

Article

Assessing the Correspondence Between Functional and Sectoral Profiles Across Kazakhstan's Regions: A Dyadic Analysis of Inter-Regional Differences and Intra-Regional Dynamics

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Abstract

The sectoral approach has traditionally served as the principal tool for analyzing regional specialization; however, it does not reveal the functional content of employment or the distribution of tasks within economic activities. This article assesses the degree of correspondence between the functional structure of employment and the sectoral structure of output across 17 harmonized regions of Kazakhstan, a resource-dependent post-Soviet economy, over the period 2019–2024. Regional functional profiles are constructed within the task-based framework and comprise four aggregate task categories: non-routine cognitive (NRC), routine cognitive (RC), routine manual (RM), and non-routine manual (NRM). The sectoral structure is represented by the distribution of nominal output across 47 sectors. Inter-regional differences are measured using Jensen–Shannon distance. The empirical analysis is conducted on a dyadic panel of 816 observations, controlling for region size, urbanization, gross regional product per capita, extractive specialization, geographic distance, and time effects. Primary statistical inference relies on the Freedman–Lane permutation procedure within multiple regression quadratic assignment procedure (MRQAP). The results indicate a positive but moderate association between the two structures. The standardized coefficient on functional distance is 0.300 (MRQAP $p = 0.001$). Including the task variable raises R^2 by 5.5 percentage points. The finding remains robust under most alternative distance metrics, different sets of control variables, and sequential exclusion of individual regions. However, the association weakens noticeably when the three largest cities—concentrating a substantial share of non-routine cognitive tasks—are excluded simultaneously. Within-region estimates of correspondence for 2019–2024 are considerably less precise. Pair fixed-effects models and correlations based on net change and cumulative path length do not reveal a systematic contemporaneous relationship between changes in functional and sectoral structures over the observed period. The six-year observation window does not allow the longer-term pattern of their coevolution or possible lagged adjustment to be determined. Overall, functional and sectoral structures are related but not interchangeable. The results provide statistically supported evidence of a positive inter-regional association, although its strength varies by distance metrics and regional subsamples. For regional policy, the findings underscore the value of combining sectoral specialization indicators with information on the characteristics of jobs and accumulated labor competencies.



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1. Introduction

Regional specialization is traditionally described through the distribution of employment, output, and value added across economic activities. The sectoral approach makes it possible to identify production concentration, assess diversification prospects, and trace long-run trajectories of regional development. Evolutionary economic geography has shown that the emergence of new activities depends on already accumulated production and technological capabilities—that is, proximity between sectors shapes the direction of subsequent diversification (Frenken et al., 2007; Neffke et al., 2011; Boschma, 2017). Yet it remains insufficiently clear which specific functions and worker competencies shape the formation of a given sectoral structure in a regional economy.

This limitation becomes especially salient amid technological transformations spanning a broad range of sectors, contemporary patterns of the division of labor, and the spatial fragmentation of production. Today, a single sector may encompass managerial, engineering, analytical, production, logistics, and service functions, while many occupations have become transversal and are deployed across diverse activities.

A body of research on functional specialization has demonstrated that territories with similar sectoral structures may perform different functional roles within production systems: one concentrates headquarters, research, design, and professional services, while another concentrates direct production and standard operating functions, leading to differences in the territorial distribution of functions and sectors (Duranton & Puga, 2005; Coe et al., 2008; Timmer et al., 2019; Coveri & Zanfei, 2023).

Among the most widely used approaches to studying functional specialization in regional economic systems is the task-based framework, in which occupations are viewed through the lens of performed operations differing in routineness, cognitive complexity, and the need for manual labor or interpersonal interaction (Autor et al., 2003; Acemoglu & Autor, 2011). Technological development and participation in global value chains may shape not only employment levels within a sector but also demand for specific tasks within occupations and production processes. This may be associated with substantial shifts in the functional structure that are not accompanied by corresponding sectoral changes, and with significant changes in output structure under relatively modest effects on a region's task profile of employment.

Many scholars studying regional economic systems have shifted emphasis from sectoral to functional structure, linked to different combinations of skills and tasks. Feser (2003) proposed characterizing regions by what they do, not only by what they produce. Barbour and Markusen (2007) and Renski et al. (2007) showed that occupational and sectoral structures overlap but not to the extent that one reliably determines the other. Later work treats worker mobility, occupational relatedness, and skill content as regional capabilities shaping available diversification paths (Fitjar & Timmermans, 2017; Farinha et al., 2019; Buyukyazici et al., 2024; Deegan et al., 2024). These studies confirm that sectoral and labor dimensions are related yet reflect different mechanisms of knowledge accumulation and transfer.

Despite considerable development of both sectoral and task-based approaches, direct comparisons of full regional distributions of sectors and tasks remain limited. Most studies either assess the emergence of individual sectors and occupations or rely on cross-sectional data from developed countries. Less frequently is the strength of the association between

functional profiles and sectoral structures tested, especially in settings characterized by substantial territorial heterogeneity and resource dependence.

Kazakhstan presents a substantively informative case for such a test. Its regional system combines major administrative and service centers, resource-rich and industrial regions, and territories with a significant agricultural role. This heterogeneity generates considerable variation in sectoral profiles while allowing one to examine whether it is accompanied by differences in the functional composition of employment. Moreover, the capital intensity of resource and metallurgical production, inherited industrial geography, and the concentration of managerial and professional functions in the largest cities may cause output and labor functions to change at different speeds.

This study addresses three interrelated questions. First, to what extent do inter-regional differences in performed tasks correspond to differences in sectoral output structure? Second, to what extent does territorial differentiation—in region size, urbanization, economic development, extractive-sector influence, and geographic location—affect the strength of the link between sectoral and functional profiles? Third, are sectoral shifts within regions accompanied by corresponding changes in functional profiles? Theoretical expectations derived from the task-based approach, related variety, and the functional specialization literature are formalized in Section 2.

The empirical analysis draws on a panel of 17 regions of Kazakhstan for 2019–2024. Functional structure is measured by the distribution of employment across non-routine cognitive, routine cognitive, routine manual, and non-routine manual tasks; sectoral structure is measured by the distribution of nominal output across 47 economic activities. For each unordered pair of regions, Jensen–Shannon distances are computed, and the association between them is estimated in a dyadic panel model. Primary inference employs Freedman–Lane MRQAP with 9999 permutations, accounting for dependence among elements of distance matrices. Additional specifications include alternative metrics, control sets, regional and pair fixed effects, year-specific models, and analysis of structural change.

The results indicate that pairs of regions differing more substantially in the functional composition of employment also exhibit, all other things being equal, greater differences in sectoral output structure. At the same time, the strength of this association remains moderate: the standardized coefficient is 0.300, and including task distance raises explained variation by 5.5 percentage points.

The association retains statistical significance in most robustness checks and remains stable under the sequential exclusion of individual regions. Its magnitude declines when Astana, Almaty, and Shymkent are excluded simultaneously, indicating that the contrast between the largest cities and the remaining regions contributes substantially to the national pattern. Within-region estimates of correspondence for 2019–2024 are less precise and yield statistically inconclusive evidence on contemporaneous co-movement between functional and sectoral changes.

Taken together, the results characterize functional and sectoral structures as related and complementary dimensions of regional economic organization. Inter-regional differences in task profiles are positively associated with differences in sectoral output structure, while the temporal relationship between changes in the two structures remains less clearly identified given the limited time series.

The article makes three contributions. First, it provides a direct comparison of complete regional distributions of tasks and sectoral output, extending the analysis beyond individual specialization indicators. Second, it combines an assessment of inter-regional correspondence with an exploratory analysis of structural change within regions. Third, the evidence from a resource-dependent and spatially heterogeneous economy broadens the empirical scope of the task-based approach beyond developed-country settings. The

policy implication is that regional development strategies benefit from integrating sectoral priorities with information on job functions, labor competencies, and the skill composition of newly created employment.

The remainder of the article is organized as follows. Section 2 reviews theoretical approaches to sectoral relatedness, task structure of labor, and functional specialization, and formulates hypotheses. Section 3 describes the data, variable construction, and econometric strategy. Section 4 presents the main inter-regional results and an exploratory analysis of within-region structural change. Section 5 discusses economic mechanisms, policy implications, and limitations. Section 6 concludes.

2. Literature Review

2.1. Sectoral Specialization, Relatedness, and Regional Trajectories

The sectoral approach has traditionally occupied a central place in the analysis of regional specialization. The distribution of employment and gross output across economic activities permits identification of production concentration, quantitative assessment of diversification, and comparative analysis of territorial economic profiles.

Evolutionary economic geography has substantially enriched this approach by demonstrating that regional development trajectories are shaped not only by the current sectoral composition but also by accumulated capabilities that simultaneously open and constrain the set of realistic diversification paths. The concepts of path dependence and regional branching explain the emergence of new economic activities through cognitive, technological, and institutional proximity to existing competencies (Martin & Sunley, 2006; Neffke et al., 2011; Boschma, 2017).

Within this paradigm, the notion of related variety links regional economic outcomes not to diversity as such but to the degree of cognitive and technological proximity among activities. Related sectors can exchange knowledge efficiently and jointly exploit shared production capabilities, whereas unrelated diversity serves primarily an insurance function, reducing vulnerability to sectoral shocks (Frenken et al., 2007). Empirical research confirms that the probability of new activities emerging is significantly higher in regions where related competencies are already present, and that trade and production linkages amplify the effect of such technological proximity (Boschma & Iammarino, 2009; Neffke et al., 2011).

Yet sectoral classification based on ISIC/NACE primarily captures the product or market in which a firm operates but poorly reflects the functional content of workers' activities. Within a single sector, heterogeneous functions may coexist—strategic management, R&D design, analytics, material production, logistics, sales, and after-sales service. Moreover, identical sectors may play substantially different roles in regional economic structure: some areas concentrate headquarters, research centers, and highly skilled professional services, while others concentrate direct production capacities.

The conceptually important shift from sectoral to functional specialization of cities, elaborated by Duranton and Puga (2005), suggests that the territorial division of headquarter and production functions may deepen even with minimal change in sectoral codes. Thus, the sectoral profile remains an important but potentially incomplete measure of regional economic structure.

2.2. The Task-Based Approach and the Functional Structure of Employment

The theoretical foundation of functional analysis is the task-based approach to the labor market. Its central idea is that occupations comprise heterogeneous tasks, and that technological innovation, organizational transformation, and international trade directly affect the feasibility or substitutability of specific labor operations.

In the seminal work of Autor et al. (2003), a basic task typology was proposed—routine and non-routine, cognitive and manual. Subsequent research deepened this scheme, demonstrating that computerization primarily substitutes formalizable routine operations while complementing analytical, interactive, and creative functions (Spitz-Oener, 2006; Acemoglu & Autor, 2011).

The task-based approach explains structural changes in employment that cannot be reduced solely to intersectoral reallocation of labor. Labor market polarization may occur both within and across sectors: demand for medium-skilled routine occupations contracts, employment in highly skilled cognitive-interactive functions expands, and the segment of non-routine low-skilled personal services grows (Autor & Dorn, 2013; Goos et al., 2014).

A fundamental methodological distinction follows: sectoral structure characterizes what is produced in a territory, whereas task (functional) structure describes what kinds of activities workers actually perform. These two dimensions are closely linked through technology and production organization, yet no rigid one-to-one correspondence exists between them.

For regional analysis, this distinction acquires particular significance. Feser (2003) proposed grouping occupations by shared knowledge and skills, thereby shifting emphasis from what regions “produce” to what they “do.” Barbour and Markusen (2007), directly comparing sectoral and occupational structures of regions, showed that one cannot reliably reconstruct the other. Similar conclusions emerged from cluster studies: production linkages among sectors serve as a weak proxy for common labor competency requirements, while labor clusters only partially coincide with sectoral value chains (Renski et al., 2007). Currid and Stolarick (2010) emphasize that mismatch between sectoral and occupational geography substantially alters understanding of the nature of regional competitive advantage.

Contemporary integrated approaches confirm that relying exclusively on sectoral or occupational data yields an incomplete description of a territory’s economic structure (Lin et al., 2019).

2.3. Skills and Occupations as Regional Capabilities for Diversification

The literature on regional relatedness has gradually extended the notion of capabilities from sectors and technologies to occupational skills. Fitjar and Timmermans (2017) showed that worker flows across sectors can be used to measure a common skill base, and that related diversification depends on labor competencies available in a region. Farinha et al. (2019) decomposed occupational relatedness into task complementarity, skill similarity, and local co-concentration. Their results indicate that the emergence and disappearance of occupations is linked to the prior structure of the regional labor market, but different relatedness mechanisms operate unevenly.

Research on developing and heterogeneous regional systems confirms the importance of the occupational dimension. Using Brazilian data, Galetti et al. (2021) found that the effect of skill relatedness on structural change depends on region type; subsequent work distinguished complementary, similar, and locally synergistic occupational relatedness (Galetti et al., 2024). Buyukyazici et al. (2024) treat worker skills as regional capabilities and demonstrate that their relatedness and complexity possess explanatory power for sectoral diversification. Finally, Deegan et al. (2024) show that the emergence of new sector–occupation combinations depends simultaneously on related sectors and related occupations.

Taken together, these studies bring sectoral and functional perspectives closer without rendering them interchangeable. Sectoral relatedness reflects commonality of technologies, intermediate products, and markets, whereas occupational and task relatedness charac-

terizes labor mobility, skill transferability, and combinations of functions. A region may possess labor competencies similar to another's yet deploy them in a different sectoral mix, or host identical sectors organized around different functions. At the theoretical level, therefore, a positive but incomplete association between sectoral and task structures is expected.

2.4. Functional Specialization Under Production Fragmentation

Additional theoretical grounds for distinguishing sectoral and functional dimensions are provided by the literature on global production networks and global value chains. Within this approach, production is treated as a system of territorially distributed operations; consequently, a region's affiliation with a sector does not imply execution of all stages and functions in the corresponding chain (Henderson et al., 2002; Gereffi et al., 2005; Coe et al., 2008). Trade-in-tasks theory shows that individual tasks, in addition to goods and sectors, may become objects of spatial specialization (Grossman & Rossi-Hansberg, 2008).

Empirical research on functional specialization in international trade confirms that countries and territories may concentrate on management, R&D, marketing, support services, or production proper even under outwardly similar product structures (Timmer et al., 2019). Position in the chain is associated with uneven value creation and capture: the highest values tend to accrue to pre-production and post-production activities, although this pattern is not universal (Stöllinger, 2021). Coveri and Zanfei (2023) further show that international division of functions generates stable hierarchies of value capture.

For the present study, this literature matters as an explanation of why a sectoral code does not predetermine the functional content of employment. Even within a national economy, headquarter, engineering, service, and production functions may be localized in different regions. Consequently, inter-regional similarity in sectoral output should be accompanied by a degree of similarity in task structure; yet organizational fragmentation of production, differing capital intensity, and the transversal character of many occupations may prevent full alignment of these structures.

2.5. Research Gap and Hypotheses

The existing literature permits three complementary conclusions. First, regional sectoral development is shaped by accumulated regional capabilities and the relatedness of existing activities. Second, tasks and skills constitute a distinct dimension of regional capabilities and may be reallocated across sectors. Third, production fragmentation allows spatial separation of individual functions within a unified production system. Collectively, these propositions imply a degree of correspondence between sectoral and functional structures of regional economies.

Yet direct empirical comparisons of sectoral and functional distributions remain scarce. Studies directly comparing the two structures rely primarily on cross-sectional data from developed economies (Barbour & Markusen, 2007; Renski et al., 2007; Currid & Stolarick, 2010; Lin et al., 2019). Research on skill relatedness typically assesses the probability of individual sectors or occupations emerging but not the degree of overall alignment between functional and sectoral profiles. The functional specialization literature in production networks focuses predominantly on countries, firms, and international flows. Questions of the robustness of inter-regional correspondence between the two structures and the synchronization of their changes over time remain insufficiently explored.

Kazakhstan constitutes a suitable setting for such a test, as its regional system combines major administrative and service centers, resource and industrial regions, and territories with a substantial agricultural role. Based on the theoretical and empirical work reviewed above, the following hypotheses are formulated:

H1. *The greater the difference between two regions in the composition of performed tasks, the greater the difference in their sectoral output structures.*

H2. *Task distance is positively associated with sectoral distance and possesses additional explanatory power after accounting for observed structural, resource, spatial, and temporal differences between regions.*

H3. *Within regions, changes in task composition are positively associated with contemporaneous changes in sectoral output composition.*

The three hypotheses address complementary dimensions of functional–sectoral correspondence. H1 evaluates the unconditional relationship between inter-regional task and sectoral distances. H2 examines the additional explanatory contribution of task distance after observed structural, resource, spatial, and temporal differences have been taken into account. H3 focuses on the contemporaneous co-movement of functional and sectoral changes within regions. Together, these hypotheses provide a framework for examining correspondence across regional profiles and structural adjustment over time. Policy interpretation remains place-based, as the combination of sectors, functions, and accumulated competencies depends on specific regional conditions (Barca et al., 2012).

3. Data and Methods

3.1. Data and Sample Construction

The study relies on annual panel data for regions of Kazakhstan over 2019–2024. The period is determined by the availability of comparable employment statistics by occupational groups. To maintain a consistent territorial structure, indicators for regions formed in 2022 are aggregated with their predecessor regions: Abai with East Kazakhstan, Jetisu with Almaty, and Ulytau with Karaganda. Cities of republican significance—Astana, Almaty, and Shymkent—are treated as separate units. The result is a balanced panel comprising 17 regions and 102 region–year observations.

Primary data are drawn from official regional statistics of the Bureau of National Statistics of the Republic of Kazakhstan. Variables include employment by occupational group, output of goods and services by economic activity, population, urbanization, gross regional product (GRP), and employment by sector (Table 1). Geographic distances are calculated between administrative centers of harmonized regions using great-circle distance.

Table 1. Data sources and variable construction.

Block	Source Indicators	Variable Construction	Purpose
Functional structure	Employment in 35 occupational groups	Shares of NRC, RC, RM, and NRM in regional employment	Main explanatory variable
Occupational structure	Employment in 35 occupational groups	Vector of occupational shares	Comparison specification
Sectoral structure	Nominal output by economic activity	Output shares across 47 sectors	Dependent variable
Regional size	Population; total employment	Absolute difference in logarithms between regions	Scale control
Development level	GRP per capita	Absolute difference in logarithms	Structural control
Urbanization	Urban and total population	Absolute difference in urban-population shares	Structural control
Resource specialization	Employment in mining and quarrying	Absolute difference in shares of total employment	Structural control
Spatial location	Coordinates of administrative centers	Geographic distance, km	Spatial control

Note: NRC—non-routine cognitive tasks; RC—routine cognitive tasks; RM—routine manual tasks; NRM—non-routine manual tasks.

Because sectoral structure is measured through nominal output, its changes reflect both dynamics of physical production volumes and differentiated dynamics of sectoral prices. This circumstance is taken into account when interpreting results concerning temporal change. The use of output as the key indicator is due to the need to compare the sectoral structure of the created economic result with the functional structure of labor involved in the regional economy.

3.2. Functional and Sectoral Structures of Regions

Regional functional structure is constructed within the task-based approach to labor market analysis (Autor et al., 2003; Acemoglu & Autor, 2011). National occupational groups are mapped to international job-content characteristics harmonized with ISCO-08, including profiles from Mihaylov and Tijdens (2019). After excluding a residual unclassifiable category—to which military personnel and special-service workers are assigned in Kazakhstan—35 occupational groups enter the analysis. Each group is assigned a fixed profile across four aggregate task types: non-routine cognitive, routine cognitive, routine manual, and non-routine manual.

The following notations are used in the text: $r, s \in R$ are regions, $t \in Y$ are years, $k, k' \in K$ are sectors, $g, g' \in G$ are occupational groups, and $a \in A$ are task types. The primed indices g' and k' are used as summation indices for all occupational groups and all sectors, respectively.

The share of occupational group g in employment in region r in year t is defined as:

$$p_{rgt}^O = \frac{E_{rgt}}{\sum_{g' \in G} E_{rg't}} \quad (1)$$

where E_{rgt} denotes employment in occupational group g in region r in year t .

The share of task a in the employment of region r in year t is calculated as the weighted sum of occupational shares:

$$p_{rat}^T = \sum_{g \in G} p_{rgt}^O \theta_{ga} \quad (2)$$

where θ_{ga} is the weight of task a in the profile of occupational group g . For each region, the four functional components sum to unity. The primary occupation–task mapping is denoted S0. An alternative mapping S9 is applied for robustness checks regarding occupational groups with less unambiguous functional profiles. The full S0 correspondence matrix is provided in Appendix A; modifications forming scenario S9 appear in Appendix B.

Sectoral structure is represented by the distribution of nominal regional output among 47 economic activities. Exclusion of overlapping aggregates and constituent sub-sectors prevents double counting. The share of sector k is defined as:

$$p_{rkt}^S = \frac{Y_{rkt}}{\sum_{k' \in K} Y_{rk't}} \quad (3)$$

where Y_{rkt} denotes nominal output of sector k in region r in year t .

A 35-component occupational employment structure is additionally constructed. This is used to test whether the identified sectoral-specific differences are related to the functional content of labor or reflect a more general mismatch in occupational composition.

3.3. Inter-Regional Distances and the Dyadic Model

Jensen–Shannon distance is applied to quantify the comparison of regional compositions. For two compositions, p and q , it is defined as:

$$D^{JS}(p, q) = \sqrt{\frac{1}{2}D^{KL}(p||m) + \frac{1}{2}D^{KL}(q||m)}, \quad m = \frac{1}{2}(p + q) \quad (4)$$

where $D^{KL}(p||m)$ denotes the Kullback–Leibler divergence:

$$D^{KL}(p||m) = \sum_b p_b \log_2 \left(\frac{p_b}{m_b} \right) \quad (5)$$

In Formula (5), b is the overall index of the component of the compared composition: for the sectoral structure, it corresponds to the sector; for the occupational structure, to the occupational group; and for the task structure, to the task type. Calculations use base-2 logarithms, so the indicator takes values from 0 (complete structural coincidence) to 1 (maximum dissimilarity). Zero shares were not replaced with arbitrary small positive values: terms with a zero numerator evaluate to zero, and components absent from both compared compositions do not contribute to the distance.

$$d_{rst}^S = D^{JS}(p_{rt}^S, p_{st}^S) \quad (6)$$

$$d_{rst}^O = D^{JS}(p_{rt}^O, p_{st}^O) \quad (7)$$

$$d_{rst}^T = D^{JS}(p_{rt}^T, p_{st}^T) \quad (8)$$

where d_{rst}^S —sector distance; d_{rst}^O —occupational distance; and d_{rst}^T —task distance between regions r and s in year t . Throughout the paper, D^{JS} denotes the general Jensen–Shannon distance function, whereas d_{rst}^S , d_{rst}^O , and d_{rst}^T denote its application to sectoral, occupational, and task structures, respectively.

All 17 regions form 136 unordered pairs in each year. Combining six annual matrices yields a dyadic panel of 816 observations. The main econometric model takes the form:

$$d_{rst}^S = \alpha + \beta d_{rst}^T + z'_{rst} \gamma + \lambda_t + \varepsilon_{rst}, \quad r < s \quad (9)$$

where d_{rst}^S —distance between the sectoral structures of regions r and s in year t ; d_{rst}^T —distance between their task profiles; z_{rst} —vector of control variables; λ_t —year fixed effects; and ε_{rst} —model error.

The vector of control variables includes absolute differences in the logarithms of population and GRP per capita, differences in urbanization levels and the shares of employment in mining, as well as the geographic distance between administrative centers. Coefficient β reflects the conditional statistical association between the functional and sectoral distances and does not admit causal interpretation.

Standardized coefficients are used to compare effect magnitudes. The additional explanatory power of the functional distance is assessed through the increment in R^2 relative to a model containing only control variables, as well as through partial R^2 , indicating the share of residual variation explained by the functional variable.

3.4. Statistical Inference and Robustness Checks

Dyadic observations are not independent, as each region enters multiple pairs and the same pairs recur across years. Primary statistical inference therefore employs multiple regression quadratic assignment procedure with the Freedman–Lane permutation scheme

(Freedman & Lane, 1983; Krackhardt, 1988; Dekker et al., 2007). Residuals from the restricted model, containing only controls and year fixed effects, are permuted by random relabeling of regional identifiers; the same permutation is applied simultaneously to all annual matrices. The procedure is repeated 9999 times. Cluster-robust standard errors by stable region pairs are reported as an additional precision measure.

The robustness of the results is examined using alternative distance metrics (Hellinger, Euclidean, and Manhattan), alternative functional profile assignment S9, occupational distance, and different control sets. Additional specifications include additive regional fixed effects, pair fixed effects, the interaction of functional distance with a time trend, year-specific models, sequential exclusion of regions, and diagnostic testing for spatial autocorrelation of residuals using Moran's I. Full robustness results appear in Appendices C–G. The main text uses only those specifications necessary for correct interpretation of the central finding.

3.5. Comparison of Structural Changes over Time

The dyadic model estimates the association between inter-regional differences in functional and sectoral profiles observed across six annual cross-sections. To examine within-region structural change over the same period, two indicators are calculated for each type of composition:

$$\text{NetChange}_r^X = D^{\text{JS}}(p_{r,2024}^X, p_{r,2019}^X), \quad X \in \{S, T\} \quad (10)$$

$$\text{Path}_r^X = \sum_{t=2020}^{2024} D^{\text{JS}}(p_{rt}^X, p_{r,t-1}^X), \quad X \in \{S, T\} \quad (11)$$

where X denotes the composition type: S —sectoral structure; and T —task structure. The first indicator, NetChange_r^X , captures the net distance of a region's structure in 2024 from its initial state in 2019. The second indicator, Path_r^X , measures the cumulative length of the change trajectory, accounting for all intermediate fluctuations. The association between functional and sectoral changes is estimated using Spearman rank correlation with permutation-based significance testing. Appendix H additionally reports year-specific and lagged comparisons, as well as checks with alternative distance metrics and smoothed periods.

Thus, the research strategy combines an analysis of inter-regional differences with an exploratory assessment of within-region structural change. The inter-regional component estimates the additional explanatory contribution of task distance after observed regional characteristics are taken into account. The within-region component evaluates contemporaneous co-movement between functional and sectoral changes during 2019–2024. The six-year panel provides an exploratory basis for examining short-run adjustment. Longer-term coevolution and lagged relationships demand a longer time series.

4. Results

4.1. Descriptive Characteristics of Inter-Regional Differences

The functional structure of employment in Kazakhstan's regions is characterized by the predominance of two task types—NRC and NRM—whose average shares are 39.7% and 38.8%, respectively. RC tasks account for 16.5%, and RM tasks for only 5.0%. The greatest inter-regional variation is observed in shares of non-routine cognitive and non-routine manual tasks.

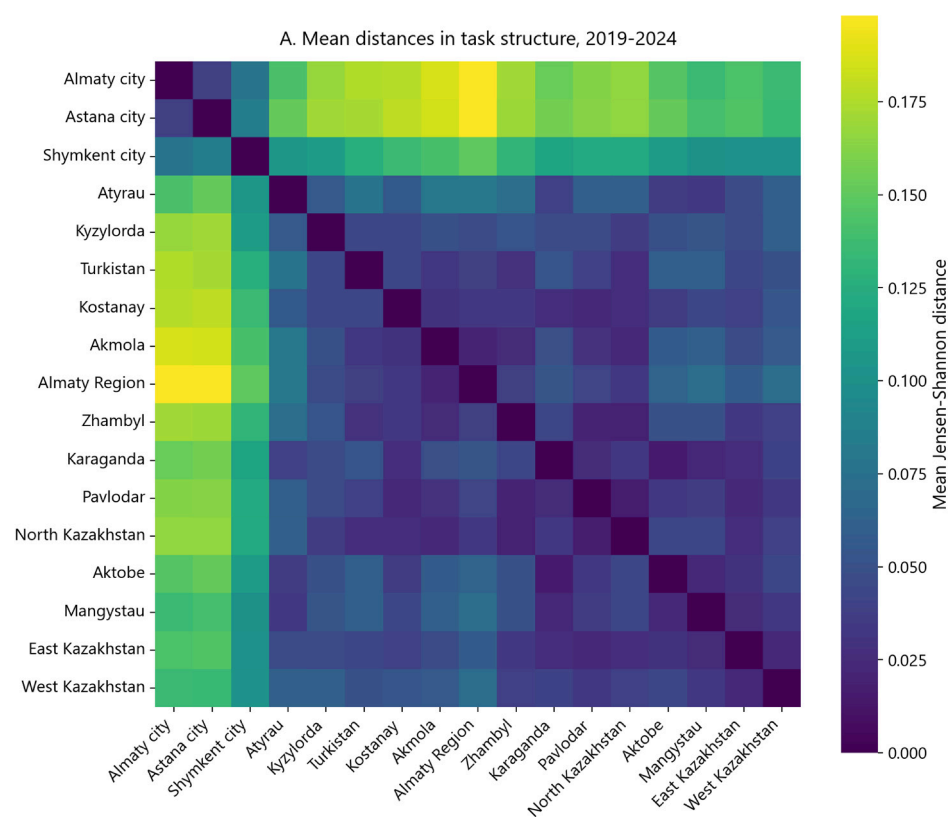
Mean inter-regional Jensen–Shannon distance for sectoral structure is 0.490, whereas for the four-component functional profile it is only 0.093 (Table 2). Differences in absolute distance values partly reflect the differing dimensionality of the compared compositions; hence, subsequent inference relies primarily on standardized coefficients.

Table 2. The descriptive statistics of the main variables.

Variable	N	Mean	Std. Dev.	Minimum	Maximum
Panel A. Regional task shares					
NRC share	102	0.3966	0.0775	0.3043	0.6442
RC share	102	0.1647	0.0198	0.1238	0.2253
RM share	102	0.0503	0.0142	0.0170	0.0717
NRM share	102	0.3884	0.0745	0.1760	0.4747
Panel B. Dyadic variables					
Sectoral distance, 47 sectors (JSD)	816	0.4904	0.1216	0.1959	0.7528
Task distance, S0 (JSD)	816	0.0928	0.0756	0.0046	0.2942
Occupational distance (JSD)	816	0.3405	0.1050	0.1336	0.5952
Difference in ln population	816	0.4926	0.3466	0.0002	1.4363
Difference in urbanization rate	816	0.2775	0.1963	0.0000	0.8029
Difference in ln GRP per capita	816	0.6813	0.5036	0.0027	2.6718
Difference in mining-employment share	816	0.0393	0.0326	0.0000	0.1247
Geographic distance, km	816	1100.6	515.3	152.3	2472.1

Note: Panel A is based on region–year observations; Panel B is based on region–pair–year observations.

Analysis of the mean distance matrices (Figure 1) shows that the largest cities differ substantially from most regions in functional employment structure. Sectoral structure displays a more fragmented configuration, reflecting pronounced differences in resource, industrial, and service specialization across regions. Similarity in several blocks of the two distance matrices suggests a degree of correspondence, which is subsequently tested in the dyadic models.

**Figure 1.** Cont.

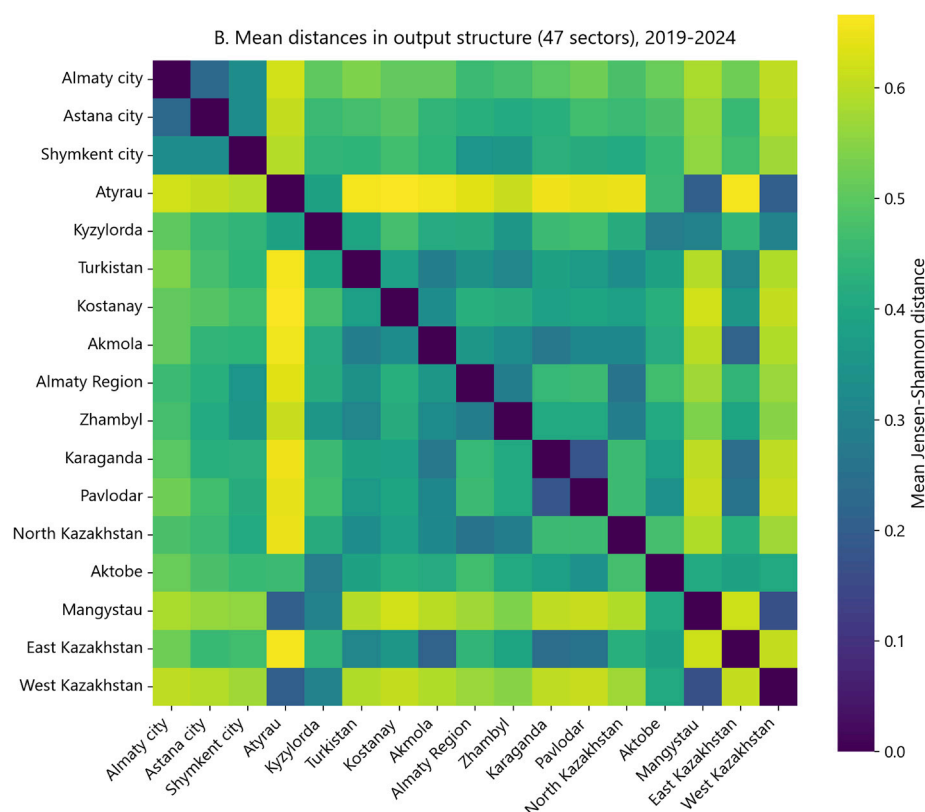


Figure 1. Mean cross-regional distances: (A) task structure; (B) output structure, 2019–2024.

4.2. Association Between Functional and Sectoral Distance

In the main dyadic specification, a statistically significant positive association is observed between functional (task) distance and differences in regional sectoral structure (Table 3). The unstandardized coefficient is 0.483; the standardized coefficient is 0.300. The MRQAP permutation test confirms high significance ($p = 0.001$). Thus, pairs of regions differing more in functional employment composition exhibit, *ceteris paribus*, greater differences in output structure. This effect persists after controlling for region size, urbanization, economic development, extractive specialization, geographic distance, and temporal shocks.

Table 3. Main models of functional–sectoral correspondence.

Statistic	(1) Controls Only	(2) Task Distance	(3) Region Effects	(4) Occupational Distance
Coefficient β	—	0.483	0.680	−0.029
Standard error	—	0.096	0.112	0.079
Standardized β	—	0.300	0.423	−0.025
MRQAP p -value	—	0.0010	0.0029	0.7472
Full-model R^2	0.4686	0.5239	0.6264	0.4690
ΔR^2	—	0.0553	0.0312	0.0004
Partial R^2	—	0.1041	0.0771	0.0008
N	816	816	816	816

All models include year fixed effects. Column (3) additionally includes additive effects for each region. The primary statistical inference is based on MRQAP.

The standalone explanatory power of functional distance is noticeable but moderate. Its inclusion raises R^2 from 0.469 to 0.524 (an increase of 5.5 percentage points), and partial R^2 equals 0.104. This indicates that task structure contains significant information

about regional sectoral profiles not reducible to observed characteristics, yet is not its determining factor.

The result remains robust after introducing additive regional fixed effects, which absorb stable territorial heterogeneity. Residual spatial autocorrelation is no longer detected under either weight matrix employed. By contrast, distance calculated from 35 detailed occupational groups, under the same controls, is statistically insignificant and close to zero. One possible explanation is that broad occupational detail captures many distinctions that are not directly related to sectoral output, whereas task aggregation isolates more general functional dimensions.

Robustness checks (Appendices C–G) confirm a positive association under Jensen–Shannon, Hellinger, and Manhattan distances; alternative functional mapping S9; and different control sets. The Euclidean specification yields a weaker coefficient and fails the MRQAP permutation test. Sequential exclusion of individual regions does not alter the qualitative conclusion; however, simultaneous exclusion of Astana, Almaty, and Shymkent noticeably weakens the association, underscoring the importance of differences between the largest cities and remaining regions.

4.3. Exploratory Analysis of Within-Region Structural Change

Within-region specifications yield statistically imprecise estimates of contemporaneous co-movement between functional and sectoral structures. The Spearman correlation between net sectoral and task changes over 2019–2024 is $\rho = -0.012$ (permutation $p = 0.968$). Figure 2 illustrates considerable regional variation in the relative magnitudes of functional and sectoral change over the observed period.

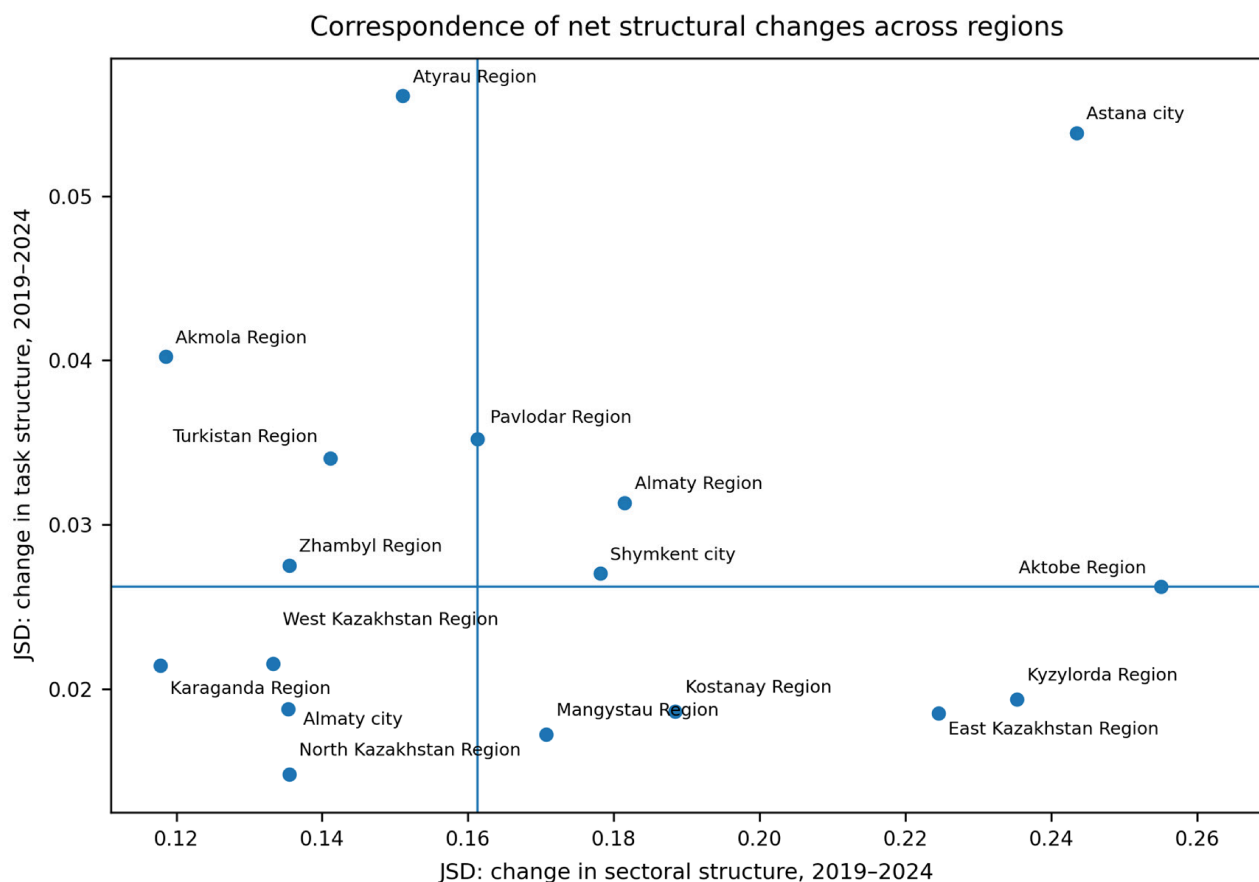


Figure 2. Changes in regional sectoral and task structures, 2019–2024.

The correlation between cumulative path lengths is $\rho = -0.118$ ($p = 0.654$) (Table 4). Alternative specifications based on Hellinger distance and three-year smoothed structures yield similarly imprecise estimates. The pair fixed-effects coefficient equals -0.107 ($p = 0.0765$). Year-specific dyadic models retain positive inter-regional coefficients, and the interaction between task distance and the time trend is statistically imprecise. The temporal pattern of functional–sectoral adjustment therefore remains weakly identified within the six-year observation window.

Table 4. Exploratory estimates of within-region change and temporal variation in the inter-regional association.

Test	Estimate	<i>p</i> -Value	N	Interpretation
Net change, 2019–2024	$\rho = -0.012$	0.968	17	Statistically imprecise estimate of contemporaneous net-change co-movement
Cumulative path length	$\rho = -0.118$	0.654	17	Statistically imprecise estimate of co-movement in cumulative structural change
Pair fixed-effects model	$\beta = -0.107$	0.0765	816	Negative and statistically imprecise within-pair estimate
Task distance $\times$ time trend	$\delta = -0.0295$	0.1014	816	Statistically imprecise linear time variation in the inter-regional coefficient

Note: Permutation *p*-values are reported for the net-change and cumulative-path estimates. The pair fixed-effects *p*-value is based on standard errors clustered by persistent region pair. The *p*-value for the interaction between task distance and the time trend is obtained using MRQAP.

Taken together, the within-region specifications yield statistically imprecise estimates of contemporaneous co-movement between functional and sectoral changes during 2019–2024. The magnitude and direction of the estimates vary across alternative measures of structural change, leaving the temporal pattern of functional–sectoral adjustment weakly identified over the observed period.

The inter-regional results provide empirical support for H1 and H2. The within-region estimates leave H3 statistically unresolved over 2019–2024.

5. Discussion

5.1. Interpretation of the Main Result

The results obtained indicate a positive, but incomplete, correspondence between the functional and sectoral structures of Kazakhstan’s regions. This finding holds true in most cross-regional specifications and robustness checks. The positive standardized coefficient indicates that sectoral specialization is associated with the functional composition of employment. At the same time, the modest increment in explained variance (R^2 rises by 5.5 percentage points; partial $R^2 \approx 0.10$) does not permit treating one structure as an adequate substitute for the other. The functional profile of regions represents a distinct informational dimension of regional economy, complementing traditional sectoral analysis.

This conclusion aligns with the task-based approach, according to which technological and organizational change affects not only the distribution of occupations and sectors but also the content of work within them (Autor et al., 2003; Acemoglu & Autor, 2011). It also resonates with Barbour and Markusen (2007), who showed that occupational and sectoral structures of regions are interrelated yet do not directly determine one another. In the Kazakhstani context, this relationship manifests against a backdrop of high resource heterogeneity and sharp differentiation between the largest cities and regions.

Possible mechanisms underlying the observed spatial pattern are rooted in features of Kazakhstan’s regional system. The location of large industrial complexes is largely inherited from Soviet industrial geography; resource specialization anchors capital-intensive

production in specific regions; and administrative, financial, and professional functions concentrate in cities of republican significance. Although this paper does not identify causal relationships, the factors identified provide the institutional and historical context in which the observed inter-regional differences in functional and sectoral profiles are formed.

5.2. Reasons for Incomplete Correspondence

Incomplete correspondence may arise from several mechanisms. First, relationships among sectors, occupations, and tasks are many-to-many. Each sector encompasses a broad spectrum of functions, from managerial and engineering to operational and logistics, while many occupations (managers, accountants, IT specialists, drivers) appear across diverse economic activities. Consequently, changes in sectoral shares need not produce proportional shifts in the aggregated task profile.

Second, identical sectors may perform different functional roles depending on the region: in one case, direct production; in another, management, design, scientific-technical services, or sales. The literature on global production networks and functional specialization of cities confirms that the distribution of functions often does not coincide with the distribution of sectoral codes (Coe et al., 2008; Coveri & Zanfei, 2023).

Third, output and employment structures respond differently to capital-intensive projects and price shocks. A large industrial enterprise may substantially alter sectoral shares in nominal output without eliciting a comparable change in the functional structure of the regional labor market.

Thus, differences in the dynamics of output and employment indicators may be associated both with the substantive difference between the structure of value created and the structure of labor used, and with the specifics of measuring nominal output.

5.3. Inter-Regional Correspondence and Temporal Adjustment

Inter-regional models identify a positive association between regional functional and sectoral profiles. Within-region estimates for 2019–2024 are less precise and vary across specifications. The two groups of models draw on different sources of variation: inter-regional models capture differences among regional profiles, while within-region models capture contemporaneous structural changes over six annual observations. The dynamic estimates therefore characterize short-run co-movement during the observed period.

Functional and sectoral structures may adjust over longer horizons and through lagged responses. The available panel leaves the timing and sequence of this adjustment weakly identified. Longer time series and models incorporating lag structures are required to assess the temporal relationship more fully.

The inter-regional relationship is partly manifested through the contrast between central cities and regions. Although exclusion of any single region does not alter the main conclusions, simultaneous exclusion of Astana, Almaty, and Shymkent substantially weakens the association. This suggests spatial heterogeneity in the distribution of functions within the national regional system: the largest cities concentrate managerial, professional, and information functions, while oblast economies are more closely associated with material production, resource, and industrial specialization.

5.4. Scientific and Policy Implications

The scientific contribution lies in the quantitative assessment of the degree of overlap between sectoral and functional approaches at the subnational level. If the related variety literature emphasizes the role of technological and cognitive proximity among sectors (Frenken et al., 2007; Boschma, 2017), the present analysis shows the need to supplement this dimension with the functional: similar sectoral composition does not guarantee identical labor content, and proximate task profiles may support different sectoral combinations.

For regional policy, the findings imply supplementing sectoral indicators with assessment of the functions and competencies shaped by jobs created. Development of the same sector may rest on simple operational functions or on highly skilled design, management, and specialized services—with substantially different consequences for human capital accumulation and future diversification. The results do not call for opposing industrial and educational policy; rather, they underscore the importance of coordinating both with the target functional profile of the region.

5.5. Limitations and Directions for Future Research

The main limitation concerns the measurement of job content. International occupational characteristics may not fully reflect actual task distribution in the Kazakhstani context, and aggregation into four categories smooths important differences among analytical, engineering, interactive, and service functions. Although the S9 check confirms the general result, the issue of country transferability remains.

Moreover, sectoral structure is measured by nominal output and is therefore sensitive to price fluctuations, especially in resource- and capital-intensive sectors. The six-year panel and the sample of 17 regions provide repeated observations of inter-regional profiles. The available temporal variation remains limited for estimating gradual structural transformation, lagged adjustment, and causal ordering between functional and sectoral structures.

Promising directions for future research include national job-content surveys, firm- or individual-level microdata, more detailed task classification, and extended temporal panels. Combining employment data with real output, value added, and inter-regional production linkages would deepen understanding of which functions form durable regional competitive advantages and how they interact with sectoral diversification.

6. Conclusions

This article investigates the degree of correspondence between two ways of describing regional economy: the functional structure of employment, reflecting the distribution of performed tasks, and the sectoral structure of output. The empirical analysis covers 17 harmonized regions of Kazakhstan over 2019–2024 and compares four-component task profiles with the distribution of nominal output across 47 economic activities. The use of a dyadic panel and MRQAP permutation procedure permits assessment of the association between full regional compositions while accounting for observation dependence.

The main finding is a positive but moderate inter-regional association. After controlling for region size, urbanization, gross regional product per capita, extractive specialization, geographic distance, and time effects, the standardized coefficient on functional distance is 0.300 (MRQAP p -value = 0.001). Including the task variable raises R^2 by 5.5 percentage points and explains approximately 10% of residual variation. Sectoral structure is thus associated with the functional content of employment but does not fully explain it; the task profile constitutes a distinct informational dimension of the regional economy.

The finding remains robust under alternative distance metrics (Jensen–Shannon, Hellinger, Manhattan), different occupation–task mappings, different control sets, and the inclusion of additive regional effects. The Euclidean specification yields a weaker result, and simultaneous exclusion of Astana, Almaty, and Shymkent substantially weakens the identified association. This indicates that the national association is substantially influenced by the contrast between the largest administrative and service centers and oblast economies.

The dynamic analysis complements the inter-regional results by examining contemporaneous structural changes within regions. The specifications for 2019–2024 yield statistically imprecise estimates of co-movement between functional and sectoral changes. The temporal relationship between the two structures remains weakly identified over the six-

year observation window. Longer time series and explicit modeling of lagged adjustment are required to assess their longer-term coevolution.

The scientific contribution of this study lies in the direct quantitative comparison of complete regional distributions of sectors and tasks using data from a resource-dependent post-Soviet country, together with an explicit distinction between inter-regional correspondence and within-region structural change. The results extend the related variety and functional specialization literature by showing that differences in production structures are systematically associated with differences in the task composition of regional employment. The transversal character of many occupations, variation in functional content within sectors, and spatial separation of managerial and production functions constrain the degree of alignment between functional and sectoral profiles.

For regional policy, this implies supplementing sectoral priorities with analysis of functions and competencies formed by new jobs. Industrial, educational, and labor policy should be coordinated with the understanding that the development of a specific sector does not guarantee automatic formation of the desired functional profile of a region.

Interpretation is limited by the transfer of international task coefficients to Kazakhstani data, the aggregation of tasks into four categories, the use of nominal output, and a relatively short observation period. Future research prospects include national job-content surveys, data in comparable prices, firm-level microdata, and longer panels.

Overall, functional and sectoral structures constitute related and complementary dimensions of regional economic organization. Their joint use provides a more comprehensive understanding of territorial specialization, the functional content of regional employment, and potential pathways for structural transformation.

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Conflicts of Interest: Authors Y.Z., D.U. and Z.O. were employed by RATIONAL SOLUTION LLP, Astana, Kazakhstan. RATIONAL SOLUTION LLP served as the implementing organization for the research project funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan, and all authors participated in the project as members of the research team. The company provided administrative and organizational support for the implementation of the project but had no independent role in the study design, data analysis, interpretation of the results, preparation of the manuscript, or the decision to submit the article for publication. The company had no commercial interest in the results of the study. The remaining authors declare no conflicts of interest.

Appendix A

Table A1. Baseline mapping of occupational groups to tasks (S0).

No.	Occupational Group	NRC	RC	RM	NRM
1	Chief executives, senior officials, legislators, and civil servants	0.9831	0	0	0.0169
2	Chief and functional managers in the corporate sector	0.9918	0.0082	0	0
3	Managers of specialized corporate units in production and specialized services	0.9810	0.0190	0	0
4	Managers in accommodation, food service, trade, and other services	0.7277	0.2452	0	0.0271
5	Science and engineering professionals	0.9906	0.0094	0	0
6	Health professionals	0.8498	0.0862	0	0.0640
7	Teaching professionals	0.9966	0.0034	0	0
8	Business and administration professionals	0.8454	0.1546	0	0
9	Information technology professionals	0.8602	0.1398	0	0
10	Legal, social, and cultural professionals	0.8799	0.0885	0	0.0315
11	Science and engineering associate professionals	0.6664	0.2382	0.0524	0.0430
12	Health associate professionals and mid-level medical and pharmaceutical personnel	0.5274	0.1334	0.0019	0.3373
13	Business and administration associate professionals	0.6788	0.3191	0	0.0021
14	Legal, social, cultural, sports, and related associate professionals	0.6617	0.2908	0	0.0474
15	Information and communications technology associate professionals	0.4331	0.5265	0	0.0404
16	Administrative clerical support workers	0.1046	0.7756	0.1032	0.0166
17	Personal service workers	0.2279	0.1688	0.0513	0.5521
18	Sales workers	0.4091	0.4011	0.0068	0.1830
19	Personal care workers	0.3628	0.1331	0	0.5041
20	Protective services workers	0.0024	0	0	0.9976
21	Market-oriented skilled agricultural workers	0.3365	0.0685	0.1292	0.4658
22	Market-oriented skilled forestry, fishery, and hunting workers	0.2772	0.1381	0.0430	0.5417
23	Subsistence farmers, fishers, and aquaculture workers	0.1552	0	0.1994	0.6454
24	Building and related trades workers, excluding electricians	0.1332	0.0052	0.0019	0.8597
25	Metal, machinery, and related trades workers, excluding electricians	0.0668	0.0944	0.2781	0.5607
26	Handicraft, precision-instrument, printing, and cartography workers	0.1050	0.3082	0.4266	0.1602
27	Electrical, electronics, and telecommunications trades workers	0.1922	0.1620	0	0.6459
28	Food-processing, woodworking, and related trades workers	0.0577	0.1658	0.2824	0.4941
29	Plant and machine operators, assemblers, and drivers	0.0104	0.3161	0.0752	0.5983
30	Cleaners and helpers	0.0092	0	0	0.9908
31	Agricultural, forestry, and fishery laborers	0	0.0683	0.1608	0.7709
32	Mining, construction, manufacturing, and transport laborers	0	0	0.3665	0.6335
33	Fast-food preparers and low-skilled food-service workers, excluding cleaners	0	0.1270	0	0.8730
34	Street and related sales and service workers	0.0217	0.1304	0	0.8479
35	Refuse workers and other elementary workers	0.0037	0.0858	0.0145	0.8960

Note: Profiles are constructed by matching national occupational groups to ISCO-08 and the task-content coefficients of Mihaylov and Tijdens (2019). The four weights in each row sum to one; values are rounded to four decimal places.

Appendix B

Table A2. Alternative task-mapping scenario S9.

Modified Occupational Group	S0: NRC/RC/RM/NRM	S9: NRC/RC/RM/NRM	Replacement Rule
Information and communications technology associate professionals	0.433/0.526/0/0.040	0.520/0.440/0.000/0.040	Mean across ISCO-08 3511–3522 (6 codes)
Plant and machine operators, assemblers, and drivers	0.010/0.316/0.075/0.598	0.018/0.165/0.515/0.302	Mean across ISCO-08 8111–8350 (39 codes)
Legal, social, and cultural professionals	0.880/0.089/0/0.032	0.869/0.068/0.000/0.062	Mean across ISCO-08 2611–2659 (21 codes)
Subsistence farmers, fishers, and aquaculture workers	0.155/0/0.199/0.645	0.136/0.000/0.231/0.632	Mean across ISCO-08 6310–6340 (4 codes)

Note: S9 simultaneously replaces the four most uncertain proxy profiles with the average profiles of all available four-digit ISCO-08 codes in the corresponding group. The remaining 31 occupational groups retain the S0 weights.

Appendix C

Table A3. Robustness to the structural-distance metric.

Metric	β	Std. β	SE	p (Pair)	MRQAP p	R^2	ΔR^2	Partial R^2	Conclusion
Jensen–Shannon	0.483	0.300	0.096	<0.001	0.0010	0.524	0.055	0.104	Supported by MRQAP
Hellinger	0.540	0.277	0.118	<0.001	0.0033	0.503	0.047	0.087	Supported by MRQAP
Euclidean	0.162	0.137	0.079	0.0408	0.2478	0.473	0.012	0.022	Not supported by MRQAP
Manhattan	0.485	0.335	0.081	<0.001	0.0004	0.606	0.069	0.150	Supported by MRQAP

Note: The dependent and explanatory distances are calculated using the same metric. Jensen–Shannon is the baseline specification; Hellinger, Euclidean, and Manhattan distances are used as robustness checks.

Appendix D

Table A4. Alternative control specifications and multicollinearity.

Specification	β	Std. β	SE	p (Pair)	MRQAP p	R^2	ΔR^2	Partial R^2
Year FE only	0.541	0.336	0.088	<0.001	0.0208	0.122	0.113	0.114
Main controls	0.483	0.300	0.096	<0.001	0.0010	0.524	0.055	0.104
+ city-of-republican-significance status	0.587	0.365	0.158	0.0003	0.0064	0.548	0.023	0.048
+ pair mean levels	0.438	0.272	0.168	0.0099	0.0115	0.602	0.011	0.028
Employment instead of population	0.502	0.312	0.097	<0.001	0.0012	0.515	0.060	0.110

Note: Main controls include absolute differences in ln population, urbanization, ln GNP per capita, the mining-employment share, geographic distance, and year fixed effects. Pair mean levels add the mean levels of the characteristics of the two regions.

Table A5. VIF for the baseline specification.

Variable	VIF
task_s0_js	1.62
abs_diff_ln_population	1.25
abs_diff_urbanization	1.74
abs_diff_ln_grp_pc	1.14
abs_diff_mining_share_total	1.09
geo_distance_km	1.26

Note: The maximum VIF in the baseline model is below 2, indicating no problematic multicollinearity.

Appendix E

Table A6. Within-pair estimates and temporal variation in the inter-regional association.

Test	Coefficient	Std. β	SE	p (Pair)	MRQAP p	Partial R^2	R^2	Interpretation
Pair fixed effects	−0.107	−0.077	0.060	0.0765	—	0.006	0.082	Negative and statistically imprecise within-pair estimate
Task distance $\times$ centered trend	−0.030	—	0.011	0.0077	0.1014	—	0.525	Statistically imprecise estimate of linear temporal variation under MRQAP inference

Table A7. Annual models with controls.

Year	β	Std. β	HC3 SE	HC3 p	MRQAP p	Holm p	Partial R^2	R^2	N
2019	0.442	0.268	0.106	0.0001	0.0017	0.0068	0.093	0.553	136
2020	0.589	0.342	0.114	<0.001	0.0003	0.0015	0.132	0.517	136
2021	0.592	0.370	0.109	<0.001	0.0001	0.0006	0.150	0.519	136
2022	0.512	0.305	0.118	<0.001	0.0029	0.0087	0.107	0.505	136
2023	0.340	0.242	0.092	0.0003	0.0152	0.0152	0.070	0.544	136
2024	0.507	0.320	0.113	<0.001	0.0062	0.0124	0.103	0.517	136

Note: In the annual models, MRQAP is implemented separately for each matrix; Holm-adjusted p -values correct for the six annual tests. In the time-interaction model, the primary statistic is the permutation p -value for the coefficient $D^T \times \text{trend}$.

Appendix F

Table A8. Influence of individual regions and sample composition.

Excluded Region	β	Std. β	SE	p (Pair)	MRQAP p	Partial R^2	R^2	N
Akmola Region	0.424	0.270	0.101	0.0001	0.0034	0.086	0.510	720
Aktobe Region	0.499	0.303	0.105	<0.001	0.0003	0.108	0.556	720
Almaty Region	0.489	0.300	0.109	<0.001	0.0025	0.101	0.507	720
Atyrau Region	0.499	0.360	0.084	<0.001	0.0015	0.132	0.481	720
West Kazakhstan Region	0.481	0.317	0.096	<0.001	0.0010	0.127	0.566	720
Zhambyl Region	0.438	0.272	0.103	<0.001	0.0042	0.088	0.513	720
Karaganda Region	0.501	0.313	0.118	<0.001	0.0016	0.096	0.521	720

Table A8. *Cont.*

Excluded Region	β	Std. β	SE	p (Pair)	MRQAP p	Partial R^2	R^2	N
Kostanay Region	0.466	0.285	0.106	<0.001	0.0009	0.105	0.574	720
Kyzylorda Region	0.511	0.315	0.102	<0.001	0.0026	0.123	0.549	720
Mangystau Region	0.528	0.347	0.094	<0.001	0.0041	0.135	0.513	720
Pavlodar Region	0.465	0.290	0.102	<0.001	0.0027	0.091	0.513	720
North Kazakhstan Region	0.504	0.315	0.098	<0.001	0.0005	0.123	0.543	720
Turkistan Region	0.428	0.271	0.104	0.0001	0.0061	0.082	0.531	720
East Kazakhstan Region	0.449	0.288	0.097	<0.001	0.0016	0.096	0.511	720
Astana City	0.475	0.239	0.112	<0.001	0.0033	0.077	0.550	720
Almaty City	0.490	0.263	0.123	0.0001	0.0028	0.077	0.491	720
Shymkent City	0.588	0.366	0.097	<0.001	0.0003	0.145	0.541	720

Table A9. Targeted exclusions.

Specification	Excluded	β	Std. β	SE	p (Pair)	MRQAP p	Partial R^2	R^2
Excluding cities of republican significance	Almaty city, Astana city, Shymkent city	0.746	0.119	0.424	0.0814	0.0778	0.022	0.528
Excluding three western oil-and-gas regions	Atyrau Region, West Kazakhstan Region, Mangystau Region	0.574	0.536	0.066	<0.001	0.0002	0.307	0.589
Excluding Astana	Astana city	0.475	0.239	0.112	<0.001	0.0033	0.077	0.550
Excluding Almaty	Almaty city	0.490	0.263	0.123	0.0001	0.0028	0.077	0.491

Note: In the leave-one-region-out analysis, all dyads containing the respective region are removed. Targeted exclusions test the role of metropolitan and oil-and-gas regions as distinct regional types.

Appendix G

Table A10. Spatial diagnostics of residuals.

Weights Matrix	Period	Moran's I	E[I]	Permutation p	2.5%	97.5%
Inverse distance	2019	0.077	−0.062	0.0309	−0.165	0.084
Inverse distance	2020	0.073	−0.062	0.0322	−0.164	0.082
Inverse distance	2021	0.079	−0.062	0.0272	−0.164	0.082
Inverse distance	2022	0.093	−0.062	0.0206	−0.162	0.087
Inverse distance	2023	0.029	−0.062	0.1330	−0.165	0.081
Inverse distance	2024	0.063	−0.062	0.0440	−0.166	0.082
Inverse distance	Mean, 2019–2024	0.069	−0.062	0.0241	−0.150	0.067
Symmetric 4-NN	2019	0.258	−0.062	0.0261	−0.282	0.260
Symmetric 4-NN	2020	0.259	−0.062	0.0276	−0.281	0.267
Symmetric 4-NN	2021	0.246	−0.062	0.0274	−0.276	0.251
Symmetric 4-NN	2022	0.317	−0.062	0.0135	−0.279	0.258
Symmetric 4-NN	2023	0.184	−0.062	0.0596	−0.275	0.252
Symmetric 4-NN	2024	0.248	−0.062	0.0330	−0.279	0.279
Symmetric 4-NN	Mean, 2019–2024	0.252	−0.062	0.0174	−0.250	0.225

Table A11. After including additive region effects.

Weights Matrix	Period	Moran's I	E[I]	Permutation p	2.5%	97.5%
Inverse distance	2019	0.036	−0.062	0.0961	−0.165	0.073
Inverse distance	2020	0.000	−0.062	0.2520	−0.175	0.056
Inverse distance	2021	−0.077	−0.062	0.8106	−0.162	0.077
Inverse distance	2022	−0.052	−0.062	0.8643	−0.164	0.078
Inverse distance	2023	−0.033	−0.062	0.5711	−0.155	0.051
Inverse distance	2024	0.017	−0.062	0.2076	−0.165	0.083
Inverse distance	Mean, 2019–2024	−0.018	−0.062	0.1447	−0.116	0.004
Symmetric 4-NN	2019	0.193	−0.062	0.0525	−0.271	0.243
Symmetric 4-NN	2020	0.132	−0.062	0.1110	−0.267	0.211
Symmetric 4-NN	2021	−0.229	−0.062	0.1927	−0.271	0.253
Symmetric 4-NN	2022	−0.179	−0.062	0.3842	−0.278	0.254
Symmetric 4-NN	2023	−0.038	−0.062	0.8270	−0.248	0.185
Symmetric 4-NN	2024	0.081	−0.062	0.2907	−0.285	0.279
Symmetric 4-NN	Mean, 2019–2024	−0.007	−0.062	0.3850	−0.175	0.082

Note: For each year, dyadic residuals are aggregated into the mean residual across all pairs containing the respective region. Moran's I is calculated using an inverse-distance matrix and a symmetric four-nearest-neighbor matrix; p -values are based on 9999 permutations of regional labels.

Appendix H

Table A12. Additional exploratory estimates of within-region structural change.

Specification	Spearman's ρ	p	N	Result	Comment
JSD: 2019 vs. 2024	−0.012	0.9681	17	Estimate is statistically imprecise	Main net-change measure
JSD: sum of annual transitions	−0.118	0.6540	17	Estimate is statistically imprecise	Captures the entire path
Hellinger: 2019 vs. 2024	−0.061	0.8185	17	Estimate is statistically imprecise	Alternative metric
Hellinger: sum of annual transitions	−0.015	0.9603	17	Estimate is statistically imprecise	Alternative path metric
JSD of means: 2019–2021 vs. 2022–2024	0.049	0.8551	17	Estimate is statistically imprecise	Reduces the influence of individual years
JSD of means: 2019–2020 vs. 2023–2024	−0.017	0.9504	17	Estimate is statistically imprecise	Smoothed endpoint periods
Leave-one-out: range of ρ	[−0.168, 0.097]	-	16	Estimates remain statistically imprecise across leave-one-out specifications	Range of Spearman's ρ across 17 leave-one-region-out re-estimations

Note: Permutation-based p -values are reported for the first six specifications. For the leave-one-out analysis, the Spearman correlation is re-estimated 17 times, each time excluding one region; therefore, each re-estimation is based on $N = 16$. The reported interval gives the minimum and maximum values of ρ across these re-estimations. Individual leave-one-out p -values are not reported.

Table A13. Correlations of annual transitions.

Transition	Mean Sectoral JSD	Median Sectoral JSD	Mean Task JSD	Median Task JSD	Spearman's ρ	p
2019–2020	0.094	0.096	0.019	0.017	0.402	0.1097
2020–2021	0.088	0.089	0.018	0.016	−0.395	0.1170
2021–2022	0.087	0.090	0.014	0.013	0.647	0.0050
2022–2023	0.111	0.100	0.020	0.020	−0.051	0.8445
2023–2024	0.080	0.065	0.016	0.012	0.525	0.0307

Note: Annual transition correlations fluctuate in sign and magnitude and are reported as a descriptive supplement to the formal panel test of the time interaction.

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