focused on international mobility of highly skilled labour, examining it as a mechanism of knowledge redistribution and a driver of scientific and technological development (Czaika and Orazbayev 2018). While this literature provides substantial insights into macro-level effects, similar processes occur within national borders, where regions with different levels of economic development, institutional capacity, and security increasingly compete for human capital. Studies of internal brain drain and intra-national intellectual migration have examined territorial imbalances in the distribution of creative and highly skilled talent in countries such as the United States (Florida 2003), China (Chen and Kenney 2007), and India (Shaji and Baskar 2024). However, these studies have largely focused on high-technology sectors and innovative firms, while the academic sector has received less attention as a distinct object of spatial analysis. This gap is important because universities and research institutions constitute major repositories of regional intellectual potential and are central to smart specialisation strategies (Pinto 2024). Related research has instead addressed territorial access to knowledge and academic institutions (Yanovska et al. 2025), university–business–government collaboration, regional ecosystems (Ferreira et al. 2025), and the broader civic and societal functions of universities (Tomasi et al. 2024).

The analysis of internal intellectual migration becomes particularly challenging in countries experiencing systemic economic, demographic, or military crises. Under such conditions, intellectual migration may involve the forced spatial redistribution of academic talent, disruption of established academic communities, and emergence of new centres of knowledge concentration. Conventional concepts of brain drain, brain gain, and brain circulation are therefore insufficient to capture redistribution shaped simultaneously by security threats, funding constraints, institutional uncertainty, and geographical displacement. These processes may involve both internal displacement (Finikov et al. 2025) and international migration (de Rassenfosse et al. 2023), with their consequences depending strongly on institutional and territorial contexts.

Ukraine provides a particularly relevant case for examining these processes. Since 2014, and especially following the full-scale invasion in 2022, the national academic ecosystem has experienced substantial disruptions to infrastructure, resources, and human capital. These shocks have interacted with pre-existing regional inequalities and contributed to the redistribution of highly qualified personnel across territories. Consequently, a new spatial configuration of academic human capital has emerged, which can be interpreted through the perspectives of intellectual migration and regional knowledge-economy theory.

The objective of this study is to analyse the regional distribution of academic human capital in Ukraine and identify spatial patterns that may indicate internal intellectual redistribution amid external shocks. Given the limited availability of longitudinal individual-level migration data for academic personnel, changes in the relative territorial concentration of human capital are used as an indirect empirical proxy for identifying potential directions of intellectual redistribution and internal intellectual migration. The analysis employs Lorenz curves, Gini coefficients, and Location Quotients (LQ) of academic personnel to examine changes in regional concentration and inequality.

The Ukrainian case provides a dual analytical perspective on high-skilled mobility. On the one hand, spatial changes in academic human capital reflect endogenous economic, demographic, and structural processes. On the other hand, they reveal the academic ecosystem's response to external security shocks, including the displacement of institutions and personnel to safer locations and the loss of human capital through international migration. Thus, the Ukrainian experience extends spatial knowledge-economy perspectives by incorporating military and political shocks, mass intellectual mobility, and the accelerated reorganisation of academic institutions.

The study employs a spatio-temporal descriptive approach with elements of cross-sectional analysis. Its empirical foundation consists of official statistical data on academic teaching staff and researchers across Ukrainian regions. The available data cover different observation periods depending on the personnel category, allowing for comparison of regional patterns before and during the full-scale war.

The analysis focuses on regional imbalances, structural shifts, and spatial asymmetries in the distribution of academic human capital.

The article contributes to the literature in three main ways. First, it extends research on intellectual migration by examining its spatial consequences for academic ecosystems under armed conflict. Second, it proposes an indirect empirical approach to identifying potential patterns of internal intellectual migration through changes in the spatial distribution of academic human capital in the absence of individual-level migration data. Third, it provides quantitative estimates of changes in the concentration and regional inequality of intellectual resources in response to an external shock.

The study is also linked to the Sustainable Development Goals, particularly quality education, reduced inequalities, and institutional resilience. Spatial disparities in academic human capital affect regional access to educational and research resources and, consequently, the capacity of regions to sustain innovation-driven development.

The study addresses the following research questions (RQs):

RQ1. How do war and political shocks affect the spatial dynamics of intellectual resources within a country?

RQ2. What spatial patterns of redistribution of academic human capital can be identified across Ukrainian regions, and to what extent may these patterns indicate internal intellectual migration under external shocks?

RQ3. How does the spatial redistribution of academic human capital affect regional inequality, innovation potential, and the resilience of the national academic ecosystem?

The remainder of the article is structured as follows. The next section reviews theoretical approaches to intellectual migration and the spatial distribution of human capital. The third section presents the contextual background, followed by the methodology and data sources. The subsequent section analyses spatial changes in the distribution of academic resources in Ukraine. The final section discusses the findings and their theoretical and practical implications and concludes the study.

2. Literature review

2.1. Theoretical Foundations of Intellectual Migration

The concept of intellectual migration emerged in relation to the outflow of European scholars and other highly qualified professionals to the United States during the first half of the twentieth century (Li et al. 2023). It initially referred largely to the forced displacement of highly qualified individuals (so-called intellectual refugees) driven by political persecution, wars, and instability, with significant consequences for science, technology, and culture in recipient countries (Bailyn and Fleming 1969). Over time, the concept expanded beyond forced migration to encompass a broader range of mobility patterns among highly skilled professionals.

Beginning in the 1960s, the drivers and consequences of intellectual migration were increasingly conceptualised through a range of theoretical models. One of the most influential was the brain drain model, which emphasises the loss of highly skilled human capital from developing countries to more economically advanced economies and its potential negative effects on the development of sending countries (Bhagwati and Hamada 1974).

Baldwin (1970) challenged the uniformly negative interpretation of brain drain, arguing that in some developing countries the supply of educated professionals exceeds domestic labour-market demand, forcing them to seek employment abroad. This phenomenon was subsequently conceptualised as brain overflow (Breinbauer 2007). A related perspective is provided by the brain waste model, which describes situations in which highly educated migrants are employed in positions below their qualifications, resulting in the partial or complete devaluation of their human capital (Mattoo et al. 2008). These concepts

highlight that the consequences of intellectual mobility depend not only on the movement of people but also on the capacity of labour markets and institutions to utilise their skills effectively.

Alternative approaches include brain retention, brain gain, brain exchange, and brain circulation. Brain retention focuses on policies and institutional conditions that encourage highly educated professionals to remain in their home countries and contribute to national development (Devi 2023). Brain gain refers to situations in which the inflow of highly qualified professionals exceeds their outflow, resulting in a positive balance of talent (Findlay 2002). The concepts of brain exchange and brain circulation further emphasise the bidirectional and recurrent nature of highly skilled mobility, including the formation of transnational innovation networks and the transfer of knowledge, skills, and capital between countries (Saxenian 2005).

The evolution of these approaches reflects the increasing complexity of high-skilled mobility. Intellectual migration has consequently moved beyond the narrow interpretation of irreversible forced emigration to encompass voluntary, recurrent, and reversible forms of mobility involving broader groups of professionals with high cognitive capabilities (Tsvirko 2025). At the same time, technological transformation and changing skill requirements influence the demand for human capital and contribute to structural changes in labour markets (Tomov et al. 2025). The competitiveness of human capital increasingly depends on adaptability, creativity, analytical capabilities, and continuous learning, which makes the capacity of professionals and institutions to respond to changing labour-market conditions an important factor in mobility decisions (Furxhiu et al. 2025). Structural labour-market imbalances may further intensify these processes by creating mismatches between available skills and regional demand (Herasymenko et al. 2025).

Taken together, these theoretical perspectives provide complementary explanations of the mechanisms and consequences of intellectual migration. Brain drain and brain gain focus on net losses or gains of human capital, whereas brain circulation and brain exchange emphasise more complex, multidirectional patterns of redistribution. Brain overflow and brain waste, in turn, highlight structural mismatches between the supply, utilisation, and demand for highly qualified labour. Consequently, intellectual migration may manifest not only in changes in the number of highly skilled professionals but also in changes in their spatial concentration and distribution.

From an empirical perspective, these approaches suggest that intellectual migration, whether driven by structural imbalances, policy environments, technological change, or external shocks, should be reflected in changes in the spatial distribution and concentration of intellectual resources. This provides a theoretical rationale for using spatial indicators as indirect proxies for identifying potential migration and redistribution processes, particularly where direct longitudinal data on individual mobility are unavailable.

2.2. Regional Resilience in the Context of Global Intellectual Mobility

The scale of intellectual migration has increased substantially in recent decades and has become an important component of global mobility. According to United Nations data, the number of international migrants reached approximately 304 million in 2024, representing 3.7% of the global population (Global Migration Data Portal 2025). Highly skilled professionals constitute an important component of these flows, with more than 30% of international students remaining in OECD countries after completing their education (Li et al. 2023).

Czaika and Orazbayev (2018) demonstrated mobility rates nearly three times higher than those of other migrant categories, reflecting the particularly internationalised nature of scientific knowledge production. Anglo-Saxon countries - the United States, the United Kingdom, Canada, and Australia - remain major destinations for highly skilled migrants, hosting nearly 70% of this group, with more than 40% concentrated in the United States alone. Retention rates of foreign talent are particularly high in developed economies, reaching 57% in Switzerland, 45% in Australia, and 38% in the United States (Kerr et al. 2016).

The concentration of highly skilled migrants is also evident in specific professional and educational sectors. In the United States, immigrants account for 27% of physicians and surgeons and more than 35% of other healthcare professionals, while international students constitute 82% of engineering students, 72% of computer science students, and 67% of economics students (Anderson 2022). Such concentrations strengthen the scientific, technological, and innovation capacities of receiving economies while potentially reducing the human-capital base of countries of origin.

The qualification structure of migrant populations further illustrates these global asymmetries. In advanced economies, highly skilled migrants account for approximately 6% of the population, compared with around 5% for migrants with medium and low skill levels (Global Migration Data Portal 2025). In many cases, migrants possess higher levels of education and professional training than native populations, contributing to structural changes in the global distribution of intellectual resources. These processes interact with technological transformation and changing labour-market requirements, which increasingly place emphasis on adaptable and continuously developing human capital (Tomov et al. 2025; Furxhiu et al. 2025).

From a regional perspective, the consequences of intellectual mobility are not limited to the international level. The redistribution of highly qualified human capital can alter the resilience and development capacity of individual territories. Regions able to attract and retain academic and professional talent may strengthen their research, education, and innovation systems, while regions experiencing persistent outflows may face cumulative losses of knowledge, skills, and institutional capacity. Such effects are particularly significant where structural labour-market imbalances interact with economic or institutional crises (Herasymenko et al. 2025).

Although intellectual migration has evolved into a complex and multidimensional phenomenon that reflects the interaction among global flows of knowledge, talent, and innovative capacity (Tsvirko 2026), its consequences remain spatially differentiated. Talent-receiving territories can strengthen research, education, innovation, and adaptability, while talent-sending territories may experience knowledge drain, reduced innovation activity, and weakening scientific and technological capacity (Bhagwati and Hamada 1974; Docquier and Rapoport 2012). These effects provide an important theoretical basis for analysing intellectual migration not only as a movement of individuals but also as a process of spatial redistribution of human capital and regional resilience.

3. Background and Context

3.1. War-Driven Academic Staff Dynamics

Under conditions of full-scale armed aggression against Ukraine, the phenomenon of intellectual migration has acquired critical urgency. More broadly, Ukraine belongs to the group of countries for which the challenge of intellectual emigration (and, consequently, brain drain) extends beyond its contemporary manifestations. Historically, the outflow of highly qualified professionals has been systemic in nature and closely linked to prolonged periods of political, economic, and cultural dependence on external centres of power. At different stages of history, these centres were first imperial regimes and later transnational structures. During the imperial period, numerous representatives of the Ukrainian intelligentsia were compelled to seek opportunities for self-realisation outside the country. For extended periods, Ukraine functioned as a donor of talent and highly skilled human capital (Pavlovskyi et al. 2024).

Throughout the twentieth century, successive waves of political emigration, scientific relocation, and forced departures of highly qualified professionals had a detrimental impact on the development of national human capital, significantly reducing its domestic concentration. In independent Ukraine, despite considerable intellectual potential, institutional constraints, chronic underfunding of higher education and science, and persistent economic and political instability created additional incentives for intellectual emigration.

The current stage of this problem is characterised by unprecedented severity driven by war, macroeconomic instability, and structural transformations of the labour market. Full-scale aggression against Ukraine has triggered large-scale migration processes encompassing both external and internal mobility. As of early 2025, approximately 6.918 million Ukrainian refugees had been recorded worldwide, of whom 6.358 million were residing in European countries and more than 560 thousand outside the European region (UNHCR 2025). At the same time, the total number of internally displaced persons within Ukraine reached approximately 4.623 million, with women accounting for 60% and men for 40% (OPORA 2025). A substantial share of forced migrants and internally displaced persons consists of highly skilled professionals. According to a 2022 study, approximately 18.5% of Ukrainian researchers left the country following the outbreak of the war (de Rassenfosse et al. 2023), while alternative estimates suggest a figure closer to 5% (Yanovska et al. 2026). Forced population displacement, particularly among scholars, engineers, and entrepreneurs, creates significant risks of irreversible human capital loss, thereby complicating post-war economic recovery.

Over the past fifteen years, war has emerged as a systemically significant factor driving the decline in the number of academic teaching staff and researchers. In the short term, its impact generates a pronounced shock effect. The first war-related shock in 2014 chronologically coincided with a significant reduction in the total number of academic staff. During a single academic year (2014-2015), their number decreased by more than 15%, representing an unprecedented deviation from pre-war trends. This shift may be linked to the onset of hostilities in eastern Ukraine and the annexation of Crimea, which led to the relocation of some universities and academic staff, while others remained in occupied territories. This period was marked by the simultaneous loss of territories with a high concentration of higher education institutions, intensified internal migration of academic personnel, and administrative reorganisations stemming from the reallocation of public expenditures in favour of the defence sector. Consequently, the initial military events not only caused immediate staffing losses but also initiated a prolonged process of academic workforce optimisation within the higher education system, which persisted at least until the 2018-2019 academic year (Figure 1).

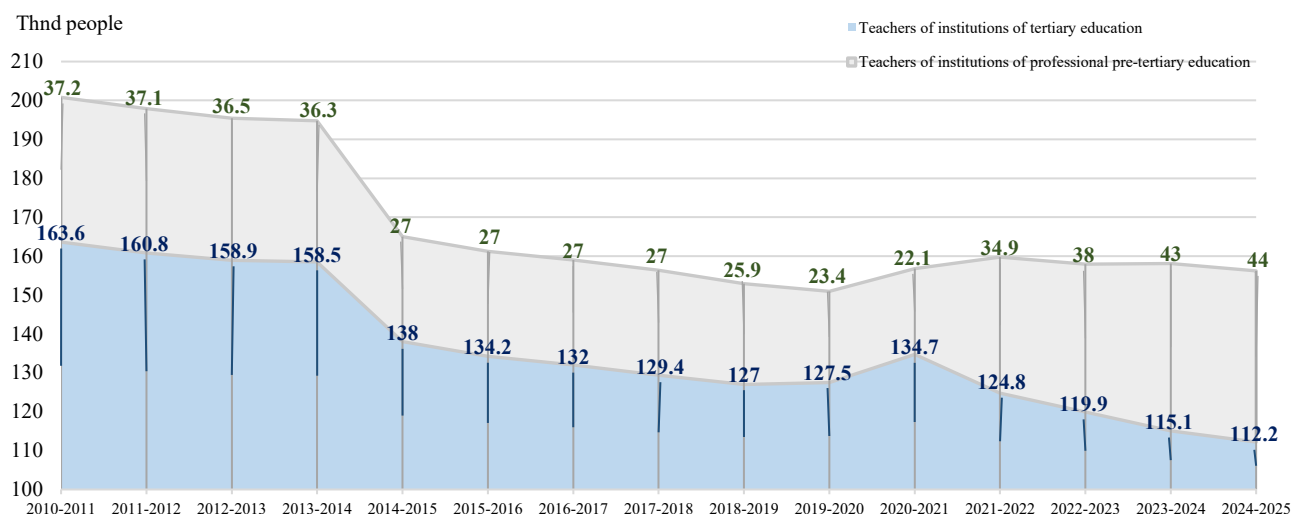


Figure 1. Dynamics of change in the number of Teachers of institutions of tertiary education and professional pre-tertiary education, thnd people, 2010-2025

The second phase of the war, marked by the full-scale invasion in February 2022, did not result in an abrupt decline in the number of academic teaching staff; however, it revealed a profound structural shift within the system. Between the 2021-2022 and 2024-2025 academic years, the number of academic

teaching staff in higher education institutions declined by more than 10%, while employment in the professional pre-tertiary education sector increased by nearly 26%. These changes can be partly explained by the education system's adaptive response to wartime conditions, including a reorientation towards short-term, practice-oriented training programmes, the creation of new vocational pathways for internally displaced persons, and the need to meet the demands of a defence-oriented economy.

Quantitative indicators point to a substantial acceleration in workforce contraction during periods of military escalation. While during 2010-2014 the average annual decline in the number of academic staff in higher education institutions approached 1%, in the 2014-2015 academic year it reached nearly 13%. The system experienced partial stabilisation between 2015 and 2019, after which contraction rates increased again to approximately 3-4% per year during 2022-2025. Thus, war amplifies the rate of decline in the human resource capacity of higher education by a factor of eight to ten compared with pre-war baseline trends, underscoring its role as a dominant exogenous shock in the sector's structural dynamics.

The data further indicate that the erosion of educational and research capacity cannot be attributed solely to the relocation of highly qualified professionals under conditions of acute insecurity. Structural transformations in the spatial configuration of the country's educational and research potential have much deeper roots. Long-standing destructive trends (chronic underfunding of academia, demographic ageing of academic staff, ineffective human capital management, and slow integration into global academic networks) had shaped a fragile institutional architecture well before the outbreak of war. The cumulative effect of these factors has been a sustained decline in the number of academic teaching staff and researchers in the R&D sector (Figura 2).

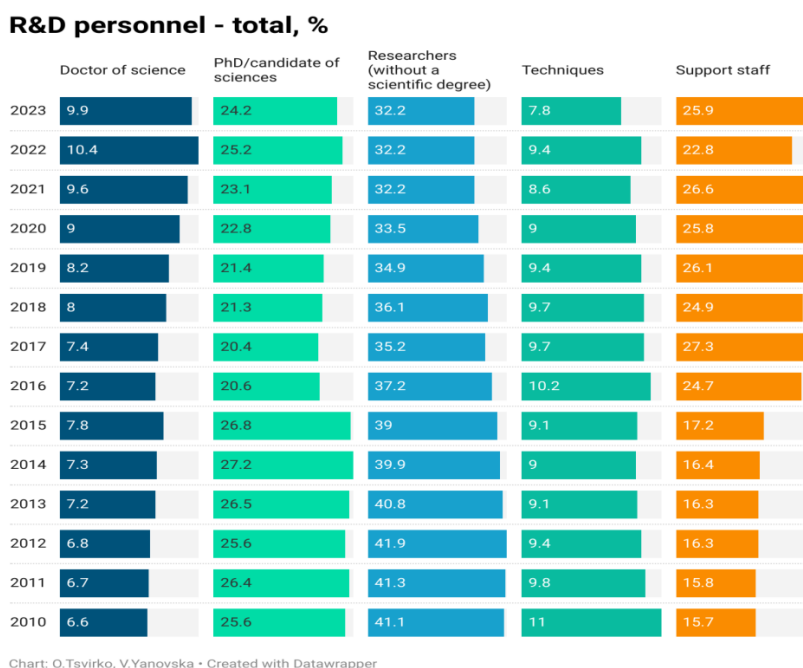


Figure 2. Structure of personnel in the field of research and development

Source: https://www.datawrapper.de/_/ia22Q/

The depletion of academic potential has been particularly pronounced in research and development. In 2006, Ukraine recorded 1.471 full-time equivalent (FTE) researchers per million inhabitants; by 2022, this figure had fallen to just 581. By comparison, in 2021 Poland had 3.534 FTE researchers per million inhabitants, while Germany recorded 5.536 (GCDL, 2022). Ukraine is among the few countries exhibiting a persistent downward trend in the number of researchers. Equally noteworthy is the ageing of the academic workforce. According to the National Academy of Sciences of Ukraine, the average age of researchers in 2024 was 56.1 years; among full members it reached 76.0 years, among

corresponding members 70.6 years, among holders of a Doctor of Sciences degree 65.8 years, and among PhD holders 52.5 years (NASU 2025).

Nevertheless, despite adverse quantitative and demographic trends, Ukraine continues to maintain a relatively high quality of human resources in research and development (Figure 2). Moreover, as a result of international grants and external assistance aimed at supporting researchers, the number of R&D personnel has shown signs of recovery since 2022.

The dynamics of the number of scientific and pedagogical workers is less threatening and, despite the existing risks of losing human resources, today this segment remains relatively stable and retains a functional reserve for further recovery and development. From the 2019-2020 to 2022-2023 academic year, in the context of consolidation and a decrease in the number of higher education institutions by 46% and a decrease in the number of higher education applicants by 23%, the teaching staff was reduced by only 10%. The dynamics of quantitative parameters of educational activities in Ukraine for the period from 2013 to 2024, taking into account secondary education institutions, including colleges and technical schools (Figure 3), demonstrates positive trends.

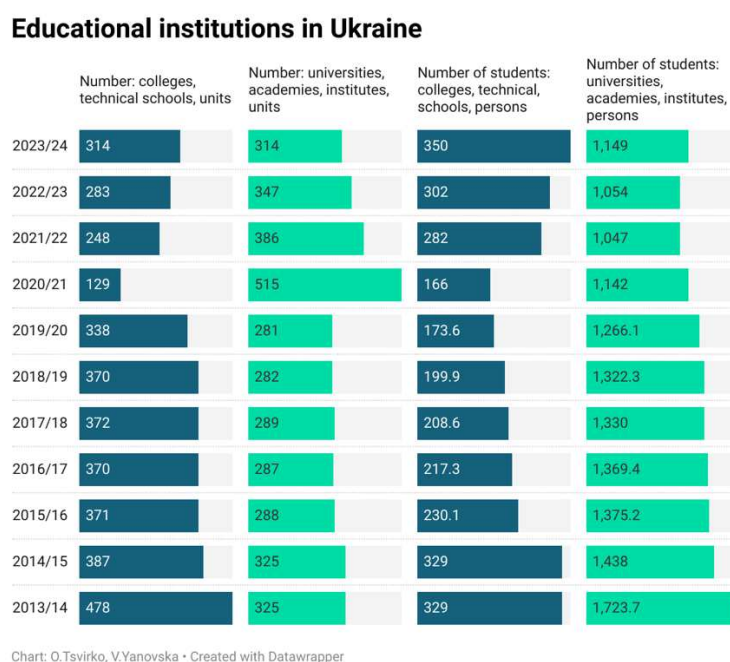


Figure 3. Number of institutions and students in secondary and higher education

Source: https://www.datawrapper.de/_/2OtOf/

Due to the peculiarities of military conscription against the background of the ongoing consolidation of higher education institutions, starting in 2022, the number of students (both at the secondary and higher education levels) and the number of colleges and technical schools are increasing.

3.2. Territorial and Structural Rebuilding

The intensification of the war has primarily intensified pre-existing challenges, triggering a new wave of intersectoral and trans-territorial intellectual migration, forcing the displacement of scholars both within the country and beyond its borders, destroying research infrastructure in specific regions, and fundamentally altering the logic of the spatial distribution of academic potential.

Since 2014, Ukraine has experienced a transformation in the spatial organisation of educational and research activities as well as in the internal functional structure of its academic ecosystem. Growing intra-regional disparities in the distribution of educational and scientific capacity have been exacerbated by

infrastructure destruction and shaped by asymmetric security conditions and heterogeneous levels of economic resilience across territories. As a result, human capital has been redistributed in favour of relatively safer regions, accompanied by a contraction of academic presence in other parts of the country.

An analysis of the spatio-temporal trajectories of higher education institutions historically located in Donetsk, Luhansk, Zaporizhzhia, and Kherson regions, as well as in the Autonomous Republic of Crimea, reveals a wave-like pattern of institutional relocation in response to escalating security threats. Comparing the institutions' historical locations, their initial relocations after 2014, and subsequent or additional relocations following 2022 points to a deepening territorial reorganisation of the national higher education sector. During the first wave (2014-2016), 14 universities were relocated, while in the second wave (2022-2024) this number increased to 21 (Finikov et al. 2025).

Nearly all institutions originating from Donetsk and Luhansk regions (except those remaining in occupied territories) undertook their initial relocation in 2014, predominantly choosing intra-regional destinations within government-controlled areas or neighbouring regions. Empirical evidence indicates that relocations during this period were largely confined to eastern or central Ukraine. This configuration of the first relocation wave reflects efforts to minimise institutional disintegration and preserve relative territorial proximity to existing educational and personnel networks. After 2022, a new relocation wave emerged, directed mainly towards western and central regions. In contrast to 2014, relocation trajectories increasingly involved more distant destinations, often associated with integration into established educational ecosystems offering greater security and infrastructural resilience. These cases indicate a gradual integration of relocated institutions into host academic environments, suggesting a transition from temporary to semi-permanent or permanent relocation models.

A notable development during 2022-2025 has been the emergence of institutional absorption processes by existing universities. This strategy is not unique to relocated institutions but reflects a broader state policy initiated as early as 2016, aimed at consolidating resource bases and strengthening administrative and academic resilience. Isolated cases of temporary suspension of access to educational services illustrate the limits of the higher education sector's adaptability under extreme conditions.

Following 2014, and especially after 2022, the Ukrainian government introduced legal and organisational mechanisms enabling the temporary relocation of higher education institutions and research organisations. Relocated universities retained their legal status, licences, accreditation certificates, and staff positions, allowing personnel to continue employment at new locations under existing contractual conditions. In most cases, the absorption of academic staff occurred through the transfer of existing positions rather than the creation of new ones in host regions. Independent academics who left insecure territories without institutional transfer more frequently encountered shortages of available positions; however, inclusive employment practices at the level of individual universities were relatively widespread, particularly in 2014.

At present, academic institutions operating in frontline areas or those that have been relocated continue to receive ongoing support. As of 1 August 2025, such support was provided to 34 universities (MESU 2025). Consequently, the partial preservation of academic potential has been achieved primarily through institutional mechanisms rather than through the expansion of academic employment opportunities in host regions. Losses of human capital resulting from faculty members' refusal to relocate and their subsequent gradual dismissal have been linked to the limited effectiveness of support mechanisms for relocated universities. To a greater extent, however, these losses stem from a general decline in demand for highly qualified personnel caused by the contraction of regional education markets, a reduction in the number of prospective students, and a partial reallocation of demand for educational services towards safer regions. Under these conditions, organisational and funding mechanisms that had been effective prior to the war proved insufficient to sustain the overall human capital of the academic ecosystem in the new realities.

The shift in centres of scientific activity driven by university relocation and the territorial redistribution of education markets has reshaped the spatial architecture of the national academic ecosystem, generating

additional challenges for strategic planning of post-war recovery and balanced socio-economic development. As emphasised by the President of the International Science Council, Peter Gluckman, Ukraine is currently experiencing a crisis of existential scale affecting citizens and infrastructure, including both the physical and human infrastructure of education and science. The consequences of this crisis extend far beyond national borders, threatening to exacerbate geostrategic tensions and posing substantial risks to the achievement of global Sustainable Development Goals (ISC 2022).

The full-scale war in Ukraine has elevated the issue of resilience of higher education and research systems under crisis conditions to the global agenda. Today, polycrisis has become a new reality, and it is highly likely that the coming years will bring additional, interconnected challenges, including wars and anthropogenic disasters. The destruction and loss of academic ecosystem capacity during crises adversely affect domestic research investment, educational processes, research activity, long-term economic development, the ability to withstand external threats, and even national sovereignty. Moreover, such processes significantly disrupt the stability of interactions within global academic networks and undermine the functioning of international research infrastructures. In times of crisis, the education and research community must be a recipient of targeted support that enables proactive action, ensuring protection, effective response, and sustainable recovery of institutions.

Under conditions of a transformed spatial architecture of educational and research activity, the analysis of regionalisation processes of intellectual potential becomes particularly important. Examining spatial dynamics through Lorenz curves, Gini coefficients, and Location Quotients of academic staff and researchers enables the identification of regional imbalances, the scale of institutional losses, transformations of scientific clusters, and potential growth nodes. This approach constitutes a critical tool for strategic post-war reconstruction planning, facilitating an understanding of deep structural changes and the formation of a new spatial architecture of the academic ecosystem capable of ensuring sustainable development, innovative inclusiveness, enhanced global competitiveness, and greater capacity to counter real and hybrid threats.

4. Methodology

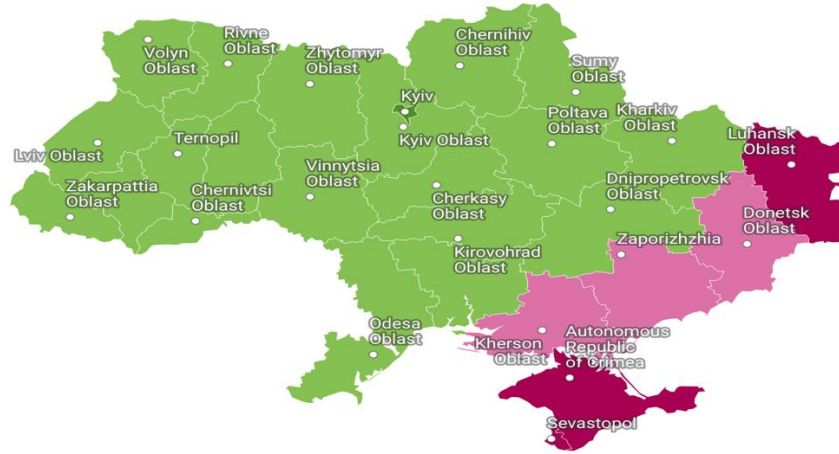
4.1. Data and workflow

The methodological framework of the study is based on a combination of spatial economics concepts, regional statistics and modern analytical tools for assessing the regional distribution of intellectual resources in higher education and science. To achieve the goal of the study, spatial analysis tools were used, which allow identifying the level of concentration of scientific and pedagogical personnel and researchers in the regions and tracking its dynamics over time (Levytska et al. 2020).

To determine the concentration of academic and scientific personnel in different regions of Ukraine, relative concentration indicators were used, which allow comparing the ratio of the share of teachers and scientists in each region with the average indicator for the country. The use of Lorenz curves and Gini coefficients made it possible to quantitatively assess the degree of unevenness of the spatial distribution of highly qualified personnel and determine the scale of interregional disparities. The methodology of analyzing the coefficients of relative concentration (Location Quotients, LQ) helped to identify the regions with the highest and lowest levels of concentration of educational and research potential, as well as to identify structural imbalances in the distribution of human capital.

The study used official statistical data of the State Statistics Service of Ukraine for 2019–2024, which cover the number of employed population in the field of education, as well as the number of scientific and pedagogical workers in higher education institutions and researchers in the R&D sector by region (Ukrstat 2025). The analysis was conducted in the context of 24 regions of Ukraine (oblasts), excluding temporarily occupied territories, which make reliable accounting and comparison impossible (Figure 4).

Regions of Ukraine



Map: O. Tsvirko, V. Yanovska • Source: Ukrstat • Created with Datawrapper

Figure 4. Map of the regions of Ukraine (red – fully occupied territories, pink – partially)

Source: https://www.datawrapper.de/_/UrW45/

The study workflow is presented in Figure 5.

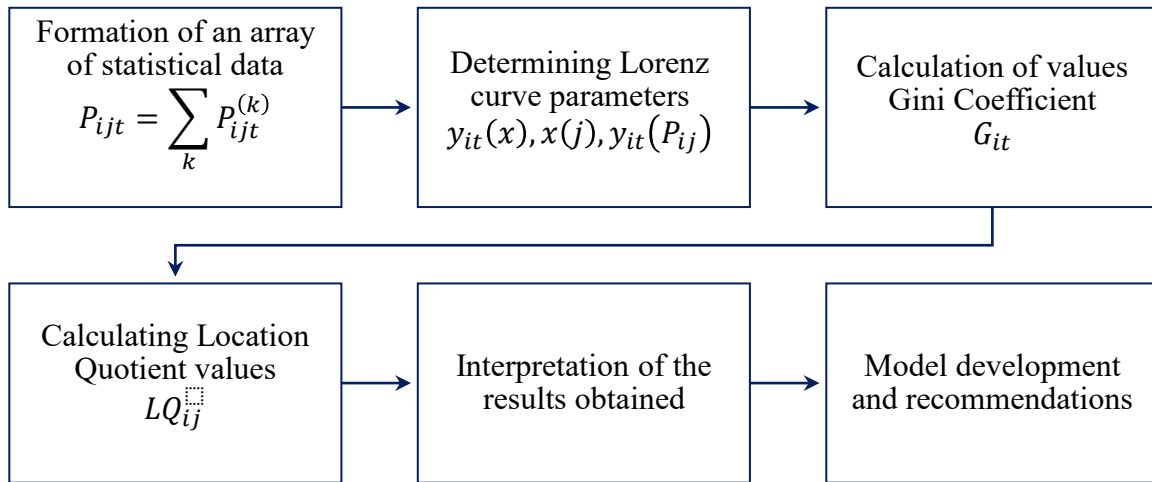


Figure 5. Study workflow

4.2. Analytical framework and quantitative metrics

Spatial Lorenz curves and Gini coefficients were used to represent the geographical proportionality of the distribution of academic staff. The Lorenz curve was proposed in 1905 by the economic statistician M. Lorenz to assess the distribution of income (Lorenz 1905). The geometric figure Lorenz curve visually represents the cumulative share of the population (x), ranked from the lowest to the highest income, relative to the cumulative share of income (y). From an economic perspective, the closer the Lorenz curve is to the line of uniform distribution, the smaller the income gap, and vice versa. In a universal representation, the observations of the distribution are ordered according to the cumulative percentage of observations (x) and cumulative importance (y).

In the study, the Lorenz curve is used to measure the overall degree of regional concentration of academic staff and to assess changes in inequality in their territorial distribution. This allows us to determine whether the concentration of personnel in the regions of Ukraine has increased after 2022. For

each year of the period 2019-2024, data sets were generated on the number of academic staff in the regions of Ukraine (regions, $j, j \in [1, n]$). Based on these data, Lorenz curves were constructed. The regions were ordered by increasing number of academic staff (i), after which the cumulative share of personnel (y) and the cumulative share of regions (x) were calculated for each region. The graphical representation of the obtained dependencies $y(x)$ made it possible to assess the level of inequality and its dynamics.

The Gini Coefficient, proposed by the Italian statistician Gini (Gini 2012), is a complex indicator that is classically used for quantitative analysis of income differences and corresponds to the normalised area between the Lorenz distribution curve and the 45-degree line. The Gini Coefficient ranges from 0 to 1. The closer the Gini Coefficient is to 0, the more even the distribution is; conversely, it indicates that the difference in income distribution is significant.

Since the unit of analysis in this study is the region (area) and all regions have the same weight, the Gini Coefficient is calculated using the standard formula for ordered discrete data (Plata-Pérez et al., 2015):

$$G = \frac{1}{n} \cdot \left(n + 1 - 2 \frac{\sum_{j=1}^n (n+1-j) \cdot P_j}{\sum_{j=1}^n P_j} \right), \quad (1)$$

where j – ranking of each region by the number of academic employees,

P_j – number of academic employees of the region j .

The key analytical indicator chosen is the Location Quotient (LQ), which is used to assess the level of concentration of a certain socio-economic characteristic (in this case, general education, scientific-pedagogical and research potential) in a particular region relative to the national average. In spatial economics, the location coefficient is widely used as a tool of economic and regional analysis to measure the concentration of individual industries in regions compared to the national average (Alves 2022). As a geographic index, LQ measures the relative concentration or distribution of a subarea compared to the entire area (Wheeler 2005). LQ is mostly considered as an indicator of the relative concentration of companies, in the industrial sector, measured by the number of employees (Wheeler, 2005). Despite the debate, its use is valuable in research work, especially in combination with other tools and methods of analysis (Isard 1960).

The Location Quotient is calculated using the formula:

$$LQ_{ij} = \frac{E_{ij}/\sum_j E_{ij}}{\sum_i E_{ij}/\sum_i \sum_j E_{ij}}, \quad (2)$$

where E_{ij} – represents employment in the sector i of the region j ,

$\sum_j E_{ij}$ – represents employment in the sector i of the country,

$\sum_i E_{ij}$ – represents employment in all sectors of the region j ,

$\sum_i \sum_j E_{ij}$ – represents employment in all sectors of the country.

According to North (1955), the Localization coefficient is defined as the ratio where the numerator represents employment in a particular sector in a region relative to total employment in all sectors in the same region. The denominator represents employment in a single sector at the state level relative to total employment in all sectors in the state.

In order to analyze the spatial distribution of academic staff in detail, the basic localisation indicator (LQ) was adapted to the specifics of structural differentiation within the educational and scientific sphere. In particular, Location Quotients (LQ) was calculated for individual qualification groups (Doctor of Science, PhD/Candidate of Science, and Other teaching staff / R&D personnel) of scientific and pedagogical workers and researchers. Unlike the classical approach, where the comparison is made relative to the total employed population of the region and the country, this study applied intra-industry normalisation, as a result of which the regional distribution indicators were correlated with the corresponding national parameters within a specific professional group (scientific and pedagogical workers and researchers).

The resulting indicators make it possible to identify regions characterised by a relative overconcentration or underrepresentation of specific types of academic personnel and, consequently, to assess structural asymmetries in the spatial distribution of educational and research resources. Particular attention is paid to groups with the highest level of academic qualification (Doctors of Science), as these actors constitute the core of regional research resilience. This approach enables the identification of regions with potential for the development of intellectual clusters, as well as regions facing an elevated risk of depletion of educational and research infrastructure.

For analytical interpretation, a discretisation method was applied, transforming the continuous LQ variable into a categorical one.

Classical interpretation of the Location Quotients is as follows. If $LQ \geq 1$, the value indicates a high degree of relative concentration of region j in activity i relative to the set of all regions (country). If $0,50 \leq LQ < 1$, the range reflects a moderate degree of relative concentration of region j in activity i relative to the total set of regions (country). If $LQ < 0,5$ the value indicates a low degree of relative concentration of region j in activity i relative to the total set of regions (country) (Vidigal et al. 2009). Following Brosnan, an $LQ > 1,25$ indicates that the region is over-represented in a particular field compared to the national average (Brosnan 2017).

In this study, a five-level interval scale was used. The application of a five-level scale allows for more precise identification of spatial asymmetries. Analogous to the approach proposed by Powers et al. for analysing disparities in access to green spaces across socio-demographic groups (Powers et al. 2024), the LQ a five-level interval scale in this study is employed to identify and assess spatial disparities in the distribution of research and educational resources.

The interpretation of LQ values in the context of the regional distribution of academic potential is as follows. Values $LQ < 0,70$ indicate a substantial deficit of academic human resources relative to the national average. Values $0,70 \leq LQ < 0,90$ reflect a limited concentration of academic capacity. The interval $0,90 \leq LQ < 1,10$ corresponds to proportional representation, where the regional share of academic resources approximates the national mean. Values $1,10 \leq LQ < 1,30$ indicate elevated concentration, while LQ values $LQ \geq 1,30$ reflect a high degree of relative concentration of academic personnel. An LQ equal to 1 represents an even distribution, in which the regional share of academic personnel corresponds exactly to the national average.

Regions with LQ above 1 can be interpreted as knowledge hubs. Conversely, values below 1 signal a relative deficit of the corresponding type of human capital, less developed academic infrastructure, limited access to scientific networks, or marginalisation of the region within the national allocation of educational and research resources.

Thus, within the differentiated assessment conducted for academic teaching staff and research personnel, disaggregated by qualification categories (Doctors of Science, PhD/Candidates of Sciences, and other staff), the Location Quotient enables the identification of regional centres of academic capacity concentration as well as structural disproportions in the distribution of highly qualified human capital. This, in turn, provides a basis for revealing spatial configurations of intellectual resources that are critically important for the formulation of effective national and regional policies in higher education and science (Alves 2022). To capture dynamic changes, an intertemporal comparative analysis of Location Quotients for the period 2019-2024 was conducted, allowing for an assessment of the impact of the war-related shock on the regional concentration of academic potential.

4.3. Research constraints

Despite the analytical value of the results obtained, the study is subject to several methodological limitations stemming from the characteristics of the available empirical sources and the chosen research framework.

First, the analysis is constrained by the temporal fragmentation of statistical data. The datasets employed cover different time spans, which poses challenges for a fully harmonised comparative assessment. Specifically, statistics on employment in the education sector cover the period 2019-2021; data on academic teaching staff in higher education institutions span the academic years 2019/2020-2023/2024; while data on research personnel engaged in R&D are available only for 2019-2022. This fragmentation limits the possibility of fully extrapolating observed trends to the most recent phase of the war.

Second, the study relies primarily on quantitative indicators. The analysis focuses on numerical measures of employment in higher education and research without incorporating qualitative dimensions of intellectual migration, such as migration motivations, career trajectories, levels of integration of displaced scholars into new institutional environments, or changes in academic productivity. The exclusive use of quantitative indicators, in the absence of complementary qualitative research, narrows the depth of interpretation of the social and professional consequences of migration.

Third, the available statistics do not allow for differentiation across types of academic mobility. In particular, it is not possible to distinguish between intra-regional, interregional, and international mobility (including forced displacement), nor to capture digital or virtual forms of academic presence. As a result, the quantitative approach is unable to fully reflect the complexity of migration processes under wartime conditions or to identify the institutional mechanisms that have contributed to the partial retention of academic capacity, including remote employment in Ukrainian educational and research institutions by scholars physically relocated to other regions or abroad.

Fourth, the analysis is affected by sectoral aggregation of the data. The use of regionally aggregated statistics without accounting for disciplinary structures of educational and research activities complicates the identification of structural shifts within specific fields, which may differ substantially in their sensitivity to wartime shocks (e.g. STEM disciplines versus the humanities and social sciences).

Fifth, the scope of professional categories considered is relatively narrow. The study focuses on academic teaching staff and researchers, thereby constraining the analytical perspective on intellectual migration. Other categories of highly qualified professionals – such as analysts, engineers, and innovation management specialists – who also actively participate in intellectual migration processes and contribute to the country's intellectual capital, remain outside the scope of the analysis.

Nevertheless, these limitations do not diminish the significance of the findings. Rather, they point to the need for further comprehensive and interdisciplinary research that combines quantitative and qualitative data collection and analysis, as well as to the necessity of improving the national system for monitoring intellectual migration under conditions of crisis-driven transformation. Such efforts are essential for the development of a resilient academic ecosystem capable of withstanding future challenges and systemic shocks.

To enhance analytical transparency and facilitate the interpretation of spatial shifts in the distribution of educational and research capacity, visual data representation tools were employed. In particular, choropleth maps of Location Quotients (LQ) were used to identify regions experiencing critical declines or growth in academic potential. The interpretation of the results focuses on identifying local and regional shifts while simultaneously revealing emerging structural patterns, including the potential formation of secondary academic centres, the relocation of human capital from affected regions to safer areas, and the redistribution of academic personnel towards transit or border regions.

5. Results and Discussion

5.1. Level of regional concentration

The analysis of regional concentration for 2019-2021 provides a baseline for assessing the spatial structure of Ukraine's educational and scientific capacity before the full-scale invasion. General educational activity was relatively evenly distributed, with Gini coefficients of 0.2399 for total activity

and 0.2442 for education. The main centres were the city of Kyiv and the Kharkiv, Dnipropetrovsk, Lviv, and Odesa regions.

Higher education teaching staff were considerably more concentrated ($G = 0.4789$), particularly in the city of Kyiv and Kharkiv region. The strongest spatial concentration was observed for R&D personnel ($G = 0.7782$): the city of Kyiv accounted for more than 47% of researchers in 2019 and 52% in 2021, while Kharkiv, Dnipropetrovsk, Lviv, and Odesa formed a secondary group of research centres. Thus, even before the full-scale invasion, Ukraine's academic system displayed a clear hierarchy: relatively balanced general educational capacity, moderate concentration of higher education personnel, and pronounced concentration of research capacity.

The subsequent Lorenz-curve analysis demonstrates how this pre-war structure changed under the influence of external shocks. For teaching staff in higher education institutions (Figure 6), the distribution remained relatively stable in 2019-2021, with Gini coefficients around 0.47-0.49. The concentration increased substantially after 2022: the coefficient reached 0.5459 in 2022-2023 and 0.5475 in 2023-2024. In the latter period, 96% of regions accounted for only 74.44% of teaching staff, while approximately one quarter was concentrated in the remaining 4% of regions. This indicates a marked increase in spatial polarisation following the onset of full-scale war.

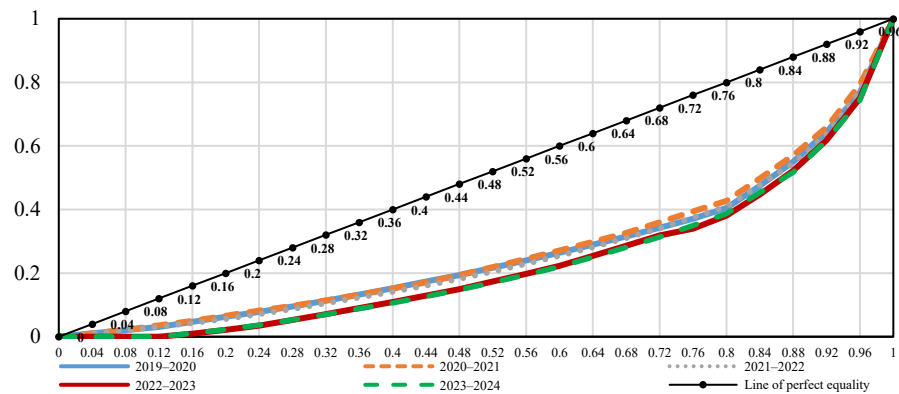


Fig. 6. Lorenz Curves of Teaching staff of HEIs

The spatial inequality of R&D personnel was substantially higher from the outset (Figure 7). The Gini coefficient reached 0.7679 in 2019 and remained above 0.77 in 2020-2021. In 2022, the curve became markedly more asymmetric: several regions recorded no measurable R&D personnel, while the upper tail retained a dominant share of national research capacity. The Gini coefficient increased to 0.7909, its highest value in the observation period. (Figure 7).

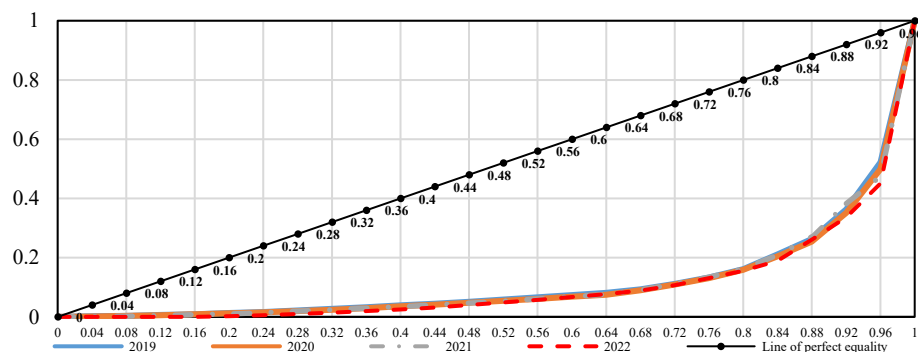


Fig. 7 Lorenz Curves of R&D personnel

The comparison of the two Lorenz curves reveals a structurally higher concentration of research personnel than teaching staff throughout the period. After 2022, both distributions became more unequal, but the change was particularly pronounced in R&D. The results therefore indicate that the war did not create spatial inequality in Ukraine's academic system but **amplified a pre-existing concentration pattern**, with the strongest effects observed in the research sector.

5.2. Spatial redistribution of academic personnel

The dynamics of Location Quotients (LQ) provide a more detailed view of the spatial redistribution of academic human capital. Figures 8 and 9 show the regional concentration of higher education teaching staff and researchers in 2019-2021, thereby establishing the spatial configuration preceding the full-scale invasion. (Figures 8 and 9).

Location Quotient - Teaching staff of HEIs in Total Activities



Chart: Tavirko O., Yanovska V. - Created with Datawrapper

Location Quotient - Number of R&D personnel in Total Activities



Chart: Tavirko O., Yanovska V. - Created with Datawrapper

Figure 8. Regional Location Quotient of scientific and pedagogical workers

https://www.datawrapper.de/_/8XYV8/

Figure 9. Regional Location Quotient of researchers

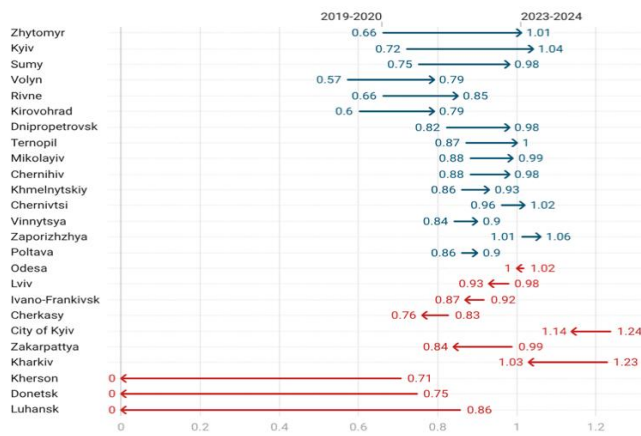
https://www.datawrapper.de/_/hnKCt/

Among teaching staff, the strongest concentration was observed in Kyiv and Kharkiv, where LQ increased from 2.43 to 2.64 and from 1.77 to 1.83, respectively, in 2020-2021. Lviv (LQ = 1.37) and Odesa (LQ = 1.08) also maintained relatively strong academic positions. In contrast, declining LQ values in Donetsk, Luhansk, Kirovohrad, Zhytomyr, and Chernihiv indicate a weakening of their relative academic capacity already before the full-scale invasion.

The research sector demonstrates substantially stronger spatial concentration. Kyiv's LQ increased from 5.89 to 6.41, confirming its dominant position in the national research system. At the same time, Kharkiv experienced a decline from 1.94 to 1.00, while Lviv and Dnipropetrovsk increased to 1.07 and 1.33, respectively. The near-zero LQ values observed in Zaporizhzhia, Kirovohrad, and Luhansk indicate a severe weakening of their research capacity.

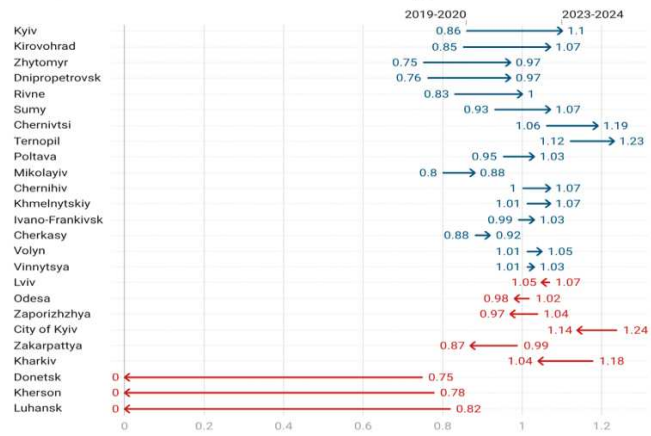
The analysis of academic personnel by qualification provides further evidence of spatial redistribution. For scientific and pedagogical staff, the dynamics of Doctors of Sciences and PhDs/Candidates of Sciences are presented in Figures 10 and 11.

Doctor of science of Teaching staff of HEIs



Source: Yanovska V., Tsvirko O. • Created with Datawrapper

PhD/candidate of sciences of Teaching staff of HEIs



Source: Yanovska V., Tsvirko O. • Created with Datawrapper

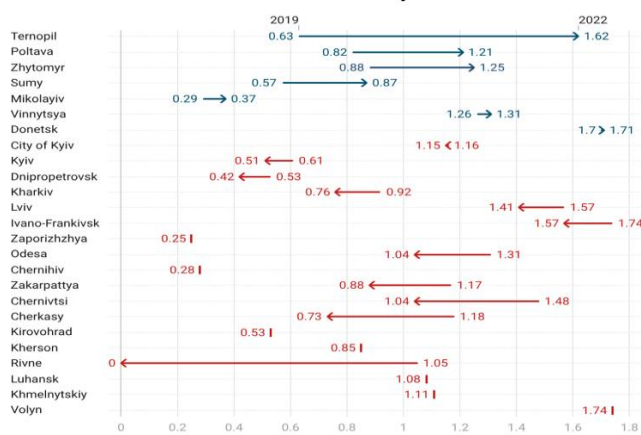
Figure 10. Dynamics of regional Location Quotient of Doctor of Science in the structure of scientific and pedagogical workers
https://www.datawrapper.de/_/F1Xi3/?v=2

Figure 11. Dynamics of regional Location Quotient of candidates of sciences/PhD in the structure of scientific and pedagogical workers
https://www.datawrapper.de/_/UqUMh/

Traditional academic centres - particularly Kyiv, Kharkiv, Odesa, and Lviv - retained relatively high concentrations of Doctors of Sciences, although their trajectories became more heterogeneous. At the same time, increasing LQ values in several western and central regions indicate a gradual redistribution of highly qualified personnel. A similar pattern is observed among PhDs/Candidates of Sciences, with growing localisation in Chernivtsi, Ternopil, Sumy, Rivne, Poltava, Kirovohrad, Ivano-Frankivsk, Zhytomyr, Dnipropetrovsk, Volyn, and Vinnytsia. These changes may indicate the relocation or reorientation of academic personnel from traditional centres toward regions offering greater institutional and security stability.

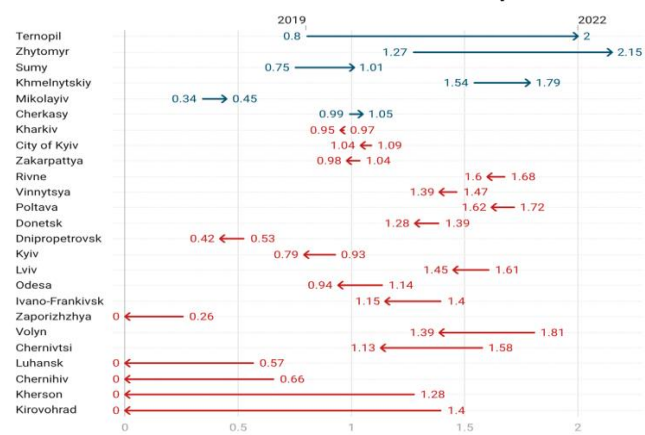
The R&D sector demonstrates a comparable but more pronounced redistribution. Figures 12 and 13 show the dynamics of LQ for Doctors of Sciences and PhDs/Candidates of Sciences among researchers.

Doctor of science of Number of R&D personnel



Source: Yanovska V., Tsvirko O. • Created with Datawrapper

PhD/candidate of sciences of Number of R&D personnel



Source: Yanovska V., Tsvirko O. • Created with Datawrapper

Figure 12. Dynamics of regional Location Quotient of doctors of science in the structure of researchers
https://www.datawrapper.de/_/tpCmw/

Figure 13. Dynamics of regional Location Quotient of candidates of sciences/PhD in the structure of researchers
https://www.datawrapper.de/_/lurLI/?v=3

The decline in LQ among highly qualified researchers in Kharkiv and Dnipropetrovsk, combined with increases in selected western and central regions, suggests a redistribution of research human capital under wartime conditions. Particularly notable are the increases observed in Ternopil, Sumy, Zhytomyr, Cherkasy, and Khmelnytskyi. Conversely, the decline in Kyiv and Kharkiv may reflect a combination of internal relocation, international migration, institutional disruption, and other wartime factors. Because direct individual-level migration data are unavailable, these changes should be interpreted as **indirect evidence of spatial intellectual redistribution rather than direct measurements of migration flows**.

Building on these principles and analyzing the distribution of teaching staff and researchers, it is essential to focus not merely on the number of universities or regional publication output. Instead, the key issue lies in understanding interaction patterns and allocation models of intellectual potential that balance the concentration of cognitive capacities with the decentralisation of academic space. Typologies of spatial knowledge organisation include at least four models, each associated with specific advantages and risks: the centralised model (Hennemann et al. 2011), the polycentric model (Tang & Dou 2022), the network-integrated model (Cooke 2017), and the digital mobility model (Meusburger 2017).

Overall, the LQ analysis demonstrates a dual process: **the strengthening of established academic centres and the emergence or reinforcement of alternative regional nodes**. The war intensified this redistribution, particularly in the research sector, while several western and central regions increased their relative concentration of qualified academic personnel. The results therefore provide empirical support for interpreting changes in the spatial distribution of academic human capital as an indirect manifestation of internal intellectual migration and institutional adaptation to external shocks.

5. Conclusions

The findings indicate a growing spatial asymmetry within Ukraine's academic ecosystem, manifested in the concentration of educational and research capacity in a limited number of regions and the deepening differentiation between core centers and peripheral territories. The results reveal the dual nature of relative concentration. On the one hand, it enhances the quality of academic output and innovation performance through critical mass effects. On the other hand, excessive centralisation undermines systemic resilience and excludes peripheral regions from academic value-creation chains. Both internal and transnational intellectual migration are largely driven by this asymmetry, thereby reinforcing the depopulation of scientific environments in less-developed regions. In this context, post-war recovery policies in higher education and research in Ukraine should avoid both excessive consolidation and fragmentation. Instead, they should preserve the potential of existing academic centers as knowledge multipliers and sources of spatial diffusion of innovation, while fostering a diversified, adaptive, and resilient academic ecosystem.

The grouping of Ukrainian regions according to types of spatial organisation of science and education reveals substantial heterogeneity in structural integration and innovative capacity. The identified subsystems follow distinct development trajectories, necessitating differentiated national and regional policy approaches to support human capital, research institutions, and educational infrastructure. The results confirm the relevance of incorporating the spatial logic of intellectual migration into strategies for the development of higher education and science. Promoting regional balance in the distribution of academic resources is critical for ensuring national academic resilience and mitigating the effects of knowledge drain. A conceptual shift from passive responses to intellectual migration toward the strategic capitalisation of internal and international intellectual mobility implies the development of digital infrastructure, the strengthening of interregional academic networks, and the design of spatially adaptive institutional arrangements. Such arrangements should preserve the advantages of knowledge agglomeration while ensuring broader regional access to academic resources. In this context, Lorenz curves, Gini coefficients, and localisation coefficients can serve both as tools of spatial diagnostics and as

an evidence base for policy design in the recovery and development of the academic environment in post-crisis conditions.

Future research may focus on expanding the empirical base to capture dynamic changes in the spatial structure of the academic ecosystem under exogenous shocks, examining the relationship between localisation trends and funding allocation mechanisms, and analyzing qualitative dimensions of intellectual migration with attention to disciplinary and sectoral specificities of academic activity. Although the available data are limited, the results demonstrate the analytical potential of the proposed approach, which can inform the development of a monitoring system to support decision-making on institutional development within academic ecosystems, particularly in contexts of crisis, disruption, and shock. This opens avenues for designing adaptive instruments for the spatial transformation of educational and research infrastructure, taking into account regional characteristics, potential risks, and opportunities to mitigate adverse effects and harness the positive impacts of intellectual migration for the institutional development of regions and the country of origin.

Declarations

The authors declare that there is no funding.

Competing interests

The authors declare no competing interests.

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