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Modeling interregional migration and spatial attractiveness: A gravity-based panel approach

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ABSTRACT

This study uses an augmented gravity model to examine interprovincial migration in Mongolia, based on a strongly balanced panel dataset of 21 provinces from 2000 to 2024 using official data. The model includes economic, spatial, social, and environmental variables and applies Estimated Generalized Least Squares (EGLS) and Seemingly Unrelated Regressions (SUR) to address heteroskedasticity and correlated errors. The results show that provinces with higher GDP per capita, higher wages, and better healthcare access attract more migrants, while greater distance from the capital and limited employment opportunities reduce migration. Residual analysis reveals clear spatial differences across provinces. For example, Khentii receives more migrants than predicted, suggesting the influence of unobserved factors such as social capital and perceived safety. In contrast, Sukhbaatar shows negative effects, likely due to weak infrastructure and limited access to services. A comparison of eastern provinces (Khentii, Dornod, and Sukhbaatar) indicates high development potential but continued out-migration, highlighting a mismatch between economic capacity and migration outcomes. The study suggests that migration policies should consider quality of life, environmental conditions, and social infrastructure, and highlights the need for region-specific strategies. However, the analysis is limited by the use of aggregate data, and future research should include micro-level approaches to better understand migration decisions.

1. Introduction

Internal migration plays a crucial yet often overlooked role in regional development, especially in countries with vast geographical territories, sparse populations, and uneven spatial structures. Beyond the economic reallocation of labor, internal migration affects spatial justice, equity in public services, and long-term regional resilience. In transition economies such as Mongolia, where disparities in infrastructure, income distribution, and access to essential services are pronounced, it is essential to understand the factors and hidden patterns that drive interregional migration. This understanding is vital for creating informed spatial and development policies (Royuela and Ordóñez, 2016; Drobne and Drešček, 2019).

The analysis of internal migration has traditionally relied on spatial interaction models, particularly the gravity model (Anderson, 2011). This model interprets migration flows as dependent on the "mass" of both the origin and the destination, commonly represented by factors such as population size or economic output, as well as on the spatial friction associated with distance. Although traditional gravity models have been criticized for their simplicity and limited explanatory power (Beyer et al., 2022), they provide a solid and adaptable basis for empirical enhancements. These enhancements may include incorporating behavioral variables, accounting for human capital (Piras, 2017), and nonlinear scaling dynamics among urban areas (Prieto Curiel et al., 2018).

Such enhancements are especially significant in countries with diverse spatial and socioeconomic configurations, such as Mongolia. Empirical applications have demonstrated the gravity model's flexibility across diverse contexts. For instance, Piras

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(2017) highlighted how human capital and housing markets shape long-run internal migration patterns in Italy, while Royuela and Ordóñez (2016) emphasized the roles of informality and structural transitions in Ecuador's regional migration flows. In the Mongolian context, pronounced positive deviations in provinces such as Khentii and persistent negative residuals in regions such as Sukhbaatar indicate that unobserved factors beyond standard economic fundamentals may significantly influence migration decisions. These patterns suggest that latent dimensions such as social capital, perceived safety, and governance effectiveness may play a meaningful role in shaping interprovincial mobility.

Despite advancements in research methods, significant gaps remain in the literature. Much of the existing work focuses on urbanized or high-income countries, resulting in a lack of empirical studies on migration behavior in transitional and data-scarce settings. Furthermore, only a few studies systematically incorporate long-term panel data to examine both the spatial and temporal variations in migration dynamics (Caballero Reina et al., 2024). More importantly, limited attention has been devoted to identifying residual migration potentials that diverge from structural determinants, leading to the relative neglect of regions that consistently overperform or underperform in attracting migrants under similar institutional conditions.

To address these shortcomings, this study applies an extended gravity model to evaluate the drivers of interprovincial migration across Mongolia's 21 provinces from 2000 to 2024. The model integrates economic, spatial, social service, and environmental variables using balanced panel data and econometric techniques, including Estimated Generalized Least Squares (EGLS) and Seemingly Unrelated Regression (SUR). Beyond traditional predictors, the study uses residual diagnostics to identify provinces whose migration behavior is not fully captured by observed variables, thereby uncovering hidden dimensions of spatial attractiveness and regional differentiation. Special attention is given to the eastern region of Mongolia, where provinces with comparable institutional and policy environments exhibit markedly different migration outcomes, offering a valuable within-region setting for examining structural mismatches between development potential and population mobility. By doing so, this research makes both theoretical and empirical contributions to the study of internal migration. It reinforces the idea that migration is not driven solely by economic incentives but also reflects deeper spatial identities, institutional trust, and perceptions of environmental security.

These insights are crucial for designing regionally balanced and socially inclusive development strategies in Mongolia and similar settings undergoing demographic and spatial transitions. A preliminary version of this study was previously made available as a preprint (Tegshjargal et al., 2025). The current version extends that work by incorporating balanced panel data through 2024 and employing advanced estimation techniques, including EGLS and SUR.

2. Theoretical and empirical background

The study of internal migration is closely related to spatial interaction theory, with the gravity model serving as the primary analytical framework for understanding this phenomenon. Inspired by Newtonian physics, the gravity model suggests that the volume of migration between two regions is directly proportional to their economic or demographic "mass" and inversely proportional to the distance separating them (Anderson, 2011). Over time, this model has evolved beyond its initial simplicity. Researchers have integrated concepts from behavioral economics, push-pull theory, and locational utility to better capture the factors driving migration (Nazeer et al., 2022). Additionally, extensions involving nonlinear dynamics and stochastic components have emerged, as demonstrated in the work of Park et al. (2018), highlighting the model's adaptability.

Despite its broad applicability, critiques remain. Beyer et al. (2022) argued that the gravity model is inadequate for explaining migration causality and struggles to achieve predictive accuracy in global settings. To address such concerns, recent studies have enhanced the model by integrating multidimensional variables, including infrastructure, social services, environmental risk, and regional inequality (Qi et al., 2025).

In post-socialist and transitional contexts, housing structures, institutional reforms, and regional transformation dynamics have further complicated the migration process (Bunea, 2012). Royuela and Ordóñez (2016) emphasized development-driven internal migration in Ecuador, while Piras (2017) incorporated human capital and heterogeneity into long-run models. In East Asia, Kim (2022) highlighted the importance of economic fundamentals.

Empirical evidence indicates that gravity models are robust across diverse regions and periods. In the United States, Ton et al. (2024) demonstrated that natural hazards significantly affect internal migration, a finding that aligns with research from Indonesia (Wajdi et al., 2017) and South Asia (Dharmadasa and Herath, 2020). In Europe, discussions are often dominated by spatial inequality and institutional legacies. Studies conducted in Slovenia (Drobne and Drešček, 2019), Spain (Hierro, 2009), the Czech Republic (Jandová and Paleta, 2015), and Romania (Bunea, 2012) emphasize the importance of infrastructure, governance, and regional identity.

Caballero Reina et al. (2024) used advanced predictive techniques to evaluate residual-based migration potential across global migration flows, whereas Maza (2020) and Pietrzak et al. (2012) employed panel-based models to examine interregional disparities. Additionally, Paudel and

Lahiri (2025) analyzed the effects of regional size in the U.S., and Qi et al. (2025) showed that internet search data can serve as a proxy for migration intentions.

Mongolia presents a unique empirical case. Provinces such as Khentii and Sukhbaatar consistently exhibit systematic deviations between observed and gravity-predicted migration flows, suggesting the presence of latent influences beyond standard economic and spatial determinants. These deviations suggest the relevance of unobserved socio-cultural and institutional factors, including cultural cohesion, trust in local governance, informal networks, and perceived quality of life, which have also been highlighted in comparative studies from Eastern Europe (Pietrzak et al., 2012; Bunea, 2012).

Despite progress, notable gaps persist. Few studies comprehensively integrate economic, social, spatial, and environmental variables within a long-term panel framework, especially in post-socialist, sparsely populated contexts such as Mongolia (Bunea, 2012). Moreover, the dynamic roles of cultural identity, historical context, and perceived governance quality remain under-quantified. Although residual-based diagnostic techniques have been applied in selected international studies, they remain underutilized in national-level analyses, limiting empirical understanding of persistent overperformance or underperformance in regional migration outcomes (Caballero Reina et al., 2024).

Drawing on these theoretical and empirical insights, this study formulates five hypotheses to investigate migration patterns across Mongolian provinces:

H1: Higher economic performance (GDP per capita, wage levels) is positively associated with in-migration.
H2: Improved access to healthcare, education, and transport infrastructure increases the regional attractiveness of migration.
H3: Greater geographic remoteness and distance from the capital are negatively correlated with migration inflows.
H4: Environmental vulnerabilities, such as extreme climatic shocks and long-term ecological stress, are expected to reduce the likelihood of in-migration, either directly or indirectly through their interactions with economic and infrastructural conditions.
H5: Certain provinces systematically overperform or underperform predicted migration flows due to persistent unobserved socio-cultural, institutional, or governance-related factors.

These hypotheses provide a comprehensive understanding of internal migration, highlighting that mobility decisions involve factors beyond economics. They also encompass spatial opportunities, environmental quality, and socio-political perceptions. This framework is particularly relevant for transition economies facing uneven regional development.

3. Methodology

3.1. Data and variables

This study uses a strongly balanced panel dataset covering all 21 provinces of Mongolia, including the capital city, and spanning 25 years from 2000 to 2024, resulting in 525 province-year observations. All variables are compiled from official administrative statistics published by the National Statistical Office of Mongolia and related government sources. The longitudinal and regional structure of the data enables a comprehensive analysis of both temporal changes and spatial variation in internal migration flows within a sparsely populated, geographically diverse country. To systematically assess the factors that influence interprovincial migration, the explanatory variables are organized into five thematic categories:

- Migration variables: The number of in-migrants (MIGIN) to each province is used as a proxy for its attractiveness or pull potential. At the same time, out-migrants (MIGOUT) reflect push factors driving population departure. All migration flow variables are derived from official population registration records rather than survey-based data. Net migration (MIGNET), calculated as the difference between in- and out-migration, indicates the net direction and intensity of migratory flows.
- Spatial and locational factors: Distance to the capital city Ulaanbaatar (DIST) is employed to approximate geographic remoteness and the cost of access to national-level infrastructure, markets, and government services. DIST is measured as the road distance in kilometers between each provincial center and Ulaanbaatar. This variable captures the spatial friction commonly emphasized in gravity-based models.
- Economic indicators: Several economic variables are included to capture labor market dynamics and regional income disparities. These include nominal and real gross provincial product per capita (PGDP and PRGDP), average monthly wages (WAGE), and the provincial unemployment rate (UNEMP). All real economic variables are expressed in constant 2010 prices, using official deflators from the National Statistical Office of Mongolia, to eliminate inflationary effects and ensure intertemporal comparability. Collectively, they represent the economic pull factors influencing migration decisions.
- Quality of life and social services: Social infrastructure is measured through the Human Development Index (HDO), which represents a composite provincial-level indicator encompassing health, education, and income dimensions, compiled by the National Statistical Office of Mongolia. In addition, the number of schools per 1,000 people (SCHOOL) serves as an indicator of educational access, while the number of physicians per 10,000 people (DOCTOR) represents

healthcare availability. These variables aim to assess non-economic aspects of regional attractiveness.

- Environmental and administrative indicators: To capture environmental and institutional dimensions, the model incorporates average annual temperature (TEMP) as a basic climatic indicator. Furthermore, the share of provincial government expenditure in regional GDP (GEGDP), local budget support per capita (LSPC), defined as per-capita fiscal transfers allocated from the central government to provincial budgets, and industrial output per capita (ISPC) are used to measure administrative capacity and development effort. Finally, livestock units per capita (LUPC) are included to reflect the agrarian and pastoral economic base that remains central to many rural provinces.

This comprehensive set of variables provides a multidimensional framework for understanding the complex and region-specific determinants of internal migration in Mongolia. The operationalization of both structural and contextual indicators enables more nuanced interpretations that extend beyond purely economic explanations, aligning with theories of extended migration and regional development.

3.2. Model structure

This research employs an augmented gravity model to estimate migration inflows, accounting for economic, spatial, and institutional factors. The classical gravity model posits that migration between two regions is positively correlated with their economic size and negatively correlated with the distance separating them. The initial model is specified as follows:

$$MIGIN_{it} = \alpha * \frac{(GDP_{it})^{\beta_1} * (GDPUB_{it})^{\beta_2}}{(DIST_i)^{\beta_3}} * e^{\varepsilon_{it}} \quad (1)$$

To linearize the model and interpret elasticities, a log-log specification is used:

$$\ln(MIGIN_{it}) = \alpha + \beta_1 \ln(GDP_{it}) + \beta_2 \ln(GDPUB_{it}) - \beta_3 \ln(DIST_i) + \varepsilon_{it} \quad (2)$$

This base model is then expanded to include additional variables from the five categories described above, leading to the following general formulation:

$$\ln(MIGIN_{it}) = \alpha + \sum_k \beta_k \ln(X_{kit}) + \varepsilon_{it} \quad (3)$$

where, X_{kit} represents the economic, social, and environmental characteristics of each province i in year t, and β_k are the estimated elasticities.

3.3. Estimation techniques

Due to the panel nature of the dataset, we utilized multiple estimation methods to address potential issues such as heteroskedasticity, autocorrelation, and cross-sectional dependence:

- Panel least squares (PLS): This method serves as a baseline estimation and does not control for region-specific effects.
- EGLS with cross-section weights: This approach corrects for heteroskedasticity across provinces by assigning different variances to each cross-section.
- EGLS with period weights: This method accounts for time-specific shocks, such as macroeconomic fluctuations related to events like the 2009 global financial crisis or the COVID-19 pandemic.
- EGLS with cross-section SUR: This technique adjusts for contemporaneous correlation between provinces, providing the most robust and efficient estimates.

To assess potential multicollinearity, Variance Inflation Factors were examined and found to remain within acceptable thresholds. Given the long-run focus of the gravity framework, the use of logarithmic transformations, and the reliance on inflation-adjusted variables, formal panel unit root testing was not deemed essential for the objectives of this study.

3.4. Regional case focus: Eastern provinces

We conducted a focused case analysis for the three eastern provinces of Dornod, Sukhbaatar, and Khentii, selected due to their shared institutional and policy environment yet markedly different migration outcomes. These provinces collectively experience high net out-migration despite significant natural resource endowments and agricultural potential. The gravity model residuals reveal persistent heterogeneity within the region, indicating a structural mismatch between development potential and actual in-migration flows, which provides a valuable setting for within-region comparative analysis of latent migration determinants.

4. Results

4.1. Estimation results of the gravity model

The estimation results from the panel-data gravity model underscore the significant influence of economic, geographic, and social-service variables on internal migration flows. Among the four model specifications tested, Panel Least Squares (PLS), EGLS with cross-section weights, EGLS with period weights, and EGLS with cross-section SUR, the SUR-based model demonstrated the highest explanatory power (R^2=0.95) and the most desirable Durbin-Watson statistic (1.91), indicating minimal serial correlation in the residuals.

These results confirm the suitability of the SUR specification for capturing cross-sectional dependence and unobserved common shocks across provinces, and it is therefore used as the preferred

model for interpretation. The comparison of different panel regression specifications is presented in Table 1.

$$MIGIN_{it} = A * \frac{GDP_{it}^{0.57} * WAGE_{it}^{1.05} * DOCTOR_{it}^{0.36}}{DIST_i^{0.48} * GDPUB_t^{1.17} * LFPR_{it}^{0.51} * e^{\varepsilon_{it}}}$$

where, the constant term is $A = e^{11.762} \approx 127{,}606.6$ and the log-linear gravity model reveals several statistically significant predictors of in-migration across provinces:

- The distance from the capital exhibited a strong and negative coefficient (-0.48), confirming that geographical remoteness remains a deterrent to migration.
- The provincial GDP showed a positive and statistically significant coefficient (0.57), suggesting that regions with higher economic output attract more migrants.
- Capital City GDP yielded a substantial negative coefficient (-1.17), indicating that the economic dominance of the capital discourages movement into other regions.
- The average wage appeared as the most influential positive factor (1.05), highlighting the pivotal role of labor compensation in influencing migration choices.
- Doctors per 10,000 people had a modest but positive impact (0.36), suggesting the importance of accessible healthcare.
- Labor Force Participation Rate was negatively associated with migration inflows (-0.51), implying that saturated labor markets reduce the relative attractiveness of regions.

Taken together, these results indicate that economic incentives and social-service availability strongly shape migration inflows, while spatial constraints and capital dominance exert persistent deterrent effects, laying the groundwork for the residual-based analysis that follows.

4.2. Migration potential based on model residuals

Gravity models help understand the key factors that drive internal migration, including economic size, geographic distance, and labor market conditions. However, they often struggle to account for hidden or non-quantifiable influences on population movement. To overcome this limitation, we performed a residual analysis by comparing the actual migration inflows with those predicted by the extended gravity model. We calculated the residual for each province and year using the following transformation:

$$\varepsilon_{it} = \ln(Actual\ MIGIN_{it}) - \ln(Fitted\ MIGIN_{it}) = ln\left(\frac{Actual}{Fitted}\right) \quad (4)$$

A positive residual (ε_{it}>0) implies that the actual number of in-migrants is higher than predicted by the model, signaling the presence of unobserved or unquantified attractors, such as cultural affinity, informal networks, administrative decisions, or perceived quality of life.

Table 1: Comparison of panel regression models

Independent variables	Panel least squares		Panel EGLS (cross-section weights)		Panel EGLS (peripd weights)		Panel EGLS (cross-section SUR)	
	coefficient	t-stat	coefficient	t-stat	coefficient	t-stat	coefficient	t-stat
Constant	11.85***	9.18	13.63***	12.44	11.63***	-15.26	11.76***	44.07
LOG(DIST)	-0.48***	-10.71	-0.42***	-12.58	-0.46***	12.40	-0.48***	-67.92
LOG(GDP)	0.58***	9.72	0.61***	15.94	0.53***	-9.08	0.57***	50.98
LOG(GDPUB)	-1.19***	-7.26	-1.08***	-8.16	-0.98***	-2.49	-1.17***	-33.55
LOG(LFPR)	-0.54**	-2.13	-0.87***	-4.05	-0.44**	5.47	-0.51***	-10.48
LOG(WAGE)	1.07***	5.08	0.89***	5.33	0.81***	2.16	1.05***	26.44
LOG(DOCTOR)	0.38**	2.06	0.14	0.91	0.28**	-15.26	0.36***	7.97
R-squared	0.463784		0.526148		0.561393		0.949768	
F-statistic	74.67131		95.86140		110.5021		1632.352	
DW stat	0.870128		0.900663		0.654472		1.908733	

***, **: Denote statistical significance at the 1%, 5%, respectively; All variables are expressed in logarithmic form, and the Constant (Intercept) term replaces the original Cyrillic label used in earlier drafts; The EGLS models are adjusted using cross-section and period weights, whereas the SUR model accounts for cross-sectional heteroskedasticity and contemporaneous correlation

This interpretation is consistent with prior findings emphasizing the role of social capital, institutional trust, and place-based identity in shaping migration outcomes. Conversely, a negative residual (ε_{it}<0) indicates that the region underperforms relative to its predicted attractiveness, potentially due to governance inefficiencies, social instability, or environmental degradation that are not captured by standard quantitative variables. Similar residual-based underperformance has been documented in studies of post-socialist and transition regions where formal economic indicators fail to reflect lived conditions and institutional quality. As shown in Fig. 1, the migration potential of eastern provinces exhibits substantial temporal fluctuations, with notable regional disparities over the period 2000–2024.

We performed a focused residual analysis for three provinces in the eastern region: Khentii, Dornod, and Sukhbaatar, which share broadly comparable institutional and policy environments yet display markedly different residual migration trajectories, making them particularly suitable for within-region comparative analysis.

- Khentii Province demonstrated consistently positive residuals across the 2000 to 2024 period, particularly during periods of national economic

stagnation. This pattern suggests that the province benefits from strong non-economic pull factors, such as cultural symbolism as the birthplace of Chinggis Khaan, ecological stability, and moderate population pressure. Despite having an average or below-average GDP and service indicators, Khentii appears to attract migrants due to the perceived quality of life, land accessibility, and perhaps stronger kinship-based migration patterns. These findings align with the literature emphasizing social capital, cultural attachment, and identity-driven mobility as persistent drivers of migration that are not easily quantified in standard economic models.

- Sukhbaatar Province, by contrast, showed persistently negative residuals throughout the period. The province underperforms even when controlling economic and geographic disadvantages, indicating a lack of compensating social or environmental attractors. Low infrastructure connectivity, weak public service delivery, and limited industrial diversification are likely to contribute to this trend. From a governance perspective, the magnitude and persistence of negative residuals suggest that existing fiscal transfers and development programs have not translated into effective improvements in perceived regional attractiveness. Importantly, the harmful residuals indicate that current development interventions are insufficient to overcome the province's structural push factors, raising questions about the effectiveness of spatially neutral policy approaches.
- Dornod Province exhibits a mixed pattern, with positive residuals prior to 2010, transitioning to consistently harmful residuals thereafter. This shift aligns with regional economic stagnation and growing inter-regional disparities following the commodity downturn. The province's early advantage, possibly stemming from its role as a transport corridor and energy base, appears to have eroded due to declining investments and environmental degradation. The observed reversal in residuals reflects a structural weakening of both economic and non-economic attractors, suggesting a deterioration in the province's relative position within the national migration system. The reversal in residuals suggests a decline in the province's perceived and actual attractiveness, with implications for both policy support and private sector engagement.

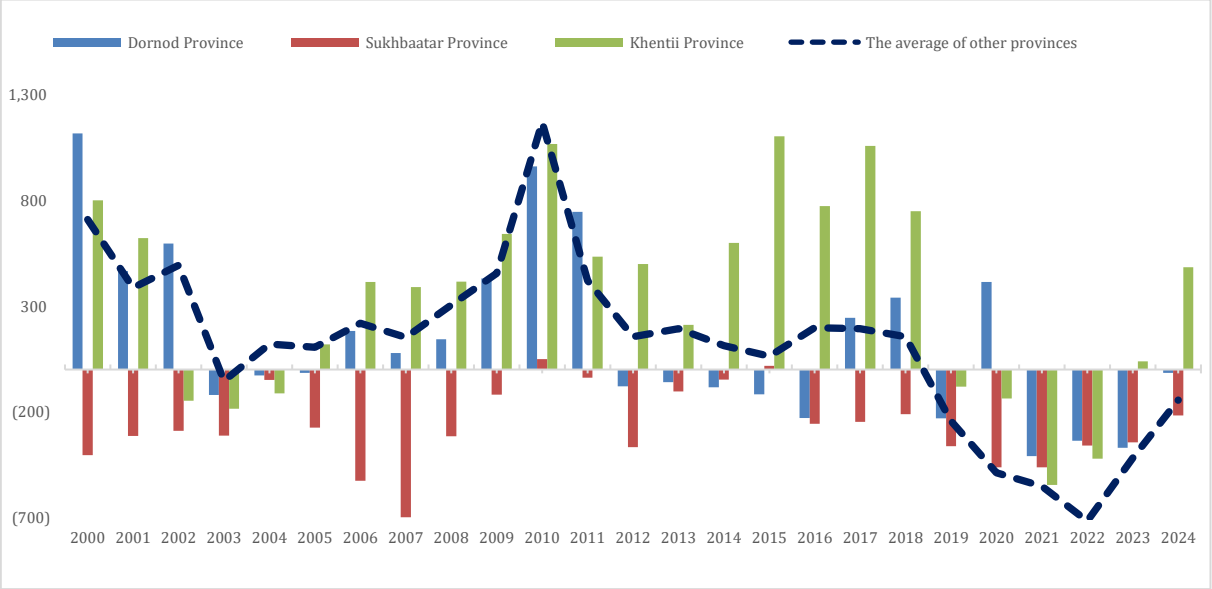

Fig. 1: Migration potential of eastern provinces: 2000-2024

4.3. Regional comparison of migration attractiveness in the eastern provinces

This section presents a comparative evaluation of migration attractiveness across the three eastern provinces using a multi-criteria assessment matrix. Six core dimensions were considered: (1) economic growth and sectoral structure, (2) access to public services, (3) transport and logistics connectivity, (4) natural resource and agricultural capacity, (5) tourism potential, and (6) environmental resilience. These dimensions were selected to complement the gravity-model results by incorporating qualitative and structural factors that are not fully captured by econometric estimation. Each dimension was assessed using both qualitative indicators and empirical data extracted from official planning documents, provincial statistics, and spatial development reports.

Table 2 summarizes the comparative characteristics of the Dornod, Sukhbaatar, and Khentii provinces across the six dimensions. The assessment reveals distinct patterns in regional development trajectories and identifies key structural advantages and constraints affecting each province's capacity to attract migrants. To quantify regional differences and support evidence-based planning, a five-point scale (1=very low, 5=very high) was used to assign scores to each criterion. The scoring procedure reflects relative performance

rather than absolute levels and is intended to facilitate within-region comparison under broadly similar institutional conditions. These scores reflect the relative strengths and weaknesses of the provinces in their capacity to absorb internal migration. Fig. 2 presents a comparative assessment of provincial attractiveness scores, highlighting substantial inter-regional variation and reinforcing the relative advantage of Khentii province across multiple dimensions.

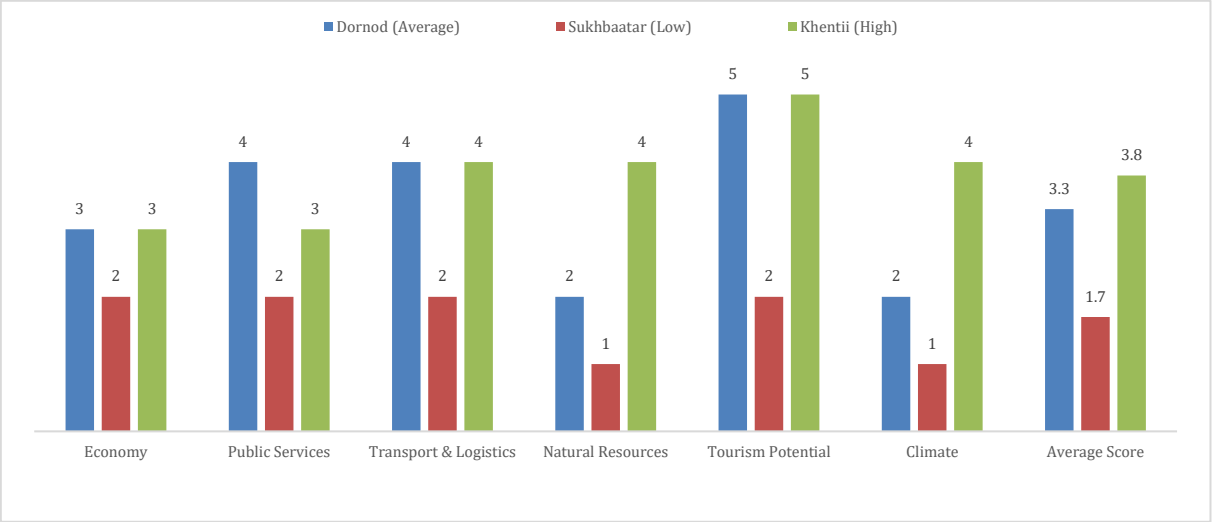

Fig. 2: Comparison of attractiveness scores of eastern provinces

Table 2: Comparative evaluation of eastern provinces' migration attractiveness

Dimension	Dornod	Score	Sukhbaatar	Score	Khentii	Score
Economic structure and growth	Mixed mining and logistics economy with emerging industrial activities	3	Pastoral economy with weak industrial diversification and high unemployment	2	Agriculture- and livestock-based economy with relatively stable employment	3
Public services	Moderate improvement in healthcare and education in urban centers	4	Limited access to healthcare, education, and administrative services	2	Expanding public services and ongoing local development programs	3
Transport and logistics connectivity	Strong rail and road connectivity through regional transport corridors	4	Weak road infrastructure and limited regional connectivity	2	Direct paved road access to Ulaanbaatar and improving local roads	4
Natural resources and agricultural capacity	Limited water resources and relatively low agricultural productivity	2	Severe land degradation and increasing desertification pressure	1	Favorable soil and vegetation conditions for agriculture and livestock	4
Tourism and cultural development	Developing eco-tourism and nature-based tourism potential	5	Limited tourism infrastructure and low tourism activity	2	Strong historical, cultural, and eco-tourism development potential	5
Environmental and climate conditions	Harsh climate conditions with ecological vulnerability	2	High environmental stress and significant desertification risk	1	Relatively favorable environmental and climatic conditions	4
Average attractiveness score	Overall moderate regional attractiveness	3.3	Lowest regional attractiveness among the three provinces	1.7	Highest regional attractiveness and migration potential	3.8

Scores are based on a five-point scale where 1 indicates very low attractiveness, and 5 indicates very high attractiveness

The results indicate that Khentii Province achieved the highest overall score, with an average of 3.8 out of 5. Khentii's strength lies in its integrated tourism potential, cultural heritage, favorable ecological zones, and improved infrastructure. Its strategic location, relatively balanced development, and targeted public programs, such as historical tourism routes and expanded educational access, contribute to its growing appeal. This multidimensional advantage is consistent with the province's persistently positive migration residuals identified in the econometric analysis. Dornod Province, with an average score of 3.3, ranks second. It demonstrates strong performance in transportation and logistics, thanks to its connections with transnational rail and road corridors, as well as moderate access to public services. However, it faces environmental vulnerabilities, such as a dry climate and limited arable land, that could hinder long-term population retention without strategic investment. These constraints help explain the observed deterioration in Dornod's migration residuals after 2010. Sukhbaatar Province emerges as the least attractive in the comparative assessment, scoring an average of only 1.7 across the six dimensions. The province experiences severe environmental degradation, inadequate infrastructure, and limited access to public services, particularly in rural soums. This combination of structural disadvantages aligns with the province's persistently negative migration residuals, indicating deep-rooted barriers to population retention. These structural deficits increase the likelihood of outmigration, underscoring the need for urgent policy interventions targeting environmental restoration,

service decentralization, and economic diversification.

Overall, the comparative assessment reinforces the residual-based findings by demonstrating that differences in migration outcomes across the eastern provinces are closely linked to multidimensional development conditions rather than economic indicators alone. These findings provide valuable input for spatial development planning and the design of inter-provincial migration policies. They also highlight the importance of regional heterogeneity in explaining population flows and suggest that differentiated policy instruments are necessary to unlock latent migration potential in underperforming areas.

5. Discussion

The results of this study validate the applicability of the extended gravity model to internal migration analysis in sparsely populated, transition economies such as Mongolia. By incorporating economic, spatial, social, and environmental variables into a panel framework, the model captures both structural and hidden factors influencing migration flows. This integrated approach addresses key limitations of conventional gravity models by explicitly accounting for latent dimensions of regional attractiveness.

Empirical support for H1 confirms that economic performance, particularly wage levels and GDP per capita, is a key driver of in-migration. The strong elasticity of average wages suggests that even modest compensation differentials influence mobility decisions, consistent with findings in Italy and East Asia (Piras, 2017; Kim, 2022). The negative relationship between labor force participation and in-migration implies that local labor market saturation reduces a province's relative attractiveness. This result highlights the importance of relative, rather than absolute, labor market conditions in shaping migration choices.

H2 is partially supported, as healthcare availability (physicians per capita) positively affects migration inflows. It aligns with theoretical perspectives on locational utility and recent evidence highlighting the role of quality-of-life factors in shaping mobility. While access to education could not be directly tested, the findings underscore the importance of public services in migration decision-making. The partial support for H2 suggests that social infrastructure influences migration primarily through specific service channels rather than uniformly across all public domains.

The consistent adverse effect of distance to the capital provides strong support for H3, confirming that geographic remoteness continues to impede migration. Moreover, the negative coefficient of Ulaanbaatar's GDP suggests that economic centralization may suppress regional mobility, a pattern seen in other post-socialist countries (Bunea, 2012; Beyer et al., 2022). This finding reflects a core-periphery dynamic in which capital-city dominance weakens the pull capacity of peripheral regions.

Although climatic variables do not directly support H4, residual analysis indicates that provinces such as Sukhbaatar, which face environmental degradation and weak infrastructure, consistently underperform in attracting migrants. This pattern aligns with studies that emphasize ecological stress as a deterrent to migration (Ton et al., 2024; Dharmadasa and Herath, 2020). Taken together, these results indicate that environmental vulnerability affects migration indirectly through its interaction with infrastructure quality and institutional capacity rather than as an isolated factor.

H5 is most clearly validated. Residual diagnostics show that some provinces systematically diverge from predicted migration flows due to unobserved factors. Khentii province, for example, exhibits consistent positive residuals, suggesting strong latent attractors such as cultural symbolism, perceived safety, and community cohesion. In contrast, Sukhbaatar consistently underperforms, reflecting a lack of compensatory assets beyond economic variables. These patterns align with findings from Eastern Europe and underscore the importance of incorporating social capital and perceptions of governance into migration models (Pietrzak et al., 2012; Caballero Reina et al., 2024). The strong validation of H5 reinforces the analytical value of residual-based diagnostics for identifying persistent regional advantages and disadvantages.

The comparative case of eastern provinces reinforces this interpretation. Khentii's integrated tourism and public service improvements support its positive migration potential. Dornod's transition from positive to adverse residual effects after 2010 highlights how declining investment and environmental stress can erode regional appeal. Sukhbaatar, with low scores across economic and service dimensions, exemplifies structural exclusion from internal mobility networks. These within-region contrasts demonstrate that similar policy environments can yield markedly different migration outcomes when local structural and institutional conditions diverge.

Overall, the study confirms that a complex interplay of economic, spatial, and institutional factors influences internal migration. The inclusion of residual-based analysis reveals hidden dimensions of regional attractiveness, offering valuable insights for spatially differentiated policy design. Rather than relying on uniform national strategies, the findings support the need for territorially targeted interventions that address place-specific deficits in services, governance capacity, and environmental resilience. In Mongolia and similar settings, migration policy must extend beyond economic incentives to address gaps in social infrastructure, ecological vulnerabilities, and the intangible qualities that make places livable and desirable.

6. Conclusion

This study employed an extended gravity model to analyze internal migration dynamics across Mongolia's 21 provinces, utilizing balanced panel data from 2000 to 2024. By incorporating spatial, economic, social, and environmental variables and employing robust panel estimation techniques (EGLS, SUR), the model successfully identified key drivers of interprovincial migration while revealing spatial heterogeneity and latent determinants. The combined econometric and residual-based approach strengthens causal interpretation by distinguishing between observable structural drivers and persistent unobserved regional effects.

Empirical evidence confirmed that economic factors, particularly GDP per capita and average wages, exert strong positive effects on in-migration, reaffirming classical migration theory and supporting recent findings in comparative settings (Piras, 2017; Kim, 2022). Healthcare availability was also positively associated with migration flows, suggesting the increasing salience of public service provision and regional welfare in shaping mobility decisions. In contrast, the effects of geographic remoteness and education infrastructure were weaker or more context-specific, highlighting spatial and demographic heterogeneity. These findings indicate that economic incentives operate most effectively when complemented by accessible social services rather than in isolation.

Residual-based diagnostics revealed structural mismatches between predicted and actual migration flows. For example, Khentii Province consistently attracted more migrants than the model anticipated, despite moderate economic fundamentals, suggesting the presence of unobserved factors such as local identity, environmental amenity, or social embeddedness (Park et al., 2018). Conversely, Sukhbaatar Province has consistently underperformed, likely due to entrenched disadvantages, including limited connectivity, weak institutional performance, and ecological fragility. The persistence of these residual patterns underscores the importance of accounting for social capital and governance quality when designing regional development interventions.

A comparative assessment of the eastern provinces reinforced these results. Khentii emerged as the most attractive region, benefiting from tourism potential and targeted development. Dornod displayed moderate attractiveness, though recent stagnation has diminished its appeal. Sukhbaatar, in contrast, consistently scored low across multiple dimensions, underscoring the need for sustained public investment and structural support. Taken together, these contrasts illustrate that provinces operating under similar national policy frameworks can experience markedly different migration outcomes due to localized institutional and environmental conditions.

Overall, the study highlights the limitations of uniform migration policy frameworks. Regionally differentiated strategies tailored to localized assets, constraints, and social dynamics are essential for fostering inclusive and balanced spatial development. Economic incentives alone are insufficient; public services, governance quality, and regional identity must also be considered. For Mongolia, the findings imply that migration policy should prioritize targeted improvements in healthcare access, transport connectivity, and place-based development initiatives in persistently underperforming provinces, particularly in environmentally vulnerable and border regions.

While the model provides robust insights, several limitations remain. The use of aggregate annual data limits its ability to capture short-term or informal migration trends; moreover, the absence of micro-level behavioral data hinders the interpretation of unmeasured causal drivers. Future research should integrate qualitative fieldwork, household surveys, and spatial econometric techniques to enrich the understanding of migration behavior in Mongolia and similar transitional economies. Such extensions would allow for a more precise identification of policy levers capable of translating development potential into sustainable population retention.

List of abbreviations

DIST	Distance to the capital city, Ulaanbaatar
DOCTOR	Number of physicians per 10,000 people
DW	Durbin–Watson
EGLS	Estimated generalized least squares
GDP	Gross domestic product
GDPUB	Capital city gross domestic product
GEGDP	Share of provincial government expenditure in regional GDP
HDO	Human development index
ISPC	Industrial output per capita
LFPR	Labor force participation rate
LOG	Logarithmic transformation/logarithm
LSPC	Local budget support per capita
LUPC	Livestock units per capita
MIGIN	Number of immigrants
MIGNET	Net migration
MIGOUT	Number of out-migrants
PGDP	Nominal gross provincial product per capita
PLS	Panel least squares
PRGDP	Real gross provincial product per capita
R^2	Coefficient of determination (R-squared)
SCHOOL	Number of schools per 1,000 people
SUR	Seemingly unrelated regressions
t-stat	t-statistic
TEMP	Average annual temperature
UB	Ulaanbaatar
UNEMP	Provincial unemployment rate
WAGE	Average monthly wages

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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